Module Handbook

for the

Master Programme “Cyber Security”

at

Rheinischen Friedrich-Wilhelms-Universität Bonn

revised version: October 27, 2023

The curriculum of the master programme comprises compulsory modules, subject-specific optional modules, and optionally non-subject-specific optional modules. The subject-specific optional modules are subdivided by the subjects cyber security and computer science (further sub-divided into four main focus areas in research of the Bonn Institute of Computer Science).

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

Contents

1 Compulsory Modules

<table>
<tr><td>Module
MA-INF 0401</td><td colspan="5">Master Thesis</td></tr>
<tr><td>Workload
900 h</td><td>Credit points
30 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5"></td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">All lecturers of computer science</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Compulsory</td><td colspan="2">Semester
4.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to solve a well-defined, significant research problem under supervision, but in principle independently</td></tr>
<tr><td>Contents</td><td colspan="5">Topics of the thesis may be chosen from any of the areas of computer science represented in the curriculum</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Independent preparation of a scientific thesis with individual coaching</td><td></td><td>0</td><td>900 S</td><td>30</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Master Thesis (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Literature</td><td colspan="5">Individual bibliographic research required for identifying relevant literature (depending on the topic of the thesis)</td></tr>
</table>

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

<table>
<tr><td>Module
MA-INF 3236</td><td colspan="4">IT Security</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Michael Meier</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Michael Meier</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Compulsory</td><td>Semester
1. or 2.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Students are introduced to a variety of active research fields in IT security. Students learn about the motivation, challenges and objectives in these fields. Additionally, they get to know selected fundamental knowledge and methods helping them to deepen their knowledge in their upcoming studies.</td></tr>
<tr><td>Contents</td><td colspan="4">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</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Required:
Fundamental knowledge in the following areas: operating systems, networks, security</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Literature</td><td colspan="4"></td></tr>
</table>

Module MA-INF 3244	**Cyber Security Seminar**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Michael Meier		
Lecturer(s)	Prof. Dr. Matthew Smith, Prof. Dr. Peter Martini, Prof. Dr. Michael Meier, Dr. Felix Boes, Dr. Matthias Wübbeling, Dr. Christian Tiefenauf, Dr. Matthias Frank		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Compulsory	**Semester** 2. or 3.
Technical skills	Ability to study and discuss current research related to Cyber Security. Didactic preparation of a written report and didactic presentation a talk for a selected topic.		
Contents	Recent research topics in cyber security based on cúrrent journal and conference publications. In addition the seminar group analyses and discusses current societal and political developments related to Cyber Security. Participation of discussion events that are announced in the seminar.		
Prerequisites	none		

Format

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

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

Exam achievements	Oral Exam (graded)
Study achievements	(not graded)
Literature	

<table>
<tr><td>Module
MA-INF 3245</td><td colspan="5">Cyber Security Lab</td></tr>
<tr><td>Workload
270 h</td><td>Credit points
9 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Michael Meier</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Michael Meier, Prof. Dr. Matthew Smith,
Prof. Dr. Peter Martini, Dr. Felix Boes,
Dr. Matthias Wübbeling, Dr. Christian Tiefenau,
Dr. Matthias Frank</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Compulsory</td><td colspan="2">Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to carry out a practical task in the context of Cyber Security. This includes test and documentation of the implemented software/system. Ability to discuss achieved results in the context of the state-of-the-art of the respective area.</td></tr>
<tr><td>Contents</td><td colspan="5">Implementation, documentation and presentation of a practical task in the context of Cyber Security.
Participation of discussion events that are announced in the lab.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">none</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lab</td><td>8</td><td>4</td><td>60 T / 210 S</td><td>9</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

2 Optional Modules

2.1 Cyber Security

<table>
<tr><td>Module
MA-INF 3108</td><td colspan="4">Secure Software Engineering</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Dr. Christian Tiefenau</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Dr. Christian Tiefenau, Mischa Meier</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
1. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">The students are introduced to the security-relevant aspects of a software-engineering lifecycle. Therefore, the main ideas of including security throughout the development process will be presented and explained by examples.

By showing common vulnerabilities throughout this course, the students will get an understanding of common vulnerabilities and attacks and how to prevent them.</td></tr>
<tr><td>Contents</td><td colspan="4">• Threat modeling
• Risk analysis
• Architectural security
• Secure coding
• Applied Cryptography
• Secure configuration and deployment
• Updates and maintenance</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
Fundamental knowledge in software-engineering and IT-security concepts.</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Written exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Literature</td><td colspan="4">Software Security: Building Security In by Gary McGraw</td></tr>
</table>

Module MA-INF 3140	**Advanced Computer Forensics**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Dr. Christian Tiefenau		
Lecturer(s)	Dr. Christian Tiefenau		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1. or 3.
Technical skills	The course covers advanced research topics in computer forensics and secure software engineering.		
Contents	Theoretical and practical aspects of computer forensics and secure software engineering are covered.		
Prerequisites	none		

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Succesful exercise participation	(not graded)
Literature		

Module MA-INF 3202	**Mobile Communication**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Peter Martini				
Lecturer(s)	Prof. Dr. Peter Martini, Dr. Matthias Frank				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	Knowledge about key concepts of mobile communication including mobility management (both technology independent and technology dependent), knowledge about wireless technologies and their interaction with other protocol layers and/or other network technologies, ability to evaluate and assess scenarios with communication of mobile devices. In-depth understanding of communication paradigms of wireless/mobile systems and network elements, productive work in small groups, strengthening skills on presentation and discussion of solutions to current challenges				
Contents	Mobility Management in the Internet, Wireless Communication Basics, Wireless Networking Technologies, Cellular/Mobile Communication Networks (voice and data communication), Ad-hoc and Sensor Networks.				
Prerequisites	**Recommended:** Bachelor level knowledge of basics of communication systems (e.g. BA-INF 101 "Kommunikation in Verteilten Systemen" (German Bachelor Programme Informatik, English lecture slides available)				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Written exam (graded)				
Study achievements	Successful exercise participation (not graded)				
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				

<table>
<tr><td>Module
MA-INF 3238</td><td colspan="4">Side Channel Attacks</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Dr. Felix Boes</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Dr. Felix Boes</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
1. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">• Students are introduced to theoretical and practical side channel effects of modern hardware.
• Students learn techniques to utilize these effects to circumvent security mechanisms.
• This includes covert channels as well as side channel attacks and microarchitectural attacks on modern CPUs.</td></tr>
<tr><td>Contents</td><td colspan="4">• Theoretical foundations of side channel effects and attacks as well as
• covert channels,
• differential power analysis,
• padding oracle,
• RSA timing attacks,
• cache based side channel effects,
• microarchitectural attacks (Spectre)</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
Fundamental knowledge about IT Security, operating systems and statistics is advantageous but not mandatory.</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Written Exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Literature</td><td colspan="4"></td></tr>
</table>

<table>
<tr><td>Module
MA-INF 3239</td><td colspan="4">Malware Analysis</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Peter Martini</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Elmar Padilla</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">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.</td></tr>
<tr><td>Contents</td><td colspan="4">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.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Required:
none
Recommended:
Basic knowledge of operating systems (kernel, threads, virtual memory), network communication (protocols, architectures), binary analysis (assembler, endianness, semantic gap, coding), software development (programming, semantics, scripting in Python)</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Literature</td><td colspan="4">The relevant literature will be announced at the beginning of the lecture</td></tr>
</table>

Module MA-INF 3241	**Practical Challenges in Human Factors of Security and Privacy**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Matthew Smith		
Lecturer(s)	Prof. Dr. Matthew Smith		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	After completing the unit students will be able to conduct related work searchers to get a deep understanding into the state of the art. They will be able to design, run and evaluate scientific studies in this area.		
Contents	In this course we will learn about and develop solutions for a specific challenge concerning human factors in security and privacy.		
Prerequisites	none		

Format

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

Exam achievements	Project work (graded)
Study achievements	Successful exercise participation (not graded)
Literature	

Module MA-INF 3242	**Security of Distributed and Resource-constrained Systems**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Michael Meier		
Lecturer(s)	Dr. Thorsten Aurisch		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1., 2. or 3.
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.		
Contents	• Group communication with IP multicast • Group key management • Broadcast encryption • Public key infrastructure • Web of trust • Multicast infrastructure protection • Distributed security mechanisms • Cyber resilience in groups • Security in tactical radio networks • Security for IoT		
Prerequisites	none		

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Literature		

Module MA-INF 3243	**Tutorenpraktikum Cyber Security**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Michael Meier		
Lecturer(s)	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		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Ability to and experience in • conveying knowledge to students, • presenting technica, conceptional and scientific content, • evaluating and assessing excercise solutions and argumentations, • development, implementation and application of teach and learning tools.		
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.		
Prerequisites	none		

Format

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

Exam achievements	Project work (graded)
Study achievements	(not graded)
Literature	

<table>
<tr><td>Module
MA-INF 3322</td><td colspan="4">Applied Binary Exploitation</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Peter Martini</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Elmar Padilla</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Static and dynamic program analysis, Exploitation (Stack-based Buffer Overflows, Format String Exploits, Heap Exploitation, Use-After-Free Exploits) and Countermeasures (Stack Cookies, NX, ASLR, RELRO)</td></tr>
<tr><td>Contents</td><td colspan="4">Our computers run a lot of closed source binary programs meaning that the source code of those programs is not available. Naturally, those programs contain bugs, mistakes that the programmer made during the development. Those bugs could (under certain circumstances) be exploited by attackers and thus may lead to arbitrary code execution. In this lecture we aim to teach you how to find well known exploitable bugs and how to exploit them. After a brief recap of basic binary program analysis such as static and dynamic analysis, we will talk about vulnerability discovery in general, meaning that you will learn how to find exploitable bugs by yourself. Next we move on to basic stack-based buffer overflows and add mitigation techniques (stack cookies, NX, ASLR, RELRO, ...) as we progress and exploit them as well. After we finished the topic of stack-based buffer overflows we move on to more advanced topics such as heap exploitation, use-after-free exploits and others. The lecture ends with an introduction to fuzzing and an analysis of a sophisticated real-world exploit.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Required:
none
Recommended:
• Binary Analysis skills (Lecture: “Applied Binary Analysis” BA-INF 155)
• Basic knowledge of the Linux operating system
• System Programming skills in C (Lecture: “Systemnahe Programmierung”)
• Basic Python programming skills</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Lecture</td><td></td><td>2</td><td>30 T / 45 S</td><td>2.5</td></tr><tr><td>Exercises</td><td></td><td>2</td><td>30 T / 75 S</td><td>3.5</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral Examination (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">Successful exercise participation (not graded)</td></tr>
<tr><td>Literature</td><td colspan="4">The relevant literature will be announced at the beginning of the lecture</td></tr>
</table>

2.2 Computer Science – Algorithms

Module MA-INF 1103	**Cryptography**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Dr. Michael Nüsken		
Lecturer(s)	Dr. Michael Nüsken		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1. or 2.
Technical skills	Understanding of security concerns and measures, and of the interplay between computing power and security requirements. Mastery of the basic techniques for cryptosystems and cryptanalysis		
Contents	Basic private-key and public-key cryptosystems: AES, RSA, group-based. Security reductions. Key exchange, cryptographic hash functions, signatures, identification; factoring integers and discrete logarithms; lower bounds in structured models.		
Prerequisites	none		

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Literature	• Jonathan Katz & Yehuda Lindell (2015/2008). Introduction to Modern Cryptography, CRC Press. • Course notes	

Module MA-INF 1105	**Algorithms for Data Analysis**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** at least every 2 years
Module coordinator	Prof. Dr. Petra Mutzel		
Lecturer(s)	Prof. Dr. Petra Mutzel		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1. or 2.
Technical skills	Deeper insights into selected methods and techniques of modern algorithmics with respect to big data and/or analytics tasks		
Contents	Advanced algorithmic techniques and data structures relevant to analytic tasks for big data, i.e., algorithms for graph similarity, parallel algorithms, I/O-data structures, and streaming algorithms.		
Prerequisites	**Required:** none **Recommended:** Introductory knowledge of foundations of algorithms and data structures is essential.		

Format

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

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

Exam achievements	Oral exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Literature		

Module MA-INF 1108	**Introduction to High Performance Computing: Architecture Features and Practical Parallel Programming**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Estela Suarez		
Lecturer(s)	Prof. Dr. Estela Suarez		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Understanding principles of computer architecture of modern HPC systems at component (processor, accelerators) and system level (system architecture, network, memory hierarchy) and their implication for application programming. Ability to program parallel computers, employing multi-core and multi-node features. Programming CPU and GPUs. Understanding the quality of performance .and scaling behaviour, and applying the measures needed to improve them.		
Contents	Computer architectures, system components (CPU, memory, network) and their interrelation. Software environment Access to HPC compute resources at the Jülich Supercomputing Centre Practical use of parallel programming paradigms (MPI, OpenMP, CUDA) Performance of applications and scaling behavior, understanding and strategies for improvement Current challenges in HPC		
Prerequisites	**Required:** Knowledge of a modern programming language (ideally C/C++ and Python). Interest in High Performance Computing Cannot be taken after completing MA-INF 1106. **Recommended:** Bachelor lecture on computer architecture		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lecture / / 2 / 30 T / 45 S / 2.5 Exercises / / 2 / 30 T / 75 S / 3.5 T = face-to-face teaching; S = independent study		
Exam achievements	Written exam (graded)		
Study achievements	Successful participation in the exercises (not graded)		
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		

Module MA-INF 1209	**Seminar Advanced Topics in Cryptography**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Dr. Michael Nüsken		
Lecturer(s)	Dr. Michael Nüsken		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Understanding research publications, often written tersely. Distilling this into a presentation. Determination of relevant vs. irrelevant material. Developing a presentation that fascinates fellow students.		
Contents	A special topic within cryptography, changing from year to year, is studied in depth, based on current research literature		
Prerequisites	**Required:** MA-INF 1103 – Cryptography and one further course in cryptography like The Art of Cryptography or eSecurity.		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report	(graded)
Study achievements		(not graded)
Literature	Current cryptographic literature.	

Module MA-INF 1221	**Lab Computational Analytics**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Petra Mutzel		
Lecturer(s)	Prof. Dr. Petra Mutzel		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Ability to design, analyze and implement efficient algorithms for computational analytics problems. The LAB also includes experimental evaluation and documentation of the implemented software.		
Contents	Design of efficient exact and approximate algorithms and data structures for computational analytics problems.		
Prerequisites	**Recommended:** Interests in algorithms		

Format

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

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

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

Module MA-INF 1222	**Lab High Performance Optimization**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Petra Mutzel		
Lecturer(s)	Prof. Dr. Petra Mutzel, Dr. Sven Mallach		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Ability to design, analyze and implement algorithms for computational analytics and optimization problems. The lab also includes experimental evaluation and documentation of the implemented software.		
Contents			
Prerequisites	none		

Format

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

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

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

Module MA-INF 1223	**Privacy Enhancing Technologies**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Dr. Michael Nüsken				
Lecturer(s)	Dr. Michael Nüsken				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.		
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.				
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 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.				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		4	60 T / 105 S	5.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Schriftliche Prüfung (graded)				
Study achievements	Erfolgreiche Übungsteilnahme (not graded)				
Literature					

Module MA-INF 1225	**Lab Exploring HPC technologies**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Estela Suarez		
Lecturer(s)	Prof. Dr. Estela Suarez		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Understanding a use case from complex code developed. Adapting and running applications to different kinds of processing units, taking into account their specific architecture characteristic and programming environments. Understanding and using parallel programming paradigms and high-level programming languages. Designing and executing a benchmarking campaign. Using performance analysis tools, understanding performance bottlenecks and measures to improve them. Software development skills and standards.		
Contents	The students carry out a practical task (project) in High Performance Computing (HPC), including test of different hardware architectures and software tools, documentation of the implemented software/system. Contents: HPC systems: access/use of compute resources at Jülich Supercomputing Centre; Use of different processor architectures; Software environment, performance analysis tools; Parallel programming; Benchmarking tools/procedures; Performance of applications and scaling behavior, strategies for improvement		
Prerequisites	**Required:** -Passed the exam of MA-INF 1106 or MA-INF 1108. -Knowledge modern programming languages (C/C++, Python). -Willing to stay for at least 2 days per week during 4 weeks at the Jülich Supercomputing Centre, dates to be discussed.		
Remarks	Registration first via direct mail communication with the lecturer, in order to identify suitable dates for the stay at JSC.		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lab / 2 / 4 / 60 T / 210 S / 9 T = face-to-face teaching; S = independent study		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
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		

Module MA-INF 1309	**Lab Efficient Algorithms: Design, Analysis and Implementation**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every year
Module coordinator	Prof. Dr. Heiko Röglin		
Lecturer(s)	Prof. Dr. Anne Driemel, Prof. Dr. Thomas Kesselheim, Prof. Dr. Heiko Röglin, PD Dr. Elmar Langetepe, Dr. Herman Haverkort		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 3.
Technical skills	Ability to design, analyze and implement efficient algorithms for selected computational problems.		
Contents	Design of efficient exact and approximate algorithms and data structures for selected computational problems.		
Prerequisites	none		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

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

Module MA-INF 1316	**Lab Cryptography**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Dr. Michael Nüsken		
Lecturer(s)	Dr. Michael Nüsken		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	The students will carry out a practical task (project) in the context of Cryptography, including test and documentation of the implemented software/system.		
Contents			
Prerequisites	none		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report	(graded)
Study achievements		(not graded)
Literature		

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

2.3 Computer Science – Graphics, Vision, Audio

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

Module MA-INF 2212	**Pattern Matching and Machine Learning for Audio Signal Processing**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	apl. Prof. Dr. Frank Kurth		
Lecturer(s)	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.
Technical skills	• Introduction into selected topics of digital signal processing; • Applications in the field of Audio Signal Processing; • Methods of Automatic Pattern Recognition		
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		
Prerequisites	none		

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Literature		

<table>
<tr><td>Module
MA-INF 2213</td><td colspan="5">Advanced Computer Vision</td></tr>
<tr><td>Workload
180 h</td><td>Credit points
6 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Jürgen Gall</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Jürgen Gall</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td colspan="2">Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Students will learn about various learning methods and their applications to computer vision problems.</td></tr>
<tr><td>Contents</td><td colspan="5">The class will cover a number of learning methods and their applications in computer vision. For example, linear methods for classification and regression, boosting, random forests, neural networks, SVMs, prototype methods, nearest neighbors, Gaussian processes, metric learning, structured learning, image classification, object detection, action recognition, pose estimation, face analysis, tracking.</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Required:
MA-INF 2201 – Computer Vision</td></tr>
<tr><td>Format</td><td colspan="5"><table>
<tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr>
<tr><td>Lecture</td><td></td><td>3</td><td>45 T / 45 S</td><td>3</td></tr>
<tr><td>Exercises</td><td></td><td>1</td><td>15 T / 75 S</td><td>3</td></tr>
</table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral exam (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">Successful exercise participation (not graded)</td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 2216	**Lab Visual Computing**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Jun.-Prof. Dr. Florian Bernard		
Lecturer(s)	Jun.-Prof. Dr. Florian Bernard		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1-3.
Technical skills	Students will carry out a practical task (project) in the context of visual computing, including test and documentation of the implemented software/system.		
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.		
Prerequisites	none		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lab / 8 / 4 / 60 T / 210 S / 9 T = face-to-face teaching; S = independent study		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Literature			

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

<table>
<tr><td>Module
MA-INF 2219</td><td colspan="5">Seminar Visualization and Medical Image Analysis</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td colspan="2">Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="5">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Lecturer(s)</td><td colspan="5">Prof. Dr. Thomas Schultz</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td colspan="2">Semester
2.</td></tr>
<tr><td>Technical skills</td><td colspan="5">Ability to understand new research results presented in original scientific papers.</td></tr>
<tr><td>Contents</td><td colspan="5">Current conference and journal papers</td></tr>
<tr><td>Prerequisites</td><td colspan="5">Recommended:
At least one of the following:
• MA-INF 2222 – Visual Data Analysis
• MA-INF 2312 – Image Acquisition and Analysis in Neuroscience</td></tr>
<tr><td>Format</td><td colspan="5"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="5">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="5">(not graded)</td></tr>
<tr><td>Literature</td><td colspan="5"></td></tr>
</table>

Module MA-INF 2220	**Lab Visualization and Medical Image Analysis**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Thomas Schultz		
Lecturer(s)	Prof. Dr. Thomas Schultz		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.
Technical skills	The students will carry out a practical task (project) in the context of data visualization and visual analytics or medical image analysis, including test and documentation of the implemented software/system.		
Contents			
Prerequisites	**Recommended:** At least one of the following: • MA-INF 2222 – Visual Data Analysis • MA-INF 2312 – Image Acquisition and Analysis in Neuroscience		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Literature	

Module MA-INF 2308	**Lab Graphics**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Reinhard Klein				
Lecturer(s)	Prof. Dr. Reinhard Klein				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 3.		
Technical skills	The students will carry out a practical task (project) in the context of geometry processing, rendering, scientific visualization or human computer interaction, including test and documentation of the implemented software/system.				
Contents	Varying selected topics close to current research in the area of geometry processing, rendering, scientific visualization or human computer interaction.				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature					

Module MA-INF 2309	**Lab Audio**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	apl. Prof. Dr. Frank Kurth				
Lecturer(s)	apl. Prof. Dr. Frank Kurth, Prof. Dr. Michael Clausen				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 3.		
Technical skills	The students will carry out a practical task (project) in the context of audio and music processing, including test and documentation of the implemented software/system.				
Contents					
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature					

Module MA-INF 2314	**Image Processing, Search and Analysis I**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Christian Bauckhage		
Lecturer(s)	Prof. Dr. Christian Bauckhage		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Upon completion, students should be able to • implement basic and advanced methods for digital image processing • implement simple and advanced algorithms for image filtering • implement algorithms for creating artistic image effects • implement algorithms for image warping • implement algorithms for image morphing • implement algorithms for color and intensity manipulation • design and implement their own algorithms for image processing		
Contents	• technical foundations / hardware aspects of digital photography • mathematical representations of digital images • coordinate systems and coordinate transformations • Fourier transforms and convolutions • low- band-, and high pass filtering • mean- and Gaussian filtering • median filtering and morphological operations • efficient implementations of various kinds of filters • interpolation methods • artistic image effects • image warping • image morphing • physiological foundations of color perception • color spaces • color manipulation		
Prerequisites	none		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lecture / / 4 / 60 T / 105 S / 5.5 Exercises / / 2 / 30 T / 75 S / 3.5 T = face-to-face teaching; S = independent study		
Exam achievements	Written exam (graded)		
Study achievements	Successful exercise participation (not graded)		
Literature	• Gonzales and Woods, "Digital Image Processing" • Jähne, "Digital Image Processing"		

2.4 Computer Science – Security, Information and Communication Management

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

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

Module MA-INF 3229	**Lab IT-Security**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Michael Meier		
Lecturer(s)	Prof. Dr. Michael Meier		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	The students will carry out a practical task (project) in the context of IT Security, including test and documentation of the implemented software/system.		
Contents			
Prerequisites	none		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lab / 8 / 4 / 60 T / 210 S / 9 T = face-to-face teaching; S = independent study		
Exam achievements	Oral presentation, written report (graded)		
Study achievements	(not graded)		
Literature			

Module MA-INF 3233	**Advanced Sensor Data Fusion in Distributed Systems**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	PD Dr. Wolfgang Koch		
Lecturer(s)	Dr. Felix Govaers		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.
Technical skills	For challenging state estimation tasks, algorithms which enhance the situational awareness by fusing sensor information are inevitable. Nowadays it has become very popular to improve the performance of systems by linking multiple sensors. This implies some challenges to the sensor data fusion methodologies such as sensor registration, communication delays, and correlations of estimation errors. In particular, if the communication links have limited bandwidth, data reduction techniques have to be applied at the sensor sites, that is local tracks have to be computed. Once recieved at a fusion center (FC), the tracks then are fused to reconstruct a global estimate. In this lecture, methodologies to a achieve a distributed state estimation are considered. Among these are tracklet fusion, the Bar-Shalom-Campo formula, the Federated Kalman Filter, naive fusion, the distributed Kalman filter and the least squares estimate.		
Contents	tracklet fusion, the Bar-Shalom-Campo formula, the Federated Kalman Filter, naive fusion, the distributed Kalman filter and the least squares estimate, Accumulated State Densities, Decorrlated fusion, product representation		
Prerequisites	**Recommended:** At least 1 of the following: BA-INF 137 – Einführung in die Sensordatenfusion MA-INF 3310 – Introduction to Sensor Data Fusion - Methods and Applications		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral exam	(graded)
Study achievements	Successful exercise participation	(not graded)
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.	

Module MA-INF 3237	**Array Signal and Multi-channel Processing**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Wolfgang Koch		
Lecturer(s)	Dr. Marc Oispuu		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Localization of multiple sources using passive sensors is a fundamental task encountered in various fields like wireless communication, radar, sonar, and seismology. In this lecture, a unified framework for electromagnetic and acoustic signals and signal processing techniques are presented. Furthermore, the sensor calibration, direction finding, and bearings-only localization problem are considered. Special applications are emphasized, like small airborne arrays for unmanned aerial vehicles (UAVs).		
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	**Recommended:** Recommended: F. Kurth: "Foundations of Audio Signal Processing" (MA-INF 2113)		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral Exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Literature	H. L. van Trees, Optimum Array Processing. Part IV of Detection, Estimation, and Modulation Theory. New York: Wiley-Interscience, 2002.	

Module MA-INF 3304	**Lab Communication and Communicating Devices**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester		
Module coordinator	Prof. Dr. Peter Martini				
Lecturer(s)	Prof. Dr. Peter Martini, Prof. Dr. Michael Meier				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of communication systems, including test and documentation of the implemented software/system.				
Contents	Selected topics close to current research in the area of communication systems, network security, mobile communication and communicating devices.				
Prerequisites	**Required:** Successful completion of at least one of the following lectures: Principles of Distributed Systems (MA-INF3105), Network Security (MA-INF3201), Mobile Communication (MA-INF3202), IT Security (MA-INF3236)				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature	The relevant literature will be announced towards the end of the previous semester.				

Module MA-INF 3305	**Lab Information Systems**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every year		
Module coordinator	Dr. Thomas Bode				
Lecturer(s)	Dr. Thomas Bode				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of information systems, including test and documentation of the implemented software/system.				
Contents	Varying selected topics close to current research in the area of database- and information systems.				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature	The relevant literature will be announced towards the end of the previous semester.				

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

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

Module MA-INF 3317	**Seminar Selected Topics in IT Security**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Michael Meier				
Lecturer(s)	Prof. Dr. Michael Meier, Prof. Dr. Peter Martini				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.		
Technical skills	Ability to understand new research results presented in original scientific papers.				
Contents	Current conference and journal papers				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature					

Module MA-INF 3319	**Lab Usable Security and Privacy**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Matthew Smith		
Lecturer(s)	Prof. Dr. Matthew Smith		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.
Technical skills	The students will carry out a practical task (project) in the context of usable security and privacy, including user studies.		
Contents	Students have a great degree of freedom to chose their own topics within the context of human aspects of security and privacy.		
Prerequisites	**Required:** Vorkenntnisse zur Durchführung und Auswertung von Benutzerstudien sind notwendig. Wie sie z.B. in BA-INF145 - Usable Security and Privacy gelehrt werden. Knowledge on how to run and evaluate user studies are required. For example as it is taught in BA-INF145 - Usable Security and Privacy.		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report	(graded)
Study achievements		(not graded)
Literature		

Module MA-INF 3320	**Lab Security in Distributed Systems**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Matthew Smith		
Lecturer(s)	Prof. Dr. Matthew Smith		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.
Technical skills	The students will carry out a practical task (project) in the context of distributed security, including documentation of the implemented software/system. Strong programming skills required.		
Contents	Security in distributed systems, including amongst others: • Secure Messaging • App Security • SSL/HTTPS • API Security • Machine Learning for Security • Passwords • Intrusion Detection Systems • Anomaly Detection • Security Visualisation		
Prerequisites	none		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report	(graded)
Study achievements		(not graded)
Literature		

Module MA-INF 3321	**Seminar Usable Security and Privacy**				
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Matthew Smith				
Lecturer(s)	Prof. Dr. Matthew Smith				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.		
Technical skills	Ability to understand new research results presented in original scientific papers.				
Contents	Current conference and journal papers				
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Seminar	10	2	30 T / 90 S	4
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature					

Module MA-INF 3323	**Lab Fuzzing Bootcamp**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Matthew Smith				
Lecturer(s)	Dr. Christian Tiefenau				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of fuzz testing, including test and documentation of the implemented software/system.				
Contents					
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature					

Module MA-INF 3324	**Lab Design of Usable Security Mechanisms**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Matthew Smith				
Lecturer(s)	Dr. Emmanuel von Zezschwitz				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.		
Technical skills	The students will carry out a practical task (project) in the context of usable security mechanisms, including test and documentation of the implemented software/system.				
Contents					
Prerequisites	none				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature					

2.5 Computer Science – Intelligent Systems

Module MA-INF 4111	**Principles of Machine Learning**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator			
Lecturer(s)	Prof. Dr.-Ing. Christian Bauckhage		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1. or 2.
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.		
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		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lecture / 2 / 30 T / 45 S / 2.5 Exercises / 2 / 30 T / 75 S / 3.5 T = face-to-face teaching; S = independent study		
Exam achievements	Schriftliche Prüfung (graded)		
Study achievements	Erfolgreiche Übungsteilnahme (not graded)		
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		

Module MA-INF 4113	**Cognitive Robotics**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Sven Behnke		
Lecturer(s)	Prof. Dr. Sven Behnke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1. or 2.
Technical skills	This lecture is one of two introductory lectures of the intelligent systems track. The lecture covers cognitive capabilities of robots, like self-localization, mapping, object perception, and action-planning in complex environments. This module complements MA-INF 4114 and can be taken before or after that module.		
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	**Required:** MA-INF 4101 - Theory of Sensorimotor Systems has not been passed.		

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)

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.

Module MA-INF 4114	**Robot Learning**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Sven Behnke		
Lecturer(s)	Prof. Dr. Sven Behnke, Dr. Nils Goerke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1. or 2.
Technical skills	This lecture is one of two introductory lectures of the intelligent systems track. Creating autonomous robots that can learn to assist humans in situations of daily life is a fascinating challenge for machine learning. The lecture covers key ingredients for a general robot learning approach to get closer towards human-like performance in robotics, such as reinforcement learning, learning models for control, learning motor primitives, learning from demonstrations and imitation learning, and interactive learning. This module complements MA-INF 4113 and can be taken before or after that module.		
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		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lecture / / 2 / 30 T / 45 S / 2.5 Exercises / / 2 / 30 T / 75 S / 3.5 T = face-to-face teaching; S = independent study		
Exam achievements	Written exam (graded)		
Study achievements	Successful exercise participation (not graded)		
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.		

Module MA-INF 4201	**Artificial Life**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Sven Behnke		
Lecturer(s)	Prof. Dr. Sven Behnke, Dr. Nils Goerke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1-3.
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		
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	none		

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)

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

Module MA-INF 4204	**Technical Neural Nets**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Joachim K. Anlauf		
Lecturer(s)	Prof. Dr. Joachim K. Anlauf, Dr. Nils Goerke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1-3.
Technical skills	Detailed knowledge of the most important neural network approaches and learning algorithms and its fields of application. Knowledge and understanding of technical neural networks as Non-Von Neumann computer architectures similar to concepts of brain functions at different stages of development		
Contents	Multi-layer perceptron, radial-basis function nets, Hopfield nets, self organizing maps (Kohonen), adaptive resonance theory, learning vector quantization, recurrent networks, back-propagation of error, reinforcement learning, Q-learning, support vector machines, pulse processing neural networks. Exemplary applications of neural nets: function approximation, prediction, quality control, image processing, speech processing, action planning, control of technical processes and robots. Implementation of neural networks in hardware and software: tools, simulators, analog and digital neural hardware.		
Prerequisites	none		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				

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

Module MA-INF 4208	**Seminar Vision Systems**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Sven Behnke		
Lecturer(s)	Prof. Dr. Sven Behnke, Prof. Dr. Joachim K. Anlauf, Dr. Nils Goerke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
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.		
Contents	Current research papers from conferences and journals in the field of vision systems covering fundamental techniques and applications.		
Prerequisites	**Recommended:** At least 1 of the following: MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning MA-INF 4204 – Technical Neural Nets		

Format

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

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

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
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.

<table>
<tr><td>Module
MA-INF 4209</td><td colspan="4">Seminar Principles of Data Mining and Learning Algorithms</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Stefan Wrobel</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Stefan Wrobel</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Enhanced and in-depth knowledge in specialized topics in the area of machine learning and data mining, acquiring the competence to independently study scientific literature, present it to others and discuss it with a knowledgeable scientific auditorium. Learn how to scientifically present prior work by others, in writing and in presentations.</td></tr>
<tr><td>Contents</td><td colspan="4">Theoretical, statistical and algorithmical principles of data mining and learning algorithms. Search and optimization algorithms. Specialized learning algorithms from the frontier of research. Fundamental results from neighbouring areas.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
At least 1 of the following:
MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning
MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">(not graded)</td></tr>
<tr><td>Literature</td><td colspan="4">The relevant literature will be announced towards the end of the previous semester.</td></tr>
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<table>
<tr><td>Module
MA-INF 4211</td><td colspan="4">Seminar Cognitive Robotics</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every semester</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Sven Behnke</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Sven Behnke, Dr. Nils Goerke</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">Knowledge in advanced topics in the area of cognitive robotics, such as robot perception, action planning, and robot learning.
Ability to understand new research results presented in original scientific papers and to present them in a research talk as well as in a seminar report.</td></tr>
<tr><td>Contents</td><td colspan="4">Current research papers from conferences and journals in the field of cognitive robotics covering fundamental techniques and applications.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
At least 1 of the following:
MA-INF 4113 – Cognitive Robotics
MA-INF 4114 – Robot Learning</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">(not graded)</td></tr>
<tr><td>Literature</td><td colspan="4">• S. Thrun, W. Burgard and D. Fox: Probabilistic Robotics. MIT Press, 2005.
• B. Siciliano, O. Khatib (Eds.): Springer Handbook of Robotics, 2008.
• Selected papers.</td></tr>
</table>

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

Module MA-INF 4214	**Lab Humanoid Robots**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Maren Bennewitz		
Lecturer(s)	Prof. Dr. Maren Bennewitz		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2.
Technical skills	Practical experience and in-depth knowledge in the design and implementation of perception, state estimation, environment representation, navigation, and motion planning techniques for humanoid robots. In small groups, the participants analyze a problem, realize a solution, and perform an experimental evaluation.		
Contents	Robot middleware, perception, state estimation, environment representations, navigation, and motion planning for humanoid robots.		
Prerequisites	**Recommended:** At least 1 of the following: MA-INF 4215 – Humanoid Robotics MA-INF 4113 – Cognitive Robotics		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report	(graded)
Study achievements		(not graded)

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.

Module MA-INF 4215	**Humanoid Robotics**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** at least every 2 years
Module coordinator	Prof. Dr. Maren Bennewitz		
Lecturer(s)	Prof. Dr. Maren Bennewitz		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2-3.
Technical skills	This lecture covers techniques for humanoid robots such as perception, navigation, and motion planning.		
Contents	Self-calibration with least squares, 3D environment representations, self-localization with particle filters, footstep planning, inverse kinematics, whole-body motion planning with rapidly exploring random trees, statistical testing.		
Prerequisites	**Recommended:** MA-INF 4113 – Cognitive Robotics		

Format

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

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

Exam achievements	Oral exam	(graded)
Study achievements	Successful exercise participation	(not graded)

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.

Module MA-INF 4228	**Foundations of Data Science**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Dr. Michael Nüsken		
Lecturer(s)	Dr. Michael Nüsken		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Knowledge: Peculiarities of high dimensional spaces in geometry and probabilities. Singular vector decomposition. Basics in machine learning and clustering. Skills: Understanding of mathematical tools.		
Contents	Data science aims at making sense of big data. To that end, various tools have to be understood for helping in analyzing the arising structures. Often data comes as a collection of vectors with a large number of components. To understand their common structure is the first main objective of understanding the data. The geometry and the linear algebra behind them becomes relevant and enlightning. Yet, the intuition from low-dimensional space turns out to be often misleading. We need to be aware of the particular properties of high-dimensional spaces when working with such data. Fruitful methods for the analysis include singular vector decomposition from linear algebra and supervised and unsupervised machine learning. If time permits, we also consider random graphs, which are the second most used model for real world phenomena.		
Prerequisites	none		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lecture / / 4 / 60 T / 105 S / 5.5 Exercises / / 2 / 30 T / 75 S / 3.5 T = face-to-face teaching; S = independent study		
Exam achievements	Schriftliche Prüfung (graded)		
Study achievements	Erfolgreiche Übungsteilnahme (not graded)		
Literature	Avrim Blum, John Hopcroft, and Ravindran Kannan (2018+). Foundations of Data Science.		

Module MA-INF 4230	**Advanced Methods of Information Retrieval**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Elena Demidova		
Lecturer(s)	Prof. Dr. Elena Demidova		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
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.		
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	none		

Format

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

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

Exam achievements	Schriftliche Prüfung	(graded)
Study achievements	Erfolgreiche Übungsteilnahme	(not graded)

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.

Module MA-INF 4231	**Seminar Advanced Topics in Information Retrieval**		
Workload 120 h	**Credit points** 4 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Elena Demidova		
Lecturer(s)	Prof. Dr. Elena Demidova		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	This module concentrates on specialized topics in information retrieval. The students obtain skills in the independent, in-depth study of state-of-the-art scientific literature on specific topics, discussion with their peers and presentation to the scientific audience.		
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		

Format

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

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

Exam achievements	Oral presentation, written report	(graded)
Study achievements	None	(not graded)
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.	

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

Module MA-INF 4302	**Advanced Learning Systems**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every 2 years
Module coordinator	Prof. Dr. Stefan Wrobel		
Lecturer(s)	Prof. Dr. Stefan Wrobel		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Participants specialize and require in-depth knowledge of one particular class of learning algorithms, they acquire the necessary knowledge to improve existing algorithms and construct their own within the given class, all the way up to the research frontier on the topic.		
Contents	The module each time concentrates on one or more specific algorithm classes, e.g. • kernel machines • neural networks • probabilistic and statistical learning approaches • logic-based learning approaches • reinforcement learning		
Prerequisites	**Recommended:** all of the following: MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)
Literature	• B. Schoelkopf, A.J. Smola, Learning with Kernels, The MIT Press, 2002, Cambridge, MA • John Shawe-Taylor, Nello Christianini, Kernel Methods for Pattern Analysis, CUP, 2004 • Christopher Bishop, Pattern Recognition and Machine Learning, The University of Edinburgh, 2006 • David MacKay, Information Theory, Inference, and Learning Algorithms, 2003 • Richard Duda, Peter Hart, David Stork, Pattern Classification, John Wiley and Sons, 2001	

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

Format

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

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

Exam achievements	Written exam	(graded)
Study achievements	Successful exercise participation	(not graded)

Literature

- Gennady Andrienko, Natalia Andrienko, Exploratory Analysis of Spatial and Temporal Data, Springer, 2006
- Diane J. Cook, Lawrence B. Holder, Mining Graph Data, Wiley & Sons, 2006
- Saso Dzeroski, Nada Lavrac, Relational Data Mining, Springer, 2001
- Sholom M. Weiss, Nitin Indurkhya, Tong Zhang, Fred J. Damerau, Text Mining. Predictive Methods for Analyzing Unstructured Information, Springer, 2004

Module MA-INF 4304	**Lab Cognitive Robotics**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Sven Behnke		
Lecturer(s)	Prof. Dr. Sven Behnke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
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.		
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		

Format

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

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

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
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.

Module MA-INF 4306	**Lab Development and Application of Data Mining and Learning Systems**				
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year		
Module coordinator	Prof. Dr. Stefan Wrobel				
Lecturer(s)	Prof. Dr. Stefan Wrobel				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 3.		
Technical skills	Students will acquire in-depth knowledge in the construction and development of intelligent learning systems for machine learning and data mining. They learn how to work with existing state-of-the-art systems and apply them to application problems, usually extending them for the requirements of their particular task.				
Contents	Data storage and process models of data analysis. Common open source frameworks for the construction of data analysis systems, specialized statistical packages. Pre-processing tools. Mathematical libraries for numerical computation. Search and optimization methods. User interfaces and visualization for analysis systems. Data analysis algorithms for embedded and distributed systems. Ubiquitous discovery systems.				
Prerequisites	**Recommended:** At least 1 of the following: MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral presentation, written report (graded)				
Study achievements	(not graded)				
Literature	The relevant literature will be announced towards the end of the previous semester.				

Module MA-INF 4308	**Lab Vision Systems**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every semester
Module coordinator	Prof. Dr. Sven Behnke		
Lecturer(s)	Dr. Nils Goerke		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 3.
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.		
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 4111 – Intelligent Learning and Analysis Systems: Machine Learning MA-INF 4204 – Technical Neural Nets		

Format

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

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

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
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.

Module MA-INF 4309	**Lab Sensor Data Interpretation**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** at least every 2 years
Module coordinator	PD. Dr. Volker Steinhage		
Lecturer(s)	PD. Dr. Volker Steinhage		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
Technical skills	Competence to implement algorithms for sensor data interpretation, efficient handling and testing, documentation.		
Contents	Varying selected up-to-date topics on sensor data interpretation		
Prerequisites	**Required:** All of the following: MA-INF 2201 – Computer Vision MA-INF 4206 – Selected Topics in Sensor Data Interpretation		

Format

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

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

Exam achievements	Oral presentation, written report (graded)
Study achievements	(not graded)
Literature	Relevant literature will be announced at start of the lab.

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

Module MA-INF 4316	**Graph Representation Learning**				
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** at least every 2 years		
Module coordinator	Dr. Pascal Welke				
Lecturer(s)	Dr. Pascal Welke				
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 1.		
Technical skills	• Deep understanding of the trade-off between expressiveness of graph representation and computational complexity, as well as practical runtime of algorithms in the context of machine learning applications. - Ability to implement, practically apply, and theoretically analyze graph representation, graph kernels, and graph mining algorithms.				
Contents	We will discuss general approaches for machine learning (ML) on graph structured data. In particular, computational methods for graph representation learning such as graph neural networks (GNNs), graph kernels, as well as graph mining techniques will be discussed, analyzed, and applied. Regarding GNNs and graph kernels, we will discuss the expressive power and how these concepts are related, as well as several specific examples. In the area of graph mining, we will likely investigate fast (approximate) algorithms to count small patterns, such as triangles, or trees. If time permits, we might venture into the realm of ranking on large-scale graphs, with applications such as recommender systems. The exercises will focus on practical implementations and the application of these methods to real world examples.				
Prerequisites	**Recommended:** Helpful: one or more of the following • MA-INF 4111 – Intelligent Learning and Analysis Systems: Machine Learning • MA-INF 4112 – Intelligent Learning and Analysis Systems: Data Mining and Knowledge Discovery • MA-INF 4212 – Data Science and Big Data • MA-INF 1105 - Algorithms for Data Analysis • MA-INF 1102 - Combinatorial Optimization				
Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lecture		2	30 T / 45 S	2.5
	Exercises		2	30 T / 75 S	3.5
	T = face-to-face teaching; S = independent study				
Exam achievements	Oral exam or written exam (graded)				
Study achievements	Successful exercise participation (not graded)				
Literature	• William L. Hamilton: Graph Representation Learning, Synthesis Lectures on Artificial Intelligence and Machine Learning, Morgan and Claypool. • Nils M. Kriege, Fredrik D. Johansson, Christopher Morris: A survey on graph kernels, Applied Network Science 5(1):6. • Karsten M. Borgwardt, M. Elisabetta Ghisu et al.: Graph Kernels: State-of-the-Art and Future Challenges, Foundations and Trends in Machine Learning 13(5-6).				

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

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

<table>
<tr><td>Module
MA-INF 4324</td><td colspan="4">Seminar Advanced Topics in Data Science</td></tr>
<tr><td>Workload
120 h</td><td>Credit points
4 CP</td><td>Duration
1 semester</td><td colspan="2">Frequency
every year</td></tr>
<tr><td>Module coordinator</td><td colspan="4">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Lecturer(s)</td><td colspan="4">Prof. Dr. Elena Demidova</td></tr>
<tr><td>Classification</td><td colspan="2">Programme
M. Sc. Cyber Security</td><td>Mode
Optional</td><td>Semester
2. or 3.</td></tr>
<tr><td>Technical skills</td><td colspan="4">This module concentrates on specialized topics in data science. The students obtain skills in the independent, in-depth study of state-of-the-art scientific literature on specific topics, discussion with their peers and presentation to the scientific audience.</td></tr>
<tr><td>Contents</td><td colspan="4">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.</td></tr>
<tr><td>Prerequisites</td><td colspan="4">Recommended:
BA-INF 150 - Einführung in die Data Science</td></tr>
<tr><td>Format</td><td colspan="4"><table><tr><th>Teaching format</th><th>Group size</th><th>h/week</th><th>Workload[h]</th><th>CP</th></tr><tr><td>Seminar</td><td>10</td><td>2</td><td>30 T / 90 S</td><td>4</td></tr></table>T = face-to-face teaching; S = independent study</td></tr>
<tr><td>Exam achievements</td><td colspan="4">Oral presentation, written report (graded)</td></tr>
<tr><td>Study achievements</td><td colspan="4">None (not graded)</td></tr>
<tr><td>Literature</td><td colspan="4">Relevant literature will be announced at the beginning of the seminar</td></tr>
</table>

Module MA-INF 4325	**Lab Data Science in Practice**		
Workload 270 h	**Credit points** 9 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Elena Demidova		
Lecturer(s)	Prof. Dr. Elena Demidova		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
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.		
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:** BA-INF 150 - Einführung in die Data Science MA-INF 4230 - Advanced Methods of Information Retrieval		

Format	**Teaching format**	**Group size**	**h/week**	**Workload[h]**	**CP**
	Lab	8	4	60 T / 210 S	9
	T = face-to-face teaching; S = independent study				

Exam achievements	Oral presentation, written report	(graded)
Study achievements	None	(not graded)
Literature		

Module MA-INF 4326	**Explainable AI and Applications**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Dr. Tiansi Dong		
Lecturer(s)	Dr. Tiansi Dong		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 3.
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)		
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		
Format	**Teaching format** / **Group size** / **h/week** / **Workload[h]** / **CP** Lecture / / 2 / 30 T / 45 S / 2.5 Exercises / / 2 / 30 T / 75 S / 3.5 T = face-to-face teaching; S = independent study		
Exam achievements	Written exam (graded)		
Study achievements	Successful exercise participation (not graded)		
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		

Module MA-INF 4328	**Spatio-Temporal Data Analytics**		
Workload 180 h	**Credit points** 6 CP	**Duration** 1 semester	**Frequency** every year
Module coordinator	Prof. Dr. Elena Demidova		
Lecturer(s)	Prof. Dr. Elena Demidova		
Classification	**Programme** M. Sc. Cyber Security	**Mode** Optional	**Semester** 2. or 3.
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.		
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	none		

Format

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

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

Exam achievements	Schriftliche Prüfung	(graded)
Study achievements	Erfolgreiche Übungsteilnahme	(not graded)
Literature		