Module Handbook

Master of Science
"Mathematics of Machine Learning and Data Science"

Universität Heidelberg
Fakultät für Mathematik und Informatik

Version as of 16.10.2024

Form of study: full time

Type of study: consecutive

Regular period of study: 4 semesters

Number of credit points to gain in this study: 120

Location of study: Heidelberg

Number of places: 40 p.a.

Fee: According to general regulations of Heidelberg University

Contents

1 Qualification objectives, profile, and particularities of the degree program

1.1 Qualification objectives of Heidelberg University

In keeping with Heidelberg University's mission statement and constitution, degree programmes are designed to provide a comprehensive academic education, incorporating subject-specific, cross-disciplinary, and career-related objectives that prepare students for their future professional careers. The resulting skills profile is a valid qualification profile that is included in the module handbooks for all university disciplines and is implemented in each degree programme's specific qualification objectives, curricula, and modules:

- Development of subject-specific skills, with a particular emphasis on research;
- Development of the skills required for trans-disciplinary dialogue;
- Development of practical problem-solving skills;
- Development of personal and social skills;
- Promotion of students' willingness to assume social responsibility on the basis of the skills acquired.

1.2 Profile of the degree program

The graduate program *Mathematics of Machine Learning and Data Science* is operated by the Faculty of Mathematics and Computer Science. The graduate program is research-oriented. It deepens and broadens the expertise, enables independent scientific work, lays the foundations for further development of the subject and prepares students for a demanding professional career or a doctorate. Graduates are qualified for roles requiring responsibility and leadership.

The graduate program focuses on the mathematical foundations of machine learning and data science. This includes concepts of teaching from both pure mathematics (topology, differential geometry, dynamical systems) and applied mathematics (statistics, optimization, numerics, functional analysis) and the interplay of concepts required for a in-depth understanding of research topics and for advancing the field. The course program also enables students to develop an understanding of how basic research problems of machine learning and data science stimulate research in mathematics.

Students become familiar with common software used in research and industry by solving concrete practical problems of machine learning and data science in the Data Science Lab. They acquire skills for prototyping algorithms on their own.

Overall, graduates are supposed to become members of the growing community of mathematicians which are qualified to address fundamental problems of machine learning and data science in basic research and in a wide range of application areas.

1.3 Subject-specific qualification objectives of the degree program

Graduates of the graduate program *Mathematics of Machine Learning and Data Science* are expected to possess the following skills:

- They acquired extensive knowledge in mathematical areas relevant to machine learning and data science, enabling them to identify and classify corresponding problems and to contextualise mathematical methods.
- They acquired in-depth knowledge in at least one direction of specialization of machine learning and data science, enabling them to interpret, analyse and evaluate current research.
- They are able to transfer mathematical methods into algorithms for solving concrete problems of machine learning and data science. They know how to operate machine learning software commonly used in research. They acquired programming skills and experience and are able to implement own algorithms.
- They gained experience with team work (problem analysis, discussion of the state of the art and approaches, software development), with reporting and presenting results.

Overall, graduates are qualified to actively contribute to current research on mathematical aspects of machine learning and data science and to tackle challenging problems in any related field of application.

1.4 Generic qualification objectives of the degree program

Graduates of the graduate program *Mathematics of Machine Learning and Data Science* should possess the following basic competencies of an interdisciplinary nature in the context of related research in mathematics.

- They are able to recognize the structure of applied problems of machine learning and data science and to classify them from the viewpoint of mathematics.
- They are used to scrutinise and to contextualise the pertinent research literature and to judge the potential both for research in mathematics and for applications to problems of machine learning and data science.
- The education through the graduate program enables them to recognize their knowledge gaps and to fill them.
- They possess theoretical and practical skills for solving problems of machine learning and data science. They flexibly use these skills in novel and unfamiliar situations.
- They have the competence to work in a team and to take on more prominent responsibility in a team (team leadership).
- They communicate effectively in professional matters, orally and in writing. In particular, they are proficient in communicating their own conclusions to practitioners based on the current state of the art and to exchange ideas with experts on an international scientific level.

Overall, graduates are qualified for a PhD project and to fill research positions in academia and industry devoted to machine learning and data science or a related field of application.

1.5 Particularities of the degree program and module descriptions

1.5.1 Description of the teaching and learning forms

- **Lecture:** Presentation of the course content by the lecturer using appropriate media; interaction and questions are possible.
- **Exercise:** Exercises and smaller parts of the syllabus are explained; questions, interaction and discussion by and with the students to understand the syllabus and the example exercises.
- **Seminar:** Independent development of a scientific topic, preparation of a presentation, giving the presentation with subsequent questions and discussion of the participants about the presentation.
- **Practicum:** Project work on the basis of a programming task, independent development of software including documentation, coordination of subtasks and solutions within a team, preparation of a project report and a presentation, presentation of the project.

1.5.2 Modalities for examinations

At the beginning of each course, the details and, in particular, deviations from the modalities for examinations listed below, will be announced by the lecturer.

Many modules have a uniform regulation for the awarding of CPs (Credit Points), so this regulation is described in detail here and then only referred to in the module descriptions.

Rules for awarding CPs. CPs are awarded if the final examination is passed. The details of the final examination are described in the individual module descriptions. Exercises are processed in a group with a tutor. In order to be admitted to the final examination, at least 50% of the points in the exercises must be achieved, unless the lecturer announces different conditions at the beginning of the course. This admission is valid for the current and the next two semesters. After that, a renewed admission to the final examination in the exercise group must be acquired.

Examination scheme. This part of the module description specifies the number of attempts which are allowed to pass the module, according to the examination regulations. Once an exam is passed, it cannot be repeated in order to improve the grade.

1+1: after the first attempt, there is only one repetition possible.

Examination period. There are two examination periods for written examinations at the end of each semester. The first examination period consists of the last week of the lecture period and the first two weeks of the lecture-free period. The second examination period consists of the last two weeks of the lecture-free period and the first week of the following lecture period. In exceptional cases, examinations can take place outside of these examination periods.

Examination dates. Written exams are offered within the first examination period mentioned above. For students who were prevented from the first attempt or failed in a second attempt, it will be offered in the second examination period. Oral exams are set by the lecturers.

If there are exceptions to the examination dates, especially if they are outside the examination periods mentioned above, the lecturer must announce them at the beginning of the course.

2 Structure of the course, admission

2.1 Module types, credit points

The assignment of an individual course to a module can be recognized by the *module code*. For almost all modules of the graduate program *Mathematics of Machine Learning and Data Science*, the module code begins with ML, followed by several letters or numbers: MLXYZ.

Compulsory modules
These modules are mandatory for every enrolled student. Students learn basics about the mathematical foundations of machine learning and data science from the viewpoints of each mathematical core area. This provides also the basis for specializing in one or two core areas by choosing elective and specialization courses accordingly. The following list gives an overview of the compulsory modules, their codes and the credit points.

Code	Compulsory module	CP
MLR	Ringvorlesung	8 CP
MLDSL	Data Science Lab	8 CP
MLSMLDA	Seminar Machine Learning and Data Science	12 CP
MLMT	Master's Thesis	30 CP
MLMTP	Master's Thesis Presentation	6 CP
MLCdC	Cross-disciplinary Competencies	8 CP

The masters thesis is presented to the supervisors of the thesis.

Core modules
Students have a restricted choice for choosing core modules, in order to ensure a sufficiently broad education in at least three core areas, yet at a deeper technical level. The examination regulations requires three core modules, each 8 CP, to be completed, overall 24 CP. Core modules are provided for each core area. They are encoded as follows.

Code	Compulsory elective core module	CP
MLC1	Geometric Methods for Machine Learning	8 CP
MLC2	High-dimensional Numerics	8 CP
MLC3	PDEs and Pattern Formation	8 CP
MLC4	Statistical Learning and Empirical Process Theory	8 CP
MLC5	Variational Methods and Numerical Optimization	8 CP

Elective module
The module MLSA Specialization Area with 24 CP allows the specialization in a research field. Various courses are offered in this module. Students may freely choose specialization courses, offered for each core area, in order to prepare for a master thesis close to current research.

2.2 Model study plan

module	CP	semester
Ringvorlesung	8	1
Data Science Lab	8	2
three Core modules	24	1 and 2
Cross-disciplinary Competencies	8	1 and 2
Seminar Machine Learning and Data Science	12	2 and 3
Specialization Area	24	2 and 3
Master's Thesis	30	4
Master's Thesis Presentation	6	4
Total		**120 CP**

2.3 Mobility window

The mobility window for the graduate program *Mathematics of Machine Learning and Data Science* usually comprises the second and third semesters. For this reason the CPs for the compulsory Data Science Lab, scheduled for the first year, can be also acquired in the third semester. The courses for the modules Seminar Machine Learning and Data Science, Specialization Area and Cross-disciplinary Competencies are suitable for a stay abroad.

The planning of a study visit should be started early. Especially for a stay abroad, the organization phase can take up to one year. Information about studying abroad within the Erasmus program can be found here.

3 Compulsory modules

This chapter specifies the compulsory modules. According to the examination regulations, the following modules have to be completed.

Code	**Compulsory module**	**CP**
MLR	Ringvorlesung	8 CP
MLDSL	Data Science Lab	8 CP
MLSMLDA	Seminar Machine Learning and Data Science	12 CP
MLMT	Master's Thesis	30 CP
MLMTP	Master's Thesis Presentation	6 CP
MLCdC	Cross-disciplinary Competencies	8 CP

The supervisor of the Master's thesis can require up to 16 CP for specific courses as a precondition for supervision.

Ringvorlesung

Code MLR	**Name** Ringvorlesung	
CP 8	**Duration** one semester	**Offered** every winter semester
Format lecture 4 SWS, exercises 2 SWS	**Workload** 240h; lecture 60h, exercises 30h, self-dependent subsequent work 120h, preparation for the exam 30h.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** several lecturers	**Examination scheme** 1+1
Learning objectives	Students - get to know and can recognize the subfields of machine learning and data science, their relation to mathematics and the interrelations between them, - are able to classify problems of machine learning and data science and to relate them to relevant mathematical topics.	
Learning content	- Overview of machine learning and data science, - Brief introduction into relevant mathematical methods from each area of specialization.	
Requirements for participation	none	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written examination, which completes the module.	
Useful literature	will be announced in the lecture	

Data Science Lab

Code MLDSL	**Name** Data Science Lab	
CP 8	**Duration** one semester	**Offered** every semester
Format Practicum 6 SWS	**Workload** 240h; 160h work on the project (optionally in small groups), 50h self-dependent study, 30h documentation and presentation of results.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** several lectures	**Examination scheme** 1+1
Learning objectives	Students are able to solve practical problems of machine learning and data science and can prototype algorithms on their own by using common software used research and industry. This will enable them to transfer mathematical methods of data analysis and machine learning into software-based solutions tailored to application problems.	
Learning content	- Implementing solutions to practical machine learning and data science problems in Python, - Using common data science and deep learning frameworks, e.g. scikit-learn, pandas, PyTorch, JAX, etc.	
Requirements for participation	Ringvorlesung (MLR); programming skills in Python	
Requirements for the assignment of credits and final grade	Students give a talk in order to report, discuss and defend the results. The defense has to showcase their own individual contribution to the final result. The defense will be graded together with a written summary that has to be submitted beforehand.	
Useful literature	tba when the course starts	

Seminar Machine Learning and Data Science

Code MLSMLDS	**Name** Seminar Machine Learning and Data Science	
CP 12	**Duration** two semesters	**Offered** every semester
Format 2 Seminars each 2 SWS + Tutorial 2 SWS	**Workload** 2 seminar courses each of 180h; thereof 60h seminar and tutorial 120h preparation of presentation and supervision	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** depending on teaching offer	**Examination scheme** 1+1
Learning objectives	- Ability to skim and scrutinise the research literature, to classify and understand the scientific content, and to explain and present it to peers in a condensed and comprehensible way, - Ability to discuss lectures given by other students, and to recognize and comment on the essential points in a concise and respectful way, - Getting to know and recognising good and bad styles of writing of scientific research papers.	
Learning content	Research topics and scientific content of a collection of research papers compiled by the lecturer beforehand.	
Requirements for participation	Core module of the corresponding area is recommended. Further recommended prior knowledge will be announced by the lecturer.	
Requirements for the assignment of credits and final grade	The module comprises two seminar courses each of them is completed with a graded exam. This exam includes the presentation of about 40- to 90-minute presentation, active and passive participation in other presetations and a written elaboration of the presentation (about 10 pages). The appropriate scope, form and content are assessed and graded. The exam must be passed in order to be awarded the CP. The final grade of the module is determined by the grades of the exams of the two seminar courses each weighted with 6 CP.	
Useful literature		

Master's Thesis

Code MLMT	**Name** Master's Thesis	
CP 30	**Duration** six month	**Offered** continuous
Format Supervised self-study	**Workload** 900 h work elaborating an individual research topic, documented in a thesis.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** varying	**Examination scheme** 1+1
Learning objectives	- Use of the acquired technical knowledge and methods to independently solve a complex problem from data science, machine learning and its applications, - Ability to independently produce a written thesis, with scientific content and organized according to the international standard: Introduction (briefly: overview, motivation, scientific topic, state of the art, own contribution), background material, sections detailing the own contribution, optionally: experimental results and discussion, conclusion.	
Learning content	Independent scientific work on a demanding problem from the fields of data science, machine learning and its applications.	
Requirements for participation	Exam regulations (PO): at least 45 CP. The master?s thesis can also be started in the third semester. The supervisor of the Master's thesis may require up to 16 CP for specific contents of teaching, as a precondition for supervision.	
Requirements for the assignment of credits and final grade	Passing the graded Master's thesis is required for awarding the CPs. The Master's thesis includes regular consulting with the advisor and the written elaboration.	
Useful literature	to be announced by the advisor	

Master's Thesis Presentation

Code MLMTP	**Name** Master's Thesis Presentation	
CP 6	**Duration**	**Offered** continuous
Format Seminar	**Workload** 180h; Preparation of the presentation, delivery and subsequent discussion	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** Thesis advisor	**Examination scheme** 1+1
Learning objectives	The students - acquire, practice and demonstrate the ability to present their own research in a scientific presentation, - are able to put their own work in the context of the current state of the research field and to communicate assumptions, methods and results, - gain skills and experience in discussing questions regarding their own research work.	
Learning content	- Presentation and defense of the content of the Master's thesis, especially the advantages and limitations as well as a comparison to the current state of the art, - Discussion of questions by peers and academics.	
Requirements for participation	Completed Master's thesis (recommended).	
Requirements for the assignment of credits and final grade	The module is completed with a graded evaluation of the presentation (approximately 30-60 minutes) and the student's ability to defend the results of his/her work in the face of questions and comments (approximately 15-45 minutes). Total time should not exceed 90 minutes. The grade must be at least a pass for the CP to be awarded. The final grade of the module is determined by the grade of the evaluation.	
Useful literature		

Cross-disciplinary Competencies

Code MLCdC	**Name** Cross-disciplinary Competencies	
CP 8	**Duration**	**Offered** depends on the individual courses
Format depends on the individual courses	**Workload** depends on the individual courses	**Availability**
Language English or German	**Lecturer(s)**	**Examination scheme**
Learning objectives	Cross-disciplinary competencies (in German: Übergreifende Kompetenzen ÜK) refer to study contents, key competencies and additional qualifications that go beyond subject-specific knowledge and convey personality and job-related competencies that are essential in today's professional life (in and outside of research).	

Learning content	There are various choices available. Prior consultation with the chairperson of the examination board is recommended. Einführung in das Textsatzsystem LaTeX: 2 CP, lecture 2 SWS, successful participation IT Project Management: 3 CP, lecture 2 SWS, pass the final examination Software Economics: 3 CP, lecture 2 SWS, pass the final examination Study Abroad: 3 CP for 3 month stay abroad, submit and pass a written report about the experiences Education through Summer School, Holiday Course, or Conference: 1 CP for 30 hours event, submit and pass a written report about the event From the Master of Computer Engineering the modules Entrepreneurship, Tools and C++ Practice can be chosen. For the module description please refer to the module handbook of the Master Computer Engineering course of studies. Within the framework of the ÜK, courses from the university's range of courses that do not belong to this study program can be accepted. This includes language courses, but not courses of the Heidelberg University Computer Center (URZ). In this case, the credit points of the courses are transferred (especially for language courses). Courses offered by the Career Service in the area of ÜK can be recognized; in this case, it is essential to consult with the Examination Office beforehand. Furthermore, irregular offers of the faculty marked as ÜK can be taken.
Requirements for participation	
Requirements for the assignment of credits and final grade	depends on the individual courses
Useful literature	

4 Core modules

The modules listed in this chapter serve as an introduction to a mathematical core area of the graduate program *Mathematics of Machine Learning and Data Science*. They typically build on a bachelor's degree.

The core modules are compulsory elective moduls. Altogether 3 modules (24 CP) have to be completed. At least two modules from this category should be completed in the first semester.

Code	**Core module**	
MLC1	Geometric Methods for Machine Learning	8 CP
MLC2	High-dimensional Numerics	8 CP
MLC3	PDEs and Pattern Formation	8 CP
MLC4	Statistical Learning and Empirical Process Theory	8 CP
MLC5	Variational Methods and Numerical Optimization	8 CP

The individual descriptions of the core modules are listed below. The core modules are offered regularly in a yearly cycle.

Geometric Methods for Machine Learning

Code MLC1	**Name** Geometric Methods for Machine Learning	
CP 8	**Duration** one semester	**Offered** every summer semester
Format lecture 4 SWS, exercises 2 SWS	**Workload** 240h; lecture 60h, exercises 30h, self-dependent subsequent work 120h, preparation for the exam 30h.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** alternating	**Examination scheme** 1+1
Learning objectives	In this course students are introduced to the research area concerned with enhancing machine learning by the use of geometric methods. At the end of the course, they will be able to apply major concepts of geometry, in particular Riemannian geometry, to machine learning. In addition, they will be able to deal with new examples and methods relevant to machine learning.	
Learning content	- Recap of basic differential geometry, including Riemannian manifolds and curvature, principal and vector bundles - Hyperbolic, Euclidean, spherical geometry; comparison theorems - Information geometry: Wasserstein and Fisher-Rao metrics - Lie groups and homogeneous spaces, examples relevant to machine learning - Graphs and synthetic notions of curvature, Simplicial approximations	
Requirements for participation	Recommended: foundational course on geometry and topology (Grundlagen der Geometrie und Topologie)	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written examination, which completes the module.	
Useful literature	tba in the lecture	

High-dimensional Numerics

Code MLC2	**Name** High-dimensional Numerics	
CP 8	**Duration** one semester	**Offered** every summer semester
Format lecture 4 SWS, exercises 2 SWS	**Workload** 240h; lecture 60h, exercises 30h, self-dependent subsequent work 120h, preparation for the exam 30h.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** alternating	**Examination scheme** 1+1
Learning objectives	At the end of the course the students will have developed a solid understanding of stochastic modeling and parametrisations of differential equations in science and engineering. They will be able to compute approximations and estimators used to quantify uncertainties in high-dimensional parameter-dependent problems, and analyze errors and computational complexities of the corresponding numerical methods.	
Learning content	Uncertainty Quantification: - Parametric Models - Model problems - Parameter regularity High-dimensional integration: - Monte Carlo methods - Sampling from random fields - Quasi-Monte Carlo - Sparse-grids - Multilevel methods High-dimensional approximation: - Regularity for infinite-parametric functions - Stochastic collocation - Low-rank tensor approximation - Random features	
Requirements for participation	Recommended: foundational course: Numerics	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written examination, which completes the module.	

Useful literature	tba in the lecture

Partial Differential Equations and Measures

Code MLC3	**Name** Partial Differential Equations and Measures	
CP 8	**Duration** one semester	**Offered** every winter semester
Format lecture 4 SWS, exercises 2 SWS	**Workload** 240h; lecture 60h, exercises 30h, self-dependent subsequent work 120h, preparation for the exam 30h.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** alternating	**Examination scheme** 1+1
Learning objectives	At the end of the course the students will have developed a solid understanding of the mathematics of PDEs and Pattern Formation and evolution of measures and their relevance for machine learning and data science. At the end of the course, they will be able to apply major concepts to machine learning. In addition, they will be able to deal with new examples and methods relevant to machine learning.	
Learning content	Introduction to Calculus of Variations, Introduction to Optimal Transport, some measure theoretical methods for PDEs, PDEs on measure spaces	
Requirements for participation	Recommended: foundational course: Functional analysis	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written examination, which completes the module.	
Useful literature	tba in the lecture	

Statistical Learning and Empirical Process Theory

Code MLC4	**Name** Statistical Learning and Empirical Process Theory	
CP 8	**Duration** one semester	**Offered** every winter semester
Format lecture 4 SWS, exercises 2 SWS	**Workload** 240h; lecture 60h, exercises 30h, self-dependent subsequent work 120h, preparation for the exam 30h.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** alternating	**Examination scheme** 1+1
Learning objectives	Basics for all areas of probability theory and statistics, mastery of calculus and thus the ability to handle the structures and explain the relationships. Independently solving tasks from the topic area with presentation in the exercises	
Learning content	I.Statistical learning: Linear models, high-dimensional models, Lasso, kernel methods for nonparametric density and data fitting II. Empirical process theory: Uniform laws of large numbers (Bracketing, finite dimensional approximation), Symmetrisation, Univariate exponential inequalities (Inequalities of Hoeffding, Bennett, Prokhorov, Bernstein), Set indexed empirical processes (Glivenko-Cantelli classes, Vapnik-Cervonenkis classes), Uniform laws of large numbers (Covering numbers), Concentration inequalities (Tsirelson-Ibragimov-Sudakov inequality, Talagrand?s inequality)	
Requirements for participation	Recommended: foundational course: Statistics & stochastic	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written examination, which completes the module.	
Useful literature	tba in the lecture	

Variational Methods and Numerical Optimization

Code MLC5	**Name** Variational Methods and Numerical Optimization	
CP 8	**Duration** one semester	**Offered** every winter semester
Format lecture 4 SWS, exercises 2 SWS	**Workload** 240h; lecture 60h, exercises 30h, self-dependent subsequent work 120h, preparation for the exam 30h.	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** alternating	**Examination scheme** 1+1
Learning objectives	At the end of the course, students will be able to associate major tasks of data science and machine learning with variational problem formulations and with variational and optimization methods for solving them. In addition, they are introduced to the research area concerned with enhancing methods of numerical optimization by machine learning.	
Learning content	The lecture covers variational and optimization methods in the context of major tasks of data science and machine learning: data embedding and representation; supervised, semi-supervised and unsupervised learning; classification, regression and density estimation using discriminative and generative models; structured prediction. Besides established classical methods, deep learning will be a central theme, including applications to numerical optimization.	
Requirements for participation	Recommended: foundational course on optimization (Grundlagen der Optimierung)	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written examination, which completes the module.	
Useful literature	tba in the lecture	

5 Elective module

The elective module *Specialization Area* comprises 24 CP. Varying courses are offered for this module. the specialization courses deepen the knowledge of a core area based on the core modules. The content of the courses of the specialization area usually closely relates to current research. The courses in the *Specialization Area* module are not subject to a cycle, which means they can be offered regularly, irregularly or even just once.

For the courses, the following information applies to the format, credits and workload of the individual courses in the course descriptions.

format and CP	Lecture 2 SWS (4 CP)
workload	120 h: 30 h lecture,
	75 h homework and independent follow-up work,
	15 h exam preparation.
format and CP	Lecture 2 SWS + Exercise 2 SWS (6 CP)
workload	180 h: 30 h lecture, 30 h exercises,
	105 h homework and independent follow-up work,
	15 h exam preparation.
format and CP	Lecture 4 SWS (6 CP)
workload	180 h: 60 h lecture,
	90 h homework and independent follow-up work,
	30 h exam preparation.
format and CP	Lecture 4 SWS + Exercise 2 SWS (8 CP)
workload	240 h: 60 h lecture, 30 h exercises,
	120 h homework and independent follow-up work,
	30 h exam preparation.

Specialization Area

Code MLSA	**Name** Specialization Area	
CP 24	**Duration** two semesters	**Offered** every semester
Format	**Workload** previously described, depends on the format and CP of the course	**Availability** M.Sc. Mathematics of Machine Learning and Data Science
Language English	**Lecturer(s)** alternating	**Examination scheme** 1+1 for each course
Learning objectives	Deeper knowledge and understanding of mathematical structures, results, methods and proof techniques and their relations to data science and machine learning; ability for coping with complex scenarios.	
Learning content	Topical research problems and frameworks of this area of work.	
Requirements for participation	Core module of the corresponding area is recommended. Further recommended prior knowledge will be announced by the lecturer.	
Requirements for the assignment of credits and final grade	Successfully working on the exercise sheets is mandatory for participating in the graded written or oral examination, which completes the module.	
Useful literature	tba in the lecture	