Mathematical Sciences
/Matematiska vetenskaper/

The research area Mathematical Sciences includes five specialisations:

- **Computational Mathematics**/ Beräkningsmatematik/ SCB code: 10105/

- **Mathematics**/ Matematik/ SCB code: 10105/

- **Mathematical Statistics**/ Matematisk statistik/ SCB code: 10106/

- **Optimization**/ Optimeringslära/ SCB code: 10105/

- **Interdisciplinary Mathematics**/ Tvärvetenskaplig matematik/ SCB code: 10105/

General description of the research area
Within mathematical sciences we study questions of a mathematical character, either from a purely theoretical perspective or directed towards practical applications. In either case the mathematical problem and its properties is the main focus. The research is based on mathematical proofs and/or computer assisted calculations.

Eligibility requirements and selection
The basic eligibility requirements as well as the general principles for selection are specified in the faculty's *Study Handbook for PhD Studies*.

Specific eligibility requirements
Admission to PhD Studies in the research area of Mathematical Sciences requires completion of courses of at least 60 ECTS at the master level in a field relevant to the research area. These 60 ECTS should include an independent project (degree project) of at least 30 ECTS in a field relevant to the research area in PhD studies, or in more mathematics oriented, applied topics.

Degree
PhD studies lead to a Degree of Doctor or a Degree of Licentiate. The latter degree can also serve as a stage in the PhD studies. The Degree of Licentiate comprises 120 ECTS, of which courses correspond to 60 ECTS and the licentiate thesis corresponds to 60 ECTS. The Degree of Doctor comprises 240 ECTS, of which courses correspond to 100-120 ECTS and the doctoral thesis corresponds to 120-140 ECTS.

The total number of course credits in Mathematics, Mathematical Statistics, Optimization and Interdisciplinary Mathematics is 60 ECTS for a Degree of Licentiate, and 120 ECTS for a Degree of Doctor. The thesis makes up the remaining credits.

The total number of course credits in Computational Mathematics is 60 ECTS for a Degree of Licentiate, and 100-120 ECTS for a Degree of Doctor. The thesis makes up the remaining credits. The number of course credits will be specified when the PhD student's individual study plan is formulated.

Goals and implementation of the PhD studies

The general goals and objectives of PhD studies are specified in the introduction to the faculty's *Study Handbook for PhD Studies*, as well as in the Higher Education Ordinance (reprinted in the *Study Handbook*'s appendix A).

PhD studies in the research area of Mathematical Sciences will equip the PhD student with the knowledge and skills to fulfill all the degree outcomes. In all the specialisations, the studies consist of research and thesis work, courses, participation in seminars and attendance at national and international conferences.

PhD studies will give basic and broad knowledge in the respective specialisation as well as in-depth insight into one or more aspects of the reserach area. The studies will also endow the PhD student with the skill to independently conduct research and development work within his/her specialisation or adjacent fields. Upon completion of PhD studies, the student should be able to critically review and evaluate research results as well as independently plan, carry out and publish research projects.

The PhD student will acquire broad knowledge and understanding of his/her research area by completing the basic course requirements (which are specified below for each specialisation), and by being a part of the department's research environment, which includes expertise in many fields of both theoretical and applied mathematics. Furthermore, there is always the possibility to expand the breadth of studies by taking relevant courses from other departments. All PhD students are also expected to regularly participate in the department's seminars.

The PhD student will acquire a deep knowledge and understanding of his/her research area, and in particular within his/her research specialisation, by actively participating in in-depth courses that are selected in consultation with the supervisors (in accordance with the descriptions of the specialisation in the general study syllabus), by participating in relevant conferences and through his/her own research work.

The PhD student will develop familiarity with scientific methodology through his/her own research, through collaboration with his/her supervisors and possibly other more experienced researchers, as well as by attending a mandatory course in research methodology.

The PhD student will acquire skills and competencies by independently planning and carrying out theoretical research work, by actively participating and presenting his/her research at conferences and seminars, and in some cases by teaching courses at the undergraduate level.

PhD students in Mathematical Sciences will develop judgement and approach by completing courses in research ethics and by actively participating in seminars in the research area. The department offers seminar series in theoretical and applied mathematics, computational mathematics, mathematical statistics, optimization and mathematical education. PhD students should also participate in the seminar series *Research Seminars*, 2 ECTS.

Teaching will be conducted in the form of lectures, seminars, group studies and supervision. Course examinations are conducted in writing or orally and are graded Pass or Fail. The PhD student should actively participate in seminars, guest lectures and conferences. These activities aim to keep the student informed of current research and applications in the field as well as developments outside of his/her specialisation.

Thesis

The overall rules regarding the format, submission and grading of a thesis can be found in the faculty's *Study Handbook for PhD Studies*.

To receive a Degree of Doctor or Degree of Licentiate, the PhD student must write a thesis. It is a requirement that the PhD student demonstrates intellectual autonomy by contributing, in an extensive manner, to the production of the research results that will become part of the thesis.

For a Degree of Doctor, the thesis should be of such level of quality that the results can be published in an international scientific journal of good quality. The thesis can be presented as a continuous piece of work (monograph thesis) or as a compilation thesis. A compilation thesis consists of attached copies of a number of research articles/manuscripts and an introduction (kappa). The articles can be written by the PhD student him-/herself or have co-authors, but in the latter case it should be possible to distinguish the PhD student's contribution to the articles. The introduction should always be written by the PhD student him-/herself, and it should introduce the reader to the thesis' research area as well as describe the attained results. The introduction should also place all the attained results in an overall context. Doctoral theses in the research area should normally be in the form of a composite thesis and should contain at least two articles that have been published or accepted for publication.

A licentiate thesis can consist of a research essay or an investigative report conducted on scientific grounds.

Individual study plan

An individual study plan will be formulated for each PhD student. The detailed planning of courses and other components will be conducted in consultation with the supervisor and documented in the individual study plan (see *Study Handbook for PhD Studies*, section 5.3). The study plan should be established within one month after admission to PhD studies, and it should be revised at least once a year.

Supervision

All PhD students will have at least two supervisors. One of the supervisors will be appointed as the main supervisor (see *Study Handbook for PhD Studies*, section 4.1).

The supervisors should assist the student in the planning of his/her studies and in the selection of research projects, and in general guide the student during the period of study.

Courses

Courses can be divided into three categories and together make up 100-120 ECTS for a Degree of Doctor, and 60 ECTS for a Degree or Licentiate depending on the specialisation:

- Faculty course requirements
- Course requirements for all specialisations
- Specialisation-specific course requirements

The faculty course requirements include courses that aim to ensure that certain degree outcomes specified in the Higher Education Ordinance are fulfilled. These courses also give PhD students who teach at Linköping University a basic pedagogical education.

The course requirements applicable to all specialisations will give PhD students breadth in the field of Mathematical Sciences. These courses focus on certain central aspects of the different specialisations that are deemed significant for all PhD students in this field.

The role of specialisation-specific course requirements is to give breadth within the specialisation as well as both depth and breadth within the actual topic of research. There is also the possibility to include courses from other research areas that are deemed to be relevant for the PhD student's studies.

The PhD student will acquire deep knowledge and understanding of Mathematical Sciences, and in particular within his/her research specialisation, by selecting suitable courses, which should be done in consultation with the supervisor in consideration of the student's thesis work.

Faculty course requirements
Scientific theory, methodology and ethics
All PhD students admitted as of 1 January 2010 should complete mandatory courses as decided by the faculty in methodology and ethics, or be deemed to have equivalent competencies, in order to receive a degree. (This applies for both a Degree of Licentiate and a Degree of Doctor)

Pedagogic studies
All PhD students who teach should complete a basic course in pedagogy. At least 3 ECTS from this course should be included in the PhD studies, and any remaining credits should be counted as departmental duties (see *Study Handbook for PhD Studies*, section 5.5).

Course requirements for all specialisations
Normally all PhD students should complete at least 5 ECTS within each of the following specialisations: computational mathematics, mathematics, mathematical statistics and optimization, alternatively be deemed to have acquired comparable knowledge in other ways.

Accreditation
The PhD student should submit an application for accreditation using the appropriate form; the application is to be approved or rejected by the main supervisor, and a positive decision on accreditation can be made by the Director of PhD Studies at the relevant department. A decision to reject an application for accreditation may not be made by the Director of PhD Studies at the department, rather, such a decision may only be made by the faculty's Board of PhD Studies. An application for accreditation that is not approved by the Director of PhD Studies at the relevant department should therefore be forwarded to the Board of PhD Studies. Master courses that are equivalent to at most half of the course requirements for the degree, that do not form part of the basic or specific eligibility requirements for the specialisation, and that are relevant to the PhD studies may be counted toward the degree. PhD courses that have been completed prior to admission to PhD studies in Mathematical Sciences, or that have been completed at other universities during the PhD studies, may be accredited in full if they are deemed to be relevant to the PhD student's studies.

Specialisations

Descriptions are given below of the different specialisations within Mathematical Sciences and their specific course requirements. Beyond these requirements, all specialisations provide scope for further broadening and deepening of studies, and these required courses may even be selected outside of the student's own field of research in consultation with the supervisor.

Computational Mathematics

Computational Mathematics is the branch of applied mathematics that develops and analyzes numerical methods and algorithms for the solution of problems, mainly from technology and science, formulated as mathematical models. Important concepts are sensitivity to noise in the data of the governing mathematical model (well posedness) and stability and convergence of the numerical approximation. Other important questions are the efficiency of algorithms, software aspects and computer implementations (eg. on parallel computers).

Specialisation-specific course requirements

In order for the PhD studies to provide sufficiently broad knowledge and deep understanding of this research specialisation, courses leading to a Degree of Doctor should contain at least 20 ECTS of basic courses that cover the following subject areas:

- Numerical methods for partial and ordinary differential equations.
- Numerical linear algebra and methods for sparse matrices.
- Algorithms and software for high performance computer systems.

Besides the basic courses, the PhD student should choose at least 40 ECTS of in-depth courses in Computational Mathematics. For a Degree of Licentiate, the basic course requirements are the same, in addition the in-depth courses should make up at least 10 ECTS. The remaining courses can be selected from other fields of mathematics or relevant applied topics.

Mathematics

The subject area *mathematics* at Linköping University is a multifaceted activity. It includes algebra, discrete mathematics, dynamical systems, functional analysis, geometry, inverse problems, complex analysis, mathematical physics, partial differential equations, applied mathematics and topology. Doctoral students thus have a multitude of research areas to choose from, and typically this election has already been done when the studies are started or carried out within six months.

Specialisation-specific course requirements

In order for the PhD studies to provide broad knowledge and understanding of Mathematics, courses leading to a Degree of Doctor should contain at least 60 ECTS from the following three subject areas:

- Algebra and discrete mathematics (at least 20 ECTS),
- Analysis and differential equations (at least 20 ECTS),
- Geometry and topology (at least 10 ECTS).

For the Degree of Licentiate, at least 30 ECTS should consist of courses from these subject areas.

Mathematical Statistics

The subject area *mathematical statistics* consists of probability theory and statistical inference. Probability theory is a branch of mathematics, based on measure and integration theory, used in the construction and analysis of models of random trials, that is, experiments whose results are due to random factors. Inference is the science of how, in the context of a particular trial, one can take advantage of observed values to predict the unknown quantities that can't be observed. Theoretical probabilistic models are indispensable tools for the latter, so the two subtopics are intimately related.

Specialisation-specific course requirements

In order for the PhD studies to provide broad knowledge and understanding of the research specialisation of Mathematical Statistics, courses leading to a Degree of Doctor should contain at least 30 ECTS from each of the following subject areas:

- Probability theory (including stochastic processes),
- Statistical inference (theory or practice).

For the Degree of Licentiate, at least 15 ECTS should consist of courses from each of these two subject areas.

Optimization

Optimization deals with theory and methods to formulate, analyze and solve decision problems with the help of mathematics. Application of optimization methodology on a decision problem requires a mathematical model of the problem and an optimization algorithm to find a solution to the problem. The mathematical model describes which solutions are possible/allowed and the value of each solution. The solutions are represented by variables (the decision maker's choice), the limitations by constraints, and the value by an objective function. An optimization algorithm is used for computing an optimal (or near-optimal) solution to a given optimization problem; different types of models require different algorithms. Since real optimization problems can have millions of decision variables, these calculations can be very time-consuming. Scientific activities in optimization are to develop new and better optimization methods for different problem classes, to derive theoretical properties of various optimization problems and optimization methods, as well as structuring and modelling decision problems in various applied fields, so that they can be attacked with optimization.

Specialisation-specific course requirements

In order for the PhD studies to provide sufficiently broad knowledge and deep understanding of this research specialisation, courses leading to both a Degree of Doctor and a Degree of Licentiate should normally contain at least 30 ECTS of basic courses that cover the following subject areas:

- Linear Optimization,
- Nonlinear Optimization,
- Discrete Optimization,
- Network Optimization.

Furthermore, courses selected should include in-depth courses that aim to provide deep knowledge and understanding of optimization, and in particular within the PhD student's own research topic. Courses can also be selected from other fields of mathematics or from relevant application.

Interdisciplinary Mathematics

The subject area *interdisciplinary mathematics* covers interdisciplinary research that includes two subject areas of which the main area is within mathematical sciences (ie computational mathematics, mathematics, mathematical statistics or optimization) and the other is an area outside the mathematical sciences (eg, physics, biology or medicine). The solution methods used should be based on mathematical methods and mathematical proofs. The doctoral student typically chooses the research area and topic before the studies begins.

Specialisation-specific course requirements

In order for the PhD studies to provide broad knowledge and understanding of Interdisciplinary Mathematics, courses leading to a Degree of Doctor should contain at least 60 ECTS from the following four subject areas: Computational Mathematics, Mathematics, Optimization, and Mathematical Statistics, of which 40 ECTS should be within the main research area.
For the Degree of Licentiate, at least 30 ECTS should be within the main research area.

In addition, courses in the second research area should be selected. Such courses should make up at least 20 ECTS for a Degree of Doctor, and at least 10 ECTS for a Degree of Licentiate.

Transitional Provisions

Changes to the general study syllabus do not apply to those who have already been admitted to PhD studies in the research area. A change to the new general study syllabus may however be approved if both the main supervisor and the PhD student agree. In such a case, this should be documented in the individual study plan.