Computational Science: Applied Mathematics and Risk Analysis

Department of Mathematics, University of Oslo

Planned start: Fall 2018

Why Applied Mathematics and Risk Analysis

Er du interessert i matematiske metoder og algoritmer, hvor de kommer fra, hvordan de kan programmeres og hva de kan brukes til? I denne studieretningen er dette hovedfokus, gjerne kombinert med anvendelser av algoritmene. Anvendelsene involverer ofte store datasett og kan dreie seg om å estimere risiko i store prosjekter, trekke ut nyttig informasjon fra datasettet, finne optimale strategier eller representere datasettet på en kompakt og hensiktsmessig måte, for eksempel som geometriske objekter eller bilder.

Dette kan omfatte formulering av matematiske modeller, konstruksjon av numeriske algoritmer, programvareutvikling, visualisering/grafikk samt vurdering av beregningsresultatenes kvalitet. Aktuelle prosjekter kan ta for seg alle disse stegene i denne prosessen eller særlig fokusere på noen av dem.

Gruppen for beregningsorientert matematikk og gruppen for risikoanalyse ved Matematisk institutt sogner til denne studieretningen.

Structure and courses

The table here is an example of a suggested path for a Master of Science project, with course work the first year and thesis work the last year.

	10 ECTS	10 ECTS	10 ECTS
4th semester	Master thesis	Master Thesis	Master Thesis
3rd semester	Master thesis	Master Thesis	Master Thesis
2nd semester	Master courses	Master courses	Master courses
1st semester	Master courses	Master courses	Master courses

This program is very flexible in its structure and students may opt for starting with their thesis work from the first semester and scatter the respective course load across all four semesters. Depending on interests and specializations, there are many courses on computational science which can make up the required

curriculum of course work. Furthermore, courses may be broken up in smaller modules, avoding thereby the limitation of 10 ECTS per course only. Some of these courses are listed below.

Courses. Depending on specialization, the following courses that can be included as part of the compulsory 60 ECTS needed for a Master of Science degree are described here.

Relevante masterkurs for anvendt matematikk:

1. MAT-INF4110 - Matematisk optimering

2. MAT-INF4130 - Numerisk lineær algebra

3. MAT-INF4170 - Splinemetoder

Mange andre emner er også relevante, for eksempel bilde- og signalbehandling og pde-emnene på Ifi (Simula).

Relevante masterkurs for risikoanalyse:

1. STK4400 - Risiko- og pålitelighetsanalyse

2. STK4405 - Elementær innføring i risiko- og pålitelighetsanalyse

3. MAT-INF4110 Matematisk optimering (også tatt med over)

Listen kan evt. utvides med flere masterkurs i finans, forsikring og statistikk

Graduate Certificates. The program plans to offer graduate certificates in

- Three of the courses with label CS-MATH gives a certificate in Computational Mathematics

- Three of the courses with label CS-PHYS gives a certificate in Computational Physics, Astrophysics, Chemistry, Materials Science and Geoscience

- Three of the courses with label CS-BIO gives a certificate in Computational life science.

- Three of the courses with label CS-INF gives a certificate in High-performance computing.

Dual Degrees. The program plans to offer dual degrees (more text to come)

Description of learning outcomes

The power of the scientific method lies in identifying a given problem as a special case of an abstract class of problems, identifying general solution methods for this class of problems, and applying a general method to the specific problem (applying means, in the case of computing, calculations by pen and paper, symbolic computing, or numerical computing by ready-made and/or self-written software). This generic view on problems and methods is particularly important for understanding how to apply available, generic software to solve a particular problem.

Computing competence represents a central element in scientific problem solving, from basic education and research to essentially almost all advanced problems in modern societies. Computing competence is simply central to further progress. It enlarges the body of tools available to students and scientists beyond classical tools and allows for a more generic handling of problems. Focusing on algorithmic aspects results in deeper insights about scientific problems.

The learning outcomes are subdivided in three general categories, knowledge, skills and general competence.

- **Knowledge**: A candidate from this program

  - has deep knowledge of the scientific method and computational science at an advanced level, meaning that the candidate

    1. has the ability to understand advanced scientific results in new fields
    2. has fundamental understanding of methods and tools
    3. can develop and apply advanced computational methods to scientific problems
    4. is capable of judging and analyzing all parts of the obtained scientific results
    5. can present results orally and in written form as scientific reports/articles
    6. can propose new hypotheses and suggest solution paths
    7. can generalize mathematical algorithms and apply them to new situations
    8. can link computational models to specific applications and/or experimental data
    9. can develop models and algorithms to describe experimental data
    10. masters methods for reproducibility and how to link this to a sound ethical scienfitic conduct
    11. has a thorough understanding of how computing is used to solve scientific problems
    12. knows fundamental algorithms in computational science

  - has a fundamental understanding and knowledge of scientific work, meaning that

1. the candidate can develop hypotheses and suggest ways to test these
2. can use relevant analytical, experimental and numerical tools and results to test the scientific hypotheses
3. can generalize from numerical and experimental data to mathematical models and underlying principles
4. can analyze the results and evaluate their relevance with respect to the actual problems and/or hypotheses
5. can present the results according to good scientific practices

- **Skills**: A candidate from this program

  - has a deep understanding of what computing means, entailing several or all of the topics listed below
    1. knows the most fundamental algorithms involved, how to optimize these and perform statistical uncertainty quantification
    2. has overview of advanced algorithms and how they can be accessed in available software and how they are used to solve scientific problems
    3. has knowledge and understands high-performance computing elements: memory usage, vectorization and parallel algorithms
    4. can use effeciently high-performance computing resources, from compilers to hardware architectures
    5. understands approximation errors and what can go wrong with algorithms
    6. has knowledge of at least one computer algebra system and how it is applied to perform classical mathematics
    7. has extensive experience with programming in a high-level language (MATLAB, Python, R)
    8. has experience with programming in a compiled language (Fortran, C, C++)
    9. has experience with implementing and applying numerical algorithms in reusable software that acknowledges the generic nature of the mathematical algorithms
    10. has experience with debugging software
    11. has experience with test frameworks and procedures
    12. has experience with different visualization techniques for different types of data
    13. can critically evaluate results and errors
    14. can develop algorithms and software for complicated scientific problems independently and in collaboration with other students
    15. masters software carpentry: can design a maintainable program in a systematic way, use version control systems, and write scripts to automate manual work

16. understands how to increase the efficiency of numerical algorithms and pertinent software
17. has knowledge of stringent requirements to efficiency and precision of software
18. understands tools to make science reproducible and has a sound ethical approach to scientific problems

- **General competence**: A candidate from this program

    - is able to develop professional competence through the thesis work, entailing:
        1. mature professionally and be able to work independently
        2. can communicate in a professional way scientific results, orally and in written form
        3. can plan and complete a research project
        4. can develop a scientific intuition and understanding that makes it possible to present and discuss scientific problems, results and uncertainties

    - is able to develop virtues, values and attitudes that lead to a better understanding of ethical aspects of the scientific method, as well as promoting central aspects of the scientific method to society. This means for example that the candidate
        1. can reflect on and develop strategies for making science reproducible and to promote the need for a proper ethical conduct
        2. has a deep understanding of the role basic and applied research and computing play for progress in society
        3. is able to promote, use and develop version control tools in order to make science reproducible
        4. is able to critically evaluate the consequences of own research and how this impacts society
        5. matures an understanding of the links between basic and applied research and how these shape, in a fundamental way, progress in science and technology
        6. can develop an understading of the role research and science can play together with industry and society in general
        7. can reflect over and develop learning strategies for life-long learning.

By completing a Master of Science thesis, the candidate will have developed a critical understanding of the scientific methods which have been studied, has a better understanding of the scientific process per se as well as having developed perspectives for future work and how to verify and validate scientific results.

Admission criteria: Applied Mathematics and Risk Analysis

This study direction requires 90 ECTS in mathematics and informatics courses.

1. 70 ECTS have to be from the following courses, equivalent or similar to the University of Oslo mathematics and programming courses MAT1110, MAT1120, MAT2100/MAT2400, STK1100, MAT-INF1100, INF1000/INF1110 and IN2900 (new code).

2. In addition, 20 ECTS have to come from at least two of the advanced courses MAT-INF3100, MAT-INF3360, STK2130, STK3405, INF3311, MAT-INF3xxx (Numerical analysis, new code) and/or MAT-INF3yyy (Dynamical systems, new code).

3. An average mark C (European grading scale) is required for the above courses.

Study abroad and international collaborators

Students at the University of Oslo may choose to take parts of their degrees at a university abroad. The University of Oslo has exchange agreements with other universities in different parts of the world. The MN Faculty has additional exchange agreements with many universities abroad.

Students in this program have a number of interesting international exchange possibilities. The involved researchers have extensive collaborations with: **add text**

Career prospects

Candidates who are capable of modeling and understanding complicated systems in natural science, are in short supply in society. The computational methods and approaches to scientific problems students learn when working on their thesis projects are very similar to the methods they will use in later stages of their careers. To handle large numerical projects demands structured thinking and good analytical skills and a thorough understanding of the problems to be solved. This knowledge makes the students unique on the labor market.

Career opportunities are many, from research institutes, universities and university colleges and a multitude of companies. Examples include IBM, Hydro, Statoil, and Telenor. The program gives an excellent background for further studies, with a PhD as one possible goal.

The program has also a strong international element which allows students to gain important experience from international collaborations in science, with the opportunity to spend parts of the time spent on thesis work at research institutions abroad.