

Master program in Computational Physics, Mathematics and Life Science

Andreas Austeng¹ Michele Cascella² Marianne Fyhn³
Morten Hjorth-Jensen⁴ Hans Petter Langtangen^{1,5} Anders
Malthe-Sørenssen⁴ Knut Mørken⁶ Joakim Sundnes^{1,5}

Department of Informatics, University of Oslo¹

Department of Chemistry, University of Oslo²

Department of Biosciences, University of Oslo³

Department of Physics, University of Oslo⁴

Simula Research Laboratory⁵

Department of Mathematics, University of Oslo⁶

October 2015

Master program in Computational Physics, Mathematics and Life Science

We propose a new Master of Science program at the Faculty of Mathematics and Natural Sciences of the University of Oslo. This program is called **Computational Physics, Mathematics and Life Science**, with acronym **CPMLS**

The program is a collaboration between five departments and classical disciplines:

- ▶ Department of Biosciences
- ▶ Department of Chemistry
- ▶ Department of Informatics
- ▶ Department of Mathematics
- ▶ Department of Physics

The program will be administrated by the Department of Physics. The program is based on the highly successful Computational Physics direction under the present Master program in physics at the University of Oslo.

Strategic importance

The program will educate the next generation of cross-disciplinary science students with the knowledge, skills, and values needed to pose and solve current and new scientific, technological and societal challenges. The program will lay the foundation for cross-disciplinary educational, research and innovation activities at the Faculty. The program will contribute to building a common cross-disciplinary approach to the key strategic initiatives at the Faculty: Energy, Materials, Life Science, and Enabling Technologies. A particular strength of physics students is their ability to pose and solve problems that combine physical insights with mathematical tools and now also computational skills. This provides a unique combination of applied and theoretical knowledge and skills. These features are invaluable for the development of multi-disciplinary educational and research programs. In this program we build on and refine this philosophy. The main focus is not to educate computer specialists, but to educate students with a solid understanding in basic science as well as an integrated knowledge on how to use essential methods from computational science. This requires an education that covers both the specific disciplines like

Scientific and educational motivation

Applications of simulation

Numerical simulations of various systems in science are central to our basic understanding of nature and technology. The increase in computational power, improved algorithms for solving problems in science as well as access to high-performance facilities, allow researchers nowadays to study complicated systems across many length and energy scales. Applications span from studying quantum physical systems in nanotechnology and the characteristics of new materials or subatomic physics at its smallest length scale, to simulating galaxies and the evolution of the universe. In between, simulations are key to understanding cancer treatment and how the brain works, predicting climate changes and this week's weather, simulating natural disasters, semi-conductor devices, quantum computers, as well as assessing risk in the insurance and financial industry. These are just a few topics already well covered at the University of Oslo and that can be topics for coming thesis projects as well as research directions.

Job market

Multiscale modeling is the big open research question

Today's problems, unlike traditional science and engineering, involve complex systems with many distinct physical processes. The wide open research topic of this century, both in industry and at universities, is how to effectively couple processes across different length and energy scales. Progress will rely on a multi-disciplinary approach and therefore a need for a multi-disciplinary educational program.

The proposed program will foster candidates with the right multi-disciplinary background and computational thinking for understanding today's simulation technology and its challenges.

The new program combines old and new initiatives

This program builds on the strengths and successes of two existing master's programs in Computational Physics (at the Dept. of Physics) and Applied Mathematics and Mechanics (at the Dept. of Mathematics).

A new master's program in Computational Life Science must anyway be developed to meet coming needs of the scientific community. If successful, it will position the University of Oslo as the leading institution nationally in computational life science. We believe this new program is best developed in close collaboration with already successful computational science programs.

The program in Computational Life Sciences will have a strong link to the Norwegian University of Life Sciences.

Computational Physics at UiO has been a great success

This initiative has its roots in the highly successful direction called **Computational Physics** under the Master program in Physics at the University of Oslo.

This program has educated almost 60 Master of Science students during the last ten years. Over 50% of these students have continued with PhD studies in Physics, Chemistry, Mathematics and now recently Biology connected with the CINPLA project.

The new program will also host the CSE project

The new proposed program will also take a leading responsibility in further developments of the highly successful [Computing in Science Education](#) initiative at UiO. Master of science thesis projects linked up to the CSE project will be offered.

If the program becomes successful, it will naturally lead to new cross-disciplinary research and a need for a new department in computational science.

Computing competence

Computing means solving scientific problems using computers. It covers numerical as well as symbolic computing. Computing is also about developing an understanding of the scientific process by enhancing algorithmic thinking when solving problems. Computing competence has always been a central part of the science and engineering education.

Computing competence is about

- ▶ derivation, verification, and implementation of algorithms
- ▶ understanding what can go wrong with algorithms
- ▶ overview of important, known algorithms
- ▶ understanding how algorithms are used to solve mathematical problems
- ▶ reproducible science and ethics
- ▶ algorithmic thinking for gaining deeper insights about scientific problems

Key elements in computing competence

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.

Today's projects in science and industry tend to involve larger

Learning outcomes

Students of this program learn to use the computer as a laboratory for solving problems in science and engineering. The program offers exciting thesis projects from many disciplines: biology and life science, chemistry, mathematics, informatics, physics, geophysics, mechanics, geology, computational finance, digital signal processing and image analysis – the students choose their field according to their own interests.

A Master's degree from this program gives the student a methodical training in planning, conducting, and reporting large research projects, often together with other students and university teachers. Projects usually emphasise finding practical solutions, developing an intuitive understanding of the science and the scientific methods needed to solve complicated problems, use of many tools, and not least developing your own creativity and independent thinking. The thesis work is a scientific project where the students learn to tackle a scientific problem in a professional manner.

Specific skills and general competence

The students learn to understand and develop insights in high-level scientific problems, involving a fundamental understanding of the methods and tools which are necessary and to present these results orally and in written form as scientific reports/articles. In addition, students learn to get

- ▶ Deep knowledge of the most fundamental algorithms involved, how to optimize these and understand statistical uncertainty quantifications.
- ▶ Overview of advanced algorithms and how they can be accessed in available software.
- ▶ Knowledge of high-performance computing elements: memory usage, vectorized and parallel algorithms.
- ▶ Understanding of approximation errors.
- ▶ Knowledge of at least one computer algebra system and how it is applied to perform classical mathematics (calculus, linear algebra, differential equations - with verification).

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

The 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, avoiding thereby the limitation of 10 ECTS per course only. Some of these courses are listed below.

Structure and specialized modules

The program allows also for replacing regular courses with specialized modules of shorter duration. These modules will be developed by the program committee but can also be developed in an ad hoc basis and tailored to the individual projects. Specialized modules can amount to up to the full course requirement of 60 ECTS.

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

The above set up shows how courses may be broken up in smaller modules.

Structure

Here follows a list of suggested courses that students may include in their required course load.

- ▶ FYS4150 Computational Physics I
- ▶ FYS4411 Computational Physics II
- ▶ FYS4460 Computational Physics III
- ▶ INF5620 Numerical Methods for Partial Differential Equations
- ▶ INF5631 Project on Numerical Methods for Partial Differential Equations
- ▶ FYS388 Computational Neuroscience
- ▶ STK4520 Laboratory for Finance and Insurance Mathematics
- ▶ STK4021 Applied Bayesian Analysis and Numerical Methods
- ▶ MAT-INF4130 Numerical Linear Algebra
- ▶ MAT-INF4110 Mathematical Optimization
- ▶ ECON4240 Equilibrium, welfare and information
- ▶ MEK4470 Computational Fluid Mechanics

Thesis directions

The program aims at offering thesis projects in a variety of fields. The scientists involved in this program can offer thesis topics that cover several disciplines. These are

- ▶ Computational mathematics
- ▶ Computational mechanics and fluid mechanics (NEED people here)
- ▶ Computational chemistry
- ▶ Computational physics
- ▶ Computational materials science
- ▶ Computational life science
- ▶ Image analysis and signal processing
- ▶ Computational finance and statistics (NEED people here)

The thesis projects will be tailored to the student's needs, wishes and scientific background. The projects can easily incorporate topics from more than one discipline.

Admission

The following higher education entrance qualifications are needed

- ▶ A completed bachelor's degree (undergraduate) comparable to a Norwegian bachelor's degree in one of the following disciplines
 1. Biology, molecular biology, biochemistry or any life science degree
 2. Physics, astrophysics, astronomy, geophysics and meteorology
 3. Mathematics, mechanics, statistics and computational mathematics
 4. Computer science and electronics
 5. Chemistry
 6. Materials Science and nanotechnology
 7. Any undergraduate degree in engineering
 8. Mathematical finance and economy
 9. Social economy
- ▶ The language of instruction is English. An internationally recognised English language proficiency test is required.

The above undergraduate degrees have some minimal requirements

The program opens up for flexible backgrounds

While discipline-based master's programs tend to introduce very strict requirements to courses, we believe in adapting a computational thesis topic to the student's background, thereby opening up for students with a wide range of bachelor's degrees. A very heterogeneous student community is thought to be a strength and unique feature of this program.

Study abroad and international collaborators

Students at the University of Oslo may choose to take part of their degrees at a university abroad.

Students in this program have a number of interesting international exchange possibilities. The involved researchers have extensive collaborations with other researchers worldwide. These exchange possibilities range from top universities in the USA, Asia and Europe as well as leading National Laboratories in the USA.

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.