Master program in Computational Science at the University of Oslo

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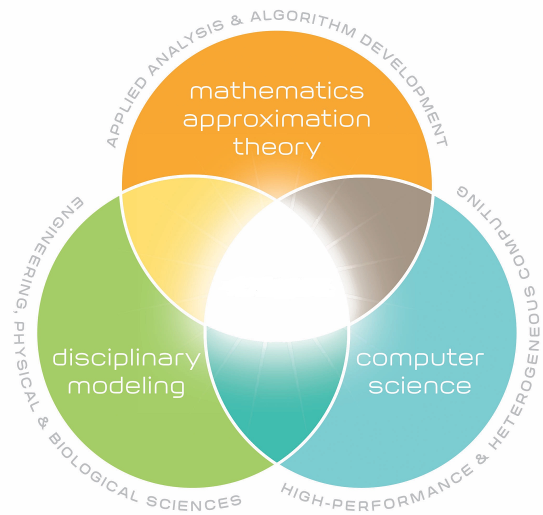
Planned start: Fall 2018

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.

It is the first educational program to comprehensively treat computation as the *triple junction* of algorithm development and analysis, high performance computing, and applications to scientific and engineering modeling and data science. This approach recognizes computation as a new discipline rather than being decentralized into isolated sub-disciplines. The CS program will will enable application-driven computational modeling while also exposing disciplinary computational scientists to advanced tools and techniques, which will ignite new transformational connections in research and education.



Vision for the future: Scientific Computing and Data Science

Scientific computing focuses on the development of predictive computer models of the world around us. As study of physical phenomena through experimentation has become impossible, impractical and/or expensive, computational modeling has become the primary tool for understanding—equal in stature to analysis and experiment. The discipline of scientific computing is the development of new methods that make challenging problems tractable on modern computing platforms, providing scientists and engineers with key windows into the world around us.

Data science focuses on the development of tools designed to find trends within datasets that help scientists who are challenged with massive amounts of data to assess key relations within those datasets. These key relations provide hooks that allow scientists to identify models which, in turn, facilitate making accurate predictions in complex systems. For example, a key data science goal on the biological side would be better care for patients (e.g., personalized medicine). Given a patient's genetic makeup, the proper data-driven model would identify the most effective treatment for that patient.

Aims of the program

A specific aim of this program is to develop the students' ability to pose and solve problems that combine physical insights with mathematical tools and 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. 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 physics, biology, geoscience, mathematics etc with a strong background in computational science.

A significant aspect of this program is the ability to offer new educational opportunities that are aligned with the needs of a 21st century workforce. Many companies are seeking individuals who have knowledge of both a specific discipline and computational modeling.

Thesis directions, as of October 17 2016

- Computational Science: Astrophysics
- Computational Science: Bioscience
- Computational Science: Chemistry
- Computational Science: Finance and Risk Analysis
- Computational Science: Imaging and Biomedical Computing
- Computational Science: Materials science
- Computational Science: Mathematics
- Computational Science: Mechanics
- Computational Science: Physics

The Bioscience direction may change to Biology and Bioinformatics with an emphasis on applied bioinformatics for the latter. The university of Oslo is lagging strongly behind NTNU and UMB when it comes to offering studies in bioinformatics and computational biology. Our inertia here can cause serious long-term recruitment problems in such rapidly growing fields. For Bioinformatics we need to clarify the distribution of roles between the CS program and the Data Science program.

The Department of Mathematics may merge the study directions Mathematics and Finance and Risk Analysis to one direction, **Mathematics and Risk**. The Mechanics direction remains as it is.

We are awaiting inputs from Steinar Holden at the Department of Economy.

Required courses

In order to build a common study program and identity as a Computational Science student, there will be two compulsory courses that aim at providing topics of common and broad interest. Both courses have a workload of 10 ECTS each. The courses are

- **CS1**: *High-Performance Computing and Numerical projects*, 10 ECTS
  1. This course teaches you to develop and structure large numerical projects, from code writing to finalizing a report
  2. Topics which are included are parallelization and vectorization (content overlap with INF3380)
  3. Machine architecture and GPU-CPU programming
  4. Optimization of code and benchmarking
  5. Numerical methods from linear algebra will be discussed as well as examples from life science.

- **CS2**: *Data analysis and machine learning*, 10 ECTS
  1. Monte Carlo methods and statistical data analysis (potential overlap with STK2100)
  2. Optimization of data and handling of large data sets (potential overlap with STK2100)
  3. Machine learning and neural networks (New course at IFI)

We expect collaborations between several departments in building up these courses. The courses **CS1** and **CS2** are courses of interest to many departments at UiO.

Presently available courses at UiO and NMBU

The program aims at reorganizing many of the existing courses. 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
- MEK4250 Finite Element Methods in Computational Mechanics
- AST5210 Stellar Atmospheres I
- AST9110 Numerical Modeling

Possible new courses

Some of these courses could incorporate (or base themselves upon) existing ones

- **CS3**: Basic methods in computational modeling (new)
- **CS4**: Computational Physics (based on FYS3150/4150)
- **CS5**: Mathematical Foundations of data science (based on MAT-INF4110 and STK4021)
- **CS6**: Computational Linear Algebra (based on MAT-INF4130)
- **CS7**: Computational differential equations (Based on INF5620)
- **CS8**: Computational Bioinformatics (Based on INF5380)
- **CS9**: Molecular dynamics in life science and materials science
- **CS10**: Advanced optimization of numerical code (follows up CS1)
- **CS11**: Computational Astrophysics (based on AST9110)
- **CS12**: Computational quantum mechanics (based on fys4411 and FYS-MENA4110)
- **CS13**: Computational statistical mechanics (based on fys4460)
- **CS14**: Computational finance (based on STK4520)
- **CS16**: Advanced data science
- **CS17**: Computational Mechanics (based on MEK4470 and MEK4250?)
- **CS18**: Advanced bioinformatics

- **CS19**: Computational Materials Science (based on FYS-MENA4111)

Many of these courses, with possible names as **CS-Discipline** (CS-Math, CS-Ast, CS-Chem, CS-PHYS etc) imply collaborations and possible revisions and merging of existing courses. The development of these courses will create a unique portfolio in computational science and data science. These courses will also allow us to offer certificates in Computational science to students from other programs.

Admission critera

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. Economy
- For international students, an internationally recognised English language proficiency test is required.

The above undergraduate degrees have some minimal requirements on specializations which need to be fulfilled. In addition to the above required undergraduate degrees, students need to have 40 ECTS in basic undergraduate mathematics and programming courses (calculus, linear algebra and/or mathematical modeling and programming). A course in programming is compulsory and should correspond at least to 10 ECTS of work load. The average mark for the mathematics and programming courses, as well as 40 ECTS in senior undergraduate courses (2000 and 3000 level in Norway) for the specific specialization has at least to be C (letter marks). As an example, an undergraduate degree in Chemistry has a minimal requirement on chemistry courses, typically amounting to at least 60 ECTS out of 180 ECTS for a bachelor's degree. The average mark on the 40 ECTS of selected senior undergraduate credits in chemistry and the 40 ECTS in mathematics and programming should at least be C.

For the Bioscience, Mathematics, Finance and Risk Analysis, Mechanics and Imaging and Biomedical Computing there will be additional constraints on the 2000 and 3000 courses included in the 40 ECTS. These will specified soon.

Graduate Certificates

The program plans to offer graduate certificates of 30 ECTS in courses to students from other programs as well as other study directions of the CS program in

- Computational Modeling (can include CS2, CS3 and CS7 as an example)
- High-performance computing (can include CS1, CS10 and CS16)
- Computational Materials Science (CS4, CS9, CS12 and CS19)
- Computational Bioinformatics and Biology (CS2, CS9, CS8, and CS18)
- Computational Mathematics (CS2, CS3, CS5, CS6, CS7, CS14)
- Computational Physics (CS4, CS11, CS13, CS13, CS9, CS19)
- Computational Data Science (CS2, CS5, CS16)
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