Planning for the future: Computing Science and Data Science, an input to the strategic plan of MN-FAK@UiO

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Executive Summary

Scientific computing plays a central role in scientific investigations and is central to innovation in most domains of our lives. It underpins the majority of today's technological, economic and societal feats. We have entered an era in which huge amounts of data offer enormous opportunities, but only to those who are able to harness them. By 2020, it is also expected that one out of every two jobs in the STEM (Science, Technology, Engineering and Mathematics) fields will be in computing (Association for Computing Machinery, 2013).

Furthermore, the 3rd Industrial Revolution will alter significantly the demands on the workforce. To adapt a highly-qualified workforce to coming challenges requires strong fundamental bases in STEM fields. Computational Science can provide such bases at all stages. Most of our students at both the undergraduate and the graduate level are unprepared to use computational modeling, data science, and high performance computing – skills valued by a very broad range of employers.

These developments, needs and future challenges, will play an essential role in shaping future technological developments. Most of these developments require true cross-disciplinary approaches.

This document aims at developing strategies for meeting these future challenges. One important step in order to meet the future, is the hiring of new researchers and faculty with the competences and skills which are needed in order to harness the many new possibilities, as well as developing new research and educational strategies that can serve our society at large.

We propose the following: 1. the injection of 15-20 new faculty and researchers focusing on the science of computational modeling and data science; 2. the foundation for developing joint cutting-edge graduate and undergraduate programs in computational science and data science.

Research and Education, an outline

Research

A central element in addressing the above needs and challenges is the hiring of new faculty and researchers. We recommend a model where 15-20 new positions (faculty and researchers, permament and/or temporary) are earmarked for the departments of Mathematics and Informatics in order to develop new research and educational directions in computational science and data science.

The new faculty will thus be tasked with developing new research and educational programs in Computational Science and Data Science. We argue strongly that the hired faculty can/should have shared positions with existing departments (for example a 70% position at say Mathematics or Informatics and 30% at the department of Physics), similarly, faculty with a computational profile and interest at existing departments can have shared positions at the department of mathematics and informatics. This will ensure transfer of knowledge as well as the establishment of new and cross-disciplinary research and oversee the development of new educational programs and efforts.

These efforts will open doors to new scientific challenges, will enable UiO to compete and propose new Center-level funding opportunities as well as totally new research areas (in the Humanities for example) in computation and data-driven related areas that are currently beyond our reach. It will facilitate the training of scientists and students to be an effective 21st century workforce. It will also develop courses on modern computational techniques and data modeling that meet the needs of society, both for the public and the private sector.

Education

We have already developed (started fall 2018) two new Master of Science programs, one in Computational Science which includes almost all disciplines at the MNFak and one on Data Science. These programs form the basis for our educational efforts that will lead to an **across the disciplines PhD program** serving the whole university.

A central aspect is the development and coordination of many of the educational activities in computational science and data science.

We propose

1. Develop a comprehensive set of courses and degree programs at both undergraduate and graduate levels that will give students across the university exposure to practical computational methods, understanding how to analyse data and more generally to the idea of computers as problem-solving tools. The courses and the degree programs can also be offered as intensive training courses and programs.

2. Develop a Bachelor program in Computational Science and Data Science
3. Develop an all university PhD program in Computational Science and Data Science.
4. Based on the new programs (start fall 2018) on Computational Science and Data Sciece, Develop an all university Master of Science Program in Computational Science and Data Science.
5. Develop courses and course modules in Computational Science and Data Science for the private and the public sectors.
6. Develop a Master of Science program and a PhD program in Computational Science and Data Science tailored to the needs of the private and the public sectors, allowing for students residing outside UiO to develop their knowledge about Computational Science and Data Science.
7. Be a driving force in the education of the next generation of school teachers and university teachers, with a strong focus on digital competences.

Why should we focus on Computational and Data Sciences?

Modern problems in science and engineering bridge a vast range of temporal and spatial scales and include a wide variety of physical processes. The analysis of such problems is not possible, so one must turn to computation. To develop computational tools for such complex systems that give physically meaningful insights requires a deep understanding of approximation theory, high performance computing, and domain specific knowledge of the area one is modeling. National laboratories like SIMULA research lab have addressed the interdisciplinary nature of computing by having experts in numerical algorithms co-located with disciplinary experts who have a deep understanding of computation, and who use scientific computing to address key topics in science.

The proposed organization with algorithmic scientists and disciplinary scientists in STEM fields as well as other fields is what facilitates the exploration of challenging multi-disciplinary and interdisciplinary topics that could not otherwise be addressed. This key observation motivates the model for the shared positions, with Mathematics and Informatics as the driving departments.

In addition, the synergy of data-driven computational modeling, combining aspects of traditional scientific computing with data science and data mining, is an exciting topic that this new unit will be uniquely suited to address. This is a rapidly emerging field that touches many of the STEM disciplines but also Medicine, Education, the Humanities and the Social Sciences, and attracting world-leading talent in this area is greatly facilitated by the the above organizational structure and educational programs.

Furthermore, the development of Computational and Data Sciences has the potential to catapult UiO into the position of being a leader in this critical new field, and will open doors to new scientific challenges as well as new Center-level funding opportunities.

Strengths, Possibilities and Synergies

The University of Oslo has within several of the STEM fields strong research and educational activities, exemplified through for example: * Several Centers of excellence in research where Computational Science plays a major role * A newly established center of excellence in education research * Newly established Master of Science programs in Computational Science and Data Science * Several excellent groups in STEM fields that do Computational Science and Data Science * Computational topics are included in all undergraduate STEM programs, with the possibility to develop a bachelor program in Computational Science and Data Science for all university colleges * Several educational prizes and awards related to computational science * Strong links with research laboratories like SIMULA research lab * UiO has the potential to develop cross-college educational programs in Computational Science and Data Science, from undergraduate programs to PhD programs that serve also the public and the private sectors * The courses to be developed can be offered to train employees and students outside UiO, serving thus the coming needs of for example Machine Learning for the public and the private sectors

With a close coordination between the department of Mathematics and Informatics, as well as other involved departments, we have the possibility to really position UiO as the leading Norwegian and perhaps European institution within Computational Science and Data Science.

Enhance Computational Science and Data Science across the disciplines

Data driven discovery and data driven modeling play already a central role in research. The global objective here is to strengthen and coordinate such activities by bringing together scientists and students across the disciplines. UiO has already strong computational research and education activities within Mathematics and the Natural Sciences. The aim here is to extend this to include

- Computational Science and Data Science in Mathematics and all of the physical sciences (Astrophysics, Chemistry, Geoscience and Physics)
- Bioinformatics
- Develop research programs in Quantum Computing and Quantum Information theory. Many universities are now developing research and educational strategies in Quantum Computing
- Develop data-driven discovery research programs utilizing recent developments in machine learning
- Computational life science
- Computational Materials Science
- Computational Economy and Data Science and computing in Law and the Social Sciences
- Data Science and computing in the Humanities

The department of Mathematics and Informatics will host and coordinate research and educational programs in Computational Science and Data Science. In particular research and education that involve data analysis and Machine Learning will play a central role here.

Courses and degree programs

Creation of a robust, coherent set of undergraduate and graduate degrees, with accompanying courses, supports two complementary goals. First, a coherent program will allow the university to consolidate undergraduate and graduate training in computation in the STEM fields as well as introducing computing to other disciplines, reducing redundancy in the courses taught and allowing the university to offer a wider range of more specialized advanced courses. Second, we will create a robust set of degrees that are designed to give our students a strong introduction to computing that will complement UiO's existing disciplinary training, and which will make them better suited to be a part of the workforce in the 21st century, but also to be able to develop and use computing and data Science across the disciplines. These programs will include: 1. An undergraduate program in Computational and Data Sciences tailored to various disciplines. 2. We have already (from fall 2018) two new Master of Science programs in Computational Science and Data Science dailored to STEM fields. The aim is to extend these to other colleges. 3. Develop a cross-college PhD program in Computational Science and Data Science. 4. Develop courses and course modules in Computational Science and Data Science for the private and the public sectors. 5. Develop a Master of Science program and a PhD program in Computational Science and Data Science tailored to the needs of the private and the public sectors, allowing for participants residing outside UiO to develop their knowledge about Computational Science and Data Science. 6. Be a driving force in the education of the next generation of school teachers and university teachers, with a strong focus on digital competences.

This range of options will allow some number of students to dive deeply into computation through the degree programs, and will enable a much broader swath of the UiO population to learn about some aspects of computational and data science through not only the various programs but also through the courses to be developed by the departments of Mathematics and Informatics.

One desired result of the creation of these courses and programs is the foundation of a strong community of students from different disciplines who use similar techniques to solve a wide range of problems, which will promote broad, interdisciplinary thinking and will help to raise the visibility of computing throughout the UiO campus. We note that an extra benefit of these educational efforts is that UiO will become an ideal place to perform research in computational science education, a topic of critical importance that has thus far received little scholarly attention. The foresee strong links with the recently established Center for Computing in Science Education.

Long term goals and sustainability

The overall goal of this focus on Computational Science and Data Science is to bring together world-leading faculty who combine the most important aspects of computation and disciplinary research, thus enabling cutting-edge interdisciplinary science and the training of both undergraduate and graduate students. The involved departments will be economically sustained through the standard base university funding. However, additional funds will be realized by the securing for example Center-level funding (as well as many single- or few-PI grants), as well grants obtained the PIs that sustain graduate students, post-docs, travel and other associated expenses.

Basic university funding (beyond faculty and support staff salaries) is necessary to support fellowships for top graduate students, speaker series and honoraria, visitor support, hardware purchases, and startup packages.

The enclosed appendices contain more details about research and education plans. Links to similar and recently established initiatives are also presented.

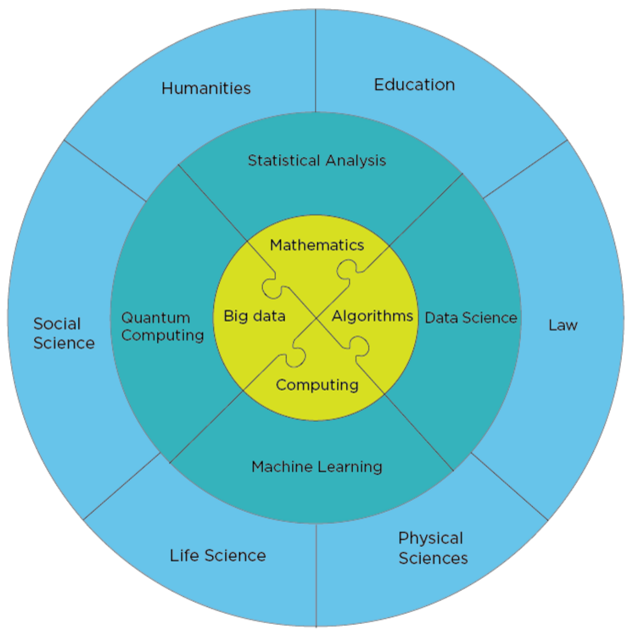
Appendix A: Working group members (2018)

1. IFI: Ole Christian Lingjærde and Anne H. Schistad Solberg
2. Math: Geir Dahl, Ingrid Glad, and Geir Olve Storvik
3. Physics: Morten Hjorth-Jensen and Heidi Sandaker

Appendix B: Structure and Justification for Planned Organization

The joint appointments with other departments will play an important role in cementing the role of Computational Science and Data Science, strengthening cross-disciplinarity collaborations. Furthermore, the task of developing new and joint courses will require extensive collaborations across departments. As an example, the faculty and researchers we plan to hire could have a 70% appointment with the department of Mathematics or Informatic and 30% with a single discipline oriented department. Similarly, a researcher with linked to the department of Chemistry, could have a shared position of for example 20% at the Department of Mathematics and 80% at the department of Chemistry. These joint appointments will facilitate the seeding of new research and the development of new courses and degree programs.

One can view the departments of Mathematics and Informatics as hubs which focus on Algorithms, Computing, Big Data, Mathematics, Quantum Computing, Machine Learning and Statistical Analysis in close collaboration with scientists working from the Physical Sciences (Chemistry, Astrophysics, Physics, Geoscience, Mechanics, Materials Science), Life Science (Bioscience and Medicine), Law, Education, Social Sciences and the Humanities. The new department will develop and strengthen the field of Computational Science and Data Science in close collaboration with all involved departments (from the MNfak and other colleges), increasing thereby the overall general competences of our students and scientific staff on these topics. The following figure illustrates schematically these links, with the two inner circles representing the most likely key research activities we wish to strengthen.



Funding

In order to secure funding in addition to those guaranteed by the University and the ministry of education and research, one should seek assiduously center funding from the Norwegian SFF and SFI system (under the auspices of the Research Council of Norway) as well as similar funding possibilities from the EU. In addition, we expect the faculty to bring in regular research grants either from industry, the Research Council of Norway or the EU.

We aim also at exploring and having, out of the 15-20 positions, five positions at the level of associate or full professor as endowed chairs and professorships from the private sector. We will in particular target companies where computational science and data science will play a major role in the future. The design of research projects linked to the needs of these companies as well as the PhD and Master of Science programs discussed below, will make sure that both the private and the public sector will benefit from highly qualified candidates.

Below we discuss several possible research directions where faculty hires can start new research directions, in close collaborations with specialists from various departments.

Appendix C: Sampling of new and transformational science that can be enabled

There are several new and emerging research directions where Computational science and Data science will play and can play a major role.

Computational life science

The Life Sciences is transforming with the explosion of High-throughput data generation technologies and the need for integrating these across all the levels of the biological hierarchy. A 'system-dynamic' (Systems Biology) approach will dominate research in the coming decades. Here, computational modelling to integrate the various data types and data sets will be a driving force. Similar developments are seen in the field of molecular image analysis, where computational methods to integrate the image streams will become essential to make sense of the growing amount of data. Translational Bioinformatics, bridging the gap between the laboratory, computer and the clinic, with the ultimate goal of personalised medicine, is an important, and exciting new dimension. Many of these developments require cross-disciplinary thinking, and often breakthroughs in Bioinformatics/Computational Life Science start with creatively adjusting and implementing algorithmic or computational solutions originally developed for other fields. A CDS department that has multidisciplinarity as its founding principle, and brings computationally skilled researchers from many fields together, will provide a solid foundation for researchers working towards these developments.

Develop data-driven discovery research programs utilizing recent developments in machine learning

Machine Learning plays nowadays a central role in the analysis of large data sets in order to extract information about complicated correlations. This information is often difficult to obtain with traditional methods. For example, there are about one trillion web pages; more than one hour of video is uploaded to YouTube every second, amounting to 10 years of content every day; the genomes of 1000s of people, each of which has a length of 3.0×10^9 base pairs, have been sequenced by various labs and so on. This deluge of data calls for automated methods of data analysis, which is exactly what machine learning provides. Developing activities in these frontier computational technologies is thus of strategic importance for our capability to address future science problems. The applicability of big data, data-driven discoveries, data-driven modeling and machine learning covers basically all disciplines and fields, with applications spanning from materials science, mechanics, medicine, applied mathematics, economic forecasting etc. Machine learning and big data concepts are being exploited in more and more fields. The big data challenge will be in the forefront of biology and life science research in the next few years. In materials science machine learning allows us to parametrize results from quantum mechanical calculations in terms of classical interactions. These interactions are in turn suitable for large scale molecular dynamics simulations of complicated systems spanning from subatomic physics to materials science and life science. To develop a multiscale science program starting with the smallest constituents and moving to larger systems can most likely only be done with the development and application of machine learning algorithms. Economists and policy makers need up-to-date information on the state of the economy to formulate effective policies. Variables such as GDP, Gini factors, unemployment rates, quality of life data etc are normally used as key indicators. These data are often only available with delays between collection and availiability to analysts, making it thus difficult to asses properly their relevance. Machine learning algorithms have the potential to deliver improved predictions as well as correlations and proper error estimates. The examples discussed here represent just a few of the possible applications of Machine Learning algorithms that the new department can aid in developing. To develop these research lines will be achieved most effectively within the multidisciplinary CDS department.

Develop research programs in Quantum Computing and Quantum Information theory

Enabling simulations of large-scale quantal many-particle systems is a long-standing problem in scientific computing. Quantum many-particle interactions define the structure of the universe, from nucleons and nuclei, to atoms, molecules, and even stars. Since the discovery of quantum mechanics, a lot of progress has been made in understanding the dynamics of certain many-particle systems. While some of our insight comes from a small set of analytically solvable models, numerical simulations have become a mainstay in our understanding of many-particle dynamics. The progress in numerical simulations has accelerated in the last few decades with the advent of modern high performance computing (HPC) and clever developments in classical simulation algorithms such as, quantum Monte Carlo,large-scale diagonalization approaches, Coupled-Cluster theory and other renormalization schemes. Despite the monumental advances, classical simulation techniques are reaching fundamental limits in terms of the size of the quantum systems that can be processed. Fortunately, the disruptive new field of quantum simulations has emerged, promising to enable simulations far beyond those which are classically tractable. In particular, scientific applications concerned with simulations of interacting fermions on a lattice are poised to reap the benefits of quantum simulations. Mathematical models of interacting fermions naturally extend to describe vastly different physics such as that of correlated electronic and the correlated nuclear systems.

Recent progress in quantum computing as well as digital and analog Quantum Algorithms (QAs) promise to enable the exciting possibility of performing simulations that are beyond the reach of all existing and future classical supercomputers. Despite the progress, there is still a gap between the resources required by state-of-the-art QA and the resources offered by available and near-future quantum hardware. It may take decades of quantum hardware development and engineering before the current QAs will outperform classical exascale class simulations. Therefore, to impact scientific computing on a more relevant time scale, improving the scalability and efficiency of quantum simulation algorithms is of the highest importance. Developments in quantum information algorithms and their mathematical properties, as well as their applications will play a critical role in studies of relevance for a wide variety of fields, from the design and studies of new materials to our basic understanding of systems of interest in chemistry and physics. The new department, in close collaboration with disciplinary experts, can play an essential role in developing this field by hiring world-leading experts in quantum information theory and quantum computing.

Computational Social Science

Survey data, the engine of the behavioral revolution of the social sciences is about to run its course, with low response rate and poorly representative samples being the norm rather than the exception. Fortunately, vast amount of new information from social media, via digitalized governmental archives, to population registries are opening up new exiting avenues for innovative social science research, such as paternity leave and children's performance in school, extent of censorship in Chinese online new reporting, or conditions for receptiveness to fake news. Moreover, the new data availability in combination with tools from machine-learning has spurred an interest in prediction and sophisticated policy-recommendations, ranging from optimize relocation of immigrants given their skill-set and local labor market needs, via probabilistic detection of election fraud, to forecasting of popular unrest and civil war. The undertaking of such research questions was, until recently, outside the realm of social science. There are however limits to the amount of new insights that can be obtained purely from richer data and "black-box" import of machine-learning tools. More robust, new insights require similar steps to be taken in the development of applied, testable, theoretical models to facilitate direct empirical evaluations of the model dynamics and the consistency of the model with the data. Such a step requires a solid grounding in computing.

Computational Geoscience

Geoscience has long been a computationally-intensive area. A typical climate simulation, used for example in the future projections discussed by the Intergovernmental Panel on Climate Change (IPCC), can generate a petabyte (1 million gigabytes) of data. Weather forecasts involve suites of complex simulations, which are then averaged to assess the probability of different scenarios. These models simulate not only the atmosphere, but the important interactions with the ocean, land and vegetation. Sophisticated models are also used for studying tectonic continental shifts, to understand the geology and climate of previous epochs, thereby informing our understanding of prehistoric life. And similar models are used to simulate hydrological reservoirs and the melting occurring at the base of major glaciers. Computation is so central to the geosciences that it is impossible to imagine the study without it.

The computational approaches relevant for geoscience can be grouped in two classes: simulation and analysis. Geoscientific computation demands advance programming techniques and optimized simulations, to ensure the fast calculations. Changes in the global ocean circulation can take tens of thousands of years, demanding the most rapid simulations possible. High performance computing approaches, for example using graphical processing units (GPUs), are now being applied to climate models, greatly increasing performance. The large amount of data generated by geophysical simulations is also a challenge and is well-suited for big data techniques. Machine learning is beginning to be used in weather forecasting and in climate simulations. This has led to the identification of weather patterns missed by researchers and to the identification of extreme events like cyclones and "atmospheric rivers", on par with that of human analysts. Computational geoscience is an exciting and developing field, and one which will make major inroads to the earth sciences in the future.

Computational Psychology

Large files of audio/video are currently unused since data is in a form that is unavailable for quantitative analysis (such as video of weekly clinical interviews from multi-center trials of treatment for thousands of patients). Analysis of prosody can shed light on change processes, and should automatic transcription reach a sufficiently good level, this will, in combination with natural language processing, open up many interesting research questions.

Accumulated data from online use already provides measurements of quantities such as personality, attitudes, skills or mental disorders which in many cases have proven to approach the level of the best instruments we have. Here one obtain much more, especially since clinical treatment will increasingly be supplemented by electronic registrations in the future, as well as being able to disconnect data from sensors in smart devices. Present instruments in use generate relatively large amounts of data (from for example EEG, ERP, and fMRI), and newer methods of pattern recognition/classification can shed light on a number of research questions.

Machine learning in education research

Quantitative education research has historically been done at the micro-scale (classrooms) and the macro-scale (K-12, baccalaureate degree programs, etc.). Micro-scale research has been done using traditional correlational statistics with data gathered from surveys, conceptual tests, classroom observations, etc. With the advent of the *digital classroom* student behavior can now be examined in fine grain. Students access of online homework platforms, video lectures, and interactions with peers via online course forums has created new data sources for education researchers. New technologies such as computer textual analysis can pick apart student conceptual understanding of hard concepts in science and mathematics. Intelligent tutors can provide real time feedback to students as they solve problems. At the macro-scale students' career decisions within their programs can be modeled. What courses they choose to take, who they choose to take courses from, and their comments on said courses, form new data sets which can be used to predict student decisions and provide timely feedback to students and faculty advisers. Ultimately these data sets can form a high dimensional picture of student learning painted by machine learning.

Appendix D: Outline of degree programs and courses

This appendix summarizes the set of degree programs and courses that can/should be administered by the department of mathematics. The range of offerings gives students the opportunity to engage with computational science at a variety of levels, from single courses to graduate programs. Market research and feedback from employers indicate that engaging with one or more of the proposed programs will substantially enhance the student's career prospects. The new classes will move to the new department once the department opens ist doors.

Degree programs

The MNFak offers from fall 2018 two new programs at the Master of Science level in Computational Science and Data Science. These programs are 1. Computational Science, start fall 2018. It is presently administrated by the department of Physics, but it belongs naturally under the department of Mathematics. It should be transfered to Mathematics by fall 2020. 2. Data Science, start fall 2018. Administrated by the department of Mathematics 3. Develop a Bachelor of Science program in Computational Science and Data Science, hosted by the Department of Mathematics. Start fall 2020. 4. Develop an all university PhD program in Computational Science and Data Science by fall 2020 5. Based on these programs and the gained experiences we plan to develop a Master of Science program in Computational Science and Data Science tailored to the needs of the private and the public sectors. This will allow students residing outside UiO to develop their knowledge about Computational Science and Data Science by fall 2021 6. Develop a PhD program in Computational Science and Data Science tailored to the needs of the public and the private sectors (so-called nærings PhD in Norwegian)

The Master of Science and PhD programs that will target students from outside UiO (from partner companies, public and private sectors) will be developed in close collaboration with external stake holders.

Courses

There are several existing and planned courses which could be offered.

The University of Oslo offers the following courses in Computational Science, split here according to main disciplines/fields.

Mathematics and Computer Science, including Mechanics and Statistics

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[MAT-INF3360 Introduction to Partial Differential Equations ](http://www.uio.no/studier/e
[MAT-INF4110 Mathematical Optimization](http://www.uio.no/studier/emner/matn
[MAT-INF4130  Numerical Linear Algebra](http://www.uio.no/studier/emner/matnat
[MAT-INF4140 Numerical Analysis ](http://www.uio.no/studier/emner/matnat/ma
[MAT-INF4160 Topics in Geometric Modelling ](http://www.uio.no/studier/emner/mat
[MAT-INF4300 Partial differential equations and Sobolev spaces I](http://www.uio.no/studier
[MAT-INF4310 Partial differential equations and Sobolev spaces II ](http://www.uio.no/studie
[MEK4250 Finite Element Methods in Computational Mechanics](http://www.uio.no/studier/
[MEK4470  Computational Fluid Mechanics](http://www.uio.no/studier/emner/mat
[INF4300 Digital image analysis](https://www.uio.no/studier/emner/matnat
[INF4331 Problem solving with high level languages](http://www.uio.no/studier/emn
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INF4820 Algorithms for artificial intelligence and natural language processing
INF5620 Numerical Methods for Partial Differential Equations
INF5631 Project on Numerical Methods for Partial Differential Equations
INF5670 Numerical methods for Navier-Stokes equations
INF5840 Computability theory
INF5850 Machine Learning for Image Analysis
STK4021 Applied Bayesian Analysis and Numerical Methods
STK4520 Laboratory for Finance and Insurance Mathematics

Physical Sciences: Physics, Astrophysics, Geosciences and Chemistry

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[FYS4150 Computational Physics I](http://www.uio.no/studier/emner/matnat/fys/FYS4150/inc
[FYS4411 Computational Physics II](http://www.uio.no/studier/emner/matnat/fys/FYS4
[FYS4460 Computational Physics III](http://www.uio.no/studier/emner/matnat/fys/FYS
[GEO4310 Stochastic methods in hydrology](http://www.uio.no/studier/emner/matnat/geofag
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GEO4510 Atmosphere and Oceans on Computers: Fundamentals
GEO4450 Geophysical Fluid Dynamics

AST5210 Stellar Atmospheres I
AST9110 Numerical Modeling

Bioscience including Bioinformatics

`[INF4490 Biologically inspired computing](http://www.uio.no/studier/emner/`
`[INF4350 Introductory Course in Bioinformatics](http://www.uio.no/studier/emner`

INF-BIO5121 High Throughput Sequencing technologies and bioinformatics analysis
INF5380 High-performance computing in bioinformatics
INF5560 Computational Physiology
MBV-INF4410 Bioinformatics for Molecular Biology
MBV3070 Bioinformatics

Add ML courses asap

Many of these courses, if properly modularized, can be offered as intensive training courses and programs. In particular, such courses will be attractive for both the private and public sectors. The following courses could be offered 1. Introductory Scientific Python 2. Advanced Scientific Python 3. Data Science and visualization 4. Applied numerical mathematics 5. Computational finance 6. Big data graph analysis 7. Supervised machine learning with scikit-learn and TensorFlow 8. Unsupervised machine learning with scikit-learn 9. Data-driven entrepreneurship 10. Courses tailored to the needs of specific companies 11. and more specialized modules

Appendix E: Computational Science and Data Science at Norwegian universities and other places

In Norway it is only UiO which offers Master of Science programs in Computational Science and Data Science. All other universities have only Master programs in Computer Science, with minor emphasis on computational science and/or data science. The University of Bergen has a Masters program in Applied Mathematics while UMB has a newly established program in data science. These are limited and more focused programs. Nationally, UiO is the only university which offers broad programs in Computational Science and Data Science.

Norway	University	Comp Science and Data dept	Bachelor program	Master program	Graduate/PhD
	UiO	No	Proposal under development	Yes	
	NTNU	No	No	No	
	UiT	No	No	No	
	UiB	No	No	Applied Math	
	UMB	No	No	Yes	
	OsloMet	No	No	No	

Norway	University	Comp Science and Data dept	Bachelor program	Master program	Graduate/PhD
	UiS	No	No		Planned fall 2019
	UiA	No	No		No, but direction in AI
	UiN	No	No		No
	USN	No	No		No

Out of 95 universities polled in the USA, there are less than 15 which have a department on Scientific Computing and more than 50 that have a center on Scientific Computing. Between 20 to 30 of these offer a bachelor, Master of Science or PhD program. On Data Science there are approximately 30 departments and 40 centers. Almost 50 of these universities offer a Masters degree in Data Science and close to 40 a PhD in Data Science. Out of 95 universities polled in the USA, there are less than 15 which have a department on Scientific Computing and more than 50 that have a center on Scientific Computing. Between 20 to 30 of these offer a bachelor, Master of Science or PhD program. On Data Science there are approximately 30 departments and 40 centers. Almost 50 of these universities offer a Masters degree in Data Science and close to 40 a PhD in Data Science. An excellent example of a department which includes computational science and data science is the newly established department at Michigan State University.

For the department of Michigan State University, the process which led to the establishment of the new department started fall 2013 and the new department opened its doors in fall 2015. It counts now 31 faculty of which 24 of them have shared positions with other departments. It offers a series of courses at all levels, minors and majors in Computational Science as well as its own graduate program. The department offers also a dual PhD with other departments. This option has been particularly popular with Physics students.

The new hires cover most STEM fields and the department has been central in starting new cross-disciplinary research activities. There are strong activities in life science and bioinformatics as well as in statistics, mathematics, physics, geoscience and engineering.

Other departments with similar scope and programs in Northern America are (the list is not exhaustive) 1. School of Computational Science and Engineering at Georgia Institute of Technology 2. Computational Science and Engineering at University of California Santa Barbara 3. Computational Science and Engineering at North Carolina Agricultural and Tecnological State University 4. Computational Science and Engineering at University of Illinois Urbana-Champaign 5. Department of Scientific Computing at Florida State University 6. New York University

Most of the other university in Northern America have a typical department of Computer Science. Programs in Computational Science and Data Science are frequently offered by the department of Mathematics and/or the department of Computer Science. 1. Purdue CCAM (Center for Computational & Applied Mathematics)

At the time of writing, no such poll has been made for European universities. From the list over Masters programs, the countries with the largest focus on these topics are Germany (SimTech in Stuttgart is a good example), Sweden and Switzerland. Examples of interest in Europe are the * London School of Economics * Imperial College and its Quantitive Sciences Research Institute * Swiss Institute of Computational Science

while in Austria we have the * Vienna Graduate School in Computational Science

The Society for Industrial and Applied Mathematics (SIAM) keeps track of graduate programs in computational Science. The list is most likely not complete.

In addition to the traction seen within data driven discoveries, Quantum Information Science (QIS) is also gaining considerable momentum presently. This represents a truly cross-disciplinary activity that cannot be placed within one single department. Though the disruptive potential of QIS has been known for over 20 years, it has been in a nascent state with a number of academic, industrial and government groups striving to understand the basics physics and to build and control many-qubit systems. There has been steady progress to a tipping point where the realization of practical QIS systems is imminent; for example the leading group in the field (Google Quantum AI) recently argued that small-scale commercialization of quantum computing devices is expected within 5 years; moreover quantum chemistry may be a “killer app” for small quantum computing systems; and prototype demonstrations are already emerging. IBM is providing a 20 QUBIT system for public use, and they expect to deliver a 50 QUBIT system in the near future.

Strategic partnerships are developing between universities, large corporations, startups, as well as federal and private funding agencies in the USA. Some of the major industrial and government investors are Google, IBM and Microsoft. In the USA both the Department of Energy and the National Science Foundation are developing QIS programs with several new initiatives.

Appendix F: Research in Computational Science at UiO

Computational Physics

Computational Bioscience

Bioinformatics

Imaging and Biomedical Computing

Astrophysics

Computational Life Science

Computational Geoscience

Applied mathematics, mechanics and Risk analysis

Appendix G: Research in Data Science