Computing Across the Disciplines (CAD); a new Department at the University of Oslo

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A proposal to the board of the Mat-Nat Fakultetet of the University of Oslo;
Establish a center (Center for Computing Across the Disciplines) by fall 2018
and as a new department (Department of Computational and Data Sciences) by
fall 2020

Executive Summary

This proposal seeks to transform the University of Oslo (UiO) to become a leader nationally and internationally in scientific discovery through large-scale computations and data-driven research. The aim is to position UiO as a leader in computational and data science by recruiting faculty whose expertise pertains to large-scale computing and mathematical foundations of data science - both generalists (algorithm/tool developers) and specialists (focused on specific disciplines).

We propose a two-step process

- By fall 2018 establish first a center, called **Center for Computing Across the Disciplines**, which will lay the foundation for cross-disciplinary activities and establish the necessary foundations and preparations for launching a new department. The center will be colocalized with the existing center for Computing in Science Education. It will develop research projects across disciplines as well as develop educational programs and initatives related to the establishment of the new department.

- Establish a new Department, called **Department of Computational and Data Sciences** by fall 2020. This department could be colocalized with the new center on life sciences and thus spur the development of computations in the life sciences. The new department will be a hub for innovative thinking and pave the way for research and education in computational and data science across all disciplines.

The new department and the center as well will be part of the Matematisk Naturvitenskapelige Fakultetet (MNFak in brief) of the university of Oslo, although it aims at becoming a true inter-disciplinary department serving all colleges (Law, Natural Science and Mathematics, Medicine, the Humanities, Education and the Social Sciences). It is the MNFak which will propose to the board of the university of Oslo the establishment of both the center and the department. We propose thus

1. a new Department of Computational and Data Sciences (CDS) that is administered by the MNFak and meant to facilitate interdisciplinary science by fall 2020;

2. the injection of 25-30 new faculty lines focusing on the science of computational modeling and data science;

3. the foundation for joint cutting-edge graduate and undergraduate programs.

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. The metrics for success are as follows. Within 5 years (2020-2025), we will have hired 25-30 worldleading research intensive faculty that form the backbone of this Department, who will bring in single-PI grants and small-scale (few-PI) collaborative grants, building the foundation for CDS to develop large-scale funding.

We have already developed (starting fall 2018) two new Master of Science programs, one in Computational Science which include almost all disciplines at the MNFak and one in Computational 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. The PhD program will start fall 2020 when the first students from our two Master of Science program have finalized their theses.

The new department will coordinate many of its educational activities with the newly established center of excellence in education, the Center for Computing in Science Education. It will give the Computing in Science Education initiative a formal institutional basis and together with the Center for Computing in Science Education it will form a unique powerhouse in educational transformations. The new department will

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. These courses will also Software Carpentry and Data Carpentry courses. The courses and the degree programs can also be offered as intensive training courses and programs.

2. Facilitate the adoption of computational tools and techniques for both research and education across campus, through education and faculty collaboration. A center and then a department will facilitate the pursuit of these goals!

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.

Finally, this department will facilitate the growth of the university by participating in cross-cutting efforts such as the upcoming life science initiative. Within 10 years, the initiative will have secured Center-level funding via for example the Norwegian SFF system and the EU. The department will also have fully developed our graduate and undergraduate curriculae with the addition of Bachelor's programs in computational modeling and data science, and will have strong enrollment numbers in all education programs.

The new CDS department will be unique among computational academic units nationally, the first to comprehensively treat computation as the triple point of algorithm development and analysis, high performance computing, and disciplinary knowledge with applications to scientific and engineering modeling and data science. There is no such department in Norway and very few ones in Europe and Northern America. The above paradigm shift recognizes computation as a new discipline rather than decomposed into isolated sub-disciplines, enabling application-driven computational modeling and data-driven discoveries, while also exposing disciplinary computationalists to advanced tools and techniques, which will ignite new transformational connections in research and education. This research nexus also gives rise to the educational opportunities driven by similar synergy, leveraging common resources among disciplines, and enabling joint programs and unique degrees across the entire computational space.

Why should we focus on developing a department in Computational and Data Sciences?

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 and 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 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. The new department will also focus on the development of courses in computational science and data science tailored to the needs of the rest of society, both for the private and the public sector.

These developments, needs and future challenges, as well as the developments which are now taking place within quantum computing, quantum information and data driven discoveries (data analysis and machine learning) will play an essential role in shaping future technological developments. Most of these developments require true cross-disciplinary approaches, approaches which normally cannot be accomplished within the realms of one single disciplinary-based department.

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 collaborative arrangement between algorithmic scientists and disciplinary scientists in the STEM 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 proposed Department - a place where we will attack the critical problems facing us in the 21st century, problem which require the development of computing skills across disciplines, from the traditional STEM fiels to the Humanities and the Social Sciences. Furthermore, this department would strive to use computing as a critical tool to explore fundamental scientific questions in subjects as diverse as the physics of specific materials and evolutionary biology. 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 introduction of the nurturing environment of the CDS department to serve as their tenure home. Furthermore, the development of the Department 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.

To jump-start this new department at the 'triple point' of mathematics, computer science and and discipline-specific computation, we propose recruiting faculty who are experts in numerical algorithms as well as those whose primary focus is the use of advanced computation to solve a wide range of challenging scientific problems. Furthermore, we wish to define scientific projects where data-driven discovery in say the Humanities and the Social Sciences can play a major role in future years. In addition, we wish to recruit scientists - having joint appointments with other units at UiO - whose expertise is computation on heterogeneous and/or distributed computing platforms, such as hardware-accelerated computing (e.g., GPU computing), cloud computing, and middleware for dynamic optimization across HPC architectures. To provide a critical mass, we propose hiring 25 to 30 new faculty across the aforementioned disciplines. Colocation and research and curriculum ties enable the CDS department to break down historical disciplinary boundaries, and become the synergistic leading-edge center of computational activities on campus. Furthermore, colocating these scientists will enhance the development of new computational algorithms to address pressing scientific and societal needs and enable the creation and deployment of the robust numerical tools required for the pursuit of leadership-class science in virtual laboratories. Most importantly, the new department will enable new science through these unique interdisciplinary collaborations and will become a focal point for computational research at UiO, bringing researchers in computational and data sciences together with domain experts in astrophysics, bioinformatics, chemistry, geoscience neuroscience, subatomic physics, materials science, life science, the Humanities, economy and many more.

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 fiels who do Computational Science

- Computational topics are included in all undergraduate STEM programs, possibility to develop a bachelor program in Computational Science

- 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 on for example Machine Learning for the public and the private sectors.

With a center and later a department we have the possibility to really position UiO as the leading Norwegian and perhaps European institution within Computational Science and Data Science and lead nationally in the development of computations in Life 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

- Bioinformatics

- Develop research programs in Quantum Computing

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

- Computational biology and life science (includes medicine)

- Computational economics and data science and computing in the social science

- Data science and computing in the Humanities

The new department 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. Similarly, the new department will be responsible for developments in quantum computing and quantum information theories.

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, reducing redundancy in the courses taught and allowing the university of 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 STEM 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 a cross-college MSc 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.

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 new department. This allows students from other fields to for example obtain a minor or a certificate in Computational Science and Data Science.

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

in the sciences and engineering throughout the UiO campus. We note that a final 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 center and then the Department will have strong links with the recently established Center for Computing in Science Education.

Structure and Justification for Planned Organization

We envision that the CDS department will be a truly interdisciplinary unit that strives to focus on algorithmic science and its applications to a range of critical research topics. The CDS department will consist of 25-30 faculty, comprising generalists and disciplinary scientists. The generalists develop crossdisciplinary tools addressing large classes of problems. The disciplinary scientists pursue model/algorithm development from a domain-specific perspective, enabling application-specific approximations and optimization of performance on exascale problems. The nexus of these groups is what makes CDS unique.

The cross-disciplinary steering committee (see below) that developed this proposal seeks the creation of a joint, inter-college department as the ideal solution. This structure, where tenure lines would be housed, is necessary to facilitate the recruiting of a core group of faculty whose focus is on algorithmic science that can be applied to new scientific challenges and computational platforms. The reasoning behind this is straightforward - the fundamental science we are interested in developing is clearly growing beyond the boundaries of existing STEM disciplines, in the same way that the discipline of computer science grew beyond the boundaries of historical roots in mathematics or electrical engineering. It is advantageous to be at the forefront of this trend. This new department is at the forefront of a key paradigm shift. Discipline-focused departments tend to only place value on the new science a computer programs can explore, and to not place value on the time or energy it takes to develop critical algorithms and tools that provide a deeper understanding of fundamental processes in science and engineering. By placing the tenure home of computational scientists in this new department, we accomplish two critical goals. First, a single department focused on the science of computation will strengthen the goal of interdisciplinary collaboration, as faculty in this new unit will have a wide range of backgrounds in many traditional STEM disciplines. Second, the new department will break down traditional barriers between departments, as the common theme of the new department is the science of algorithms and their applications, providing a key place for critical interactions between different scientific communities. While many faculty will have full appointments in the department, joint appointments will help to cement interdepartmental collaboration and build up a strong interdisciplinary community. This gives UiO the flexibility to grow into this critical area by hiring cutting-edge interdisciplinary scientists, and will also allow existing disciplinary departments the opportunity to grow beyond their current boundaries. In the case of joint appointments, the department with the majority appointment will lead on issues of reappointment, promotion,

and tenure. For all faculty appointed in the new unit, either fully or partially, a key consideration in reappointment, promotion, and tenure will include the development of algorithms and computational codes and libraries that contribute broadly to the advancement of research.

A potentially major issue with the proposed format is that a great deal of teaching capacity will be required to launch the new undergraduate and graduate programs. Consolidation of existing classes on campus will free up some teaching slots; however, to ensure success we propose teaching slots be assigned to the new unit based on percentage appointment within the new department. For example, if the faculty has 50% appointment within this new unit and is assigned a 1-1 teaching load, one of the courses they teach each academic year will be assigned by this new department. A key point in making this new unit work is the creation of a robust community of scholars. To that end, it is key that the new faculty and graduate students in this department be co-located within the same space. We propose the creation of a common space that can hold a substantial number of people, including 25 to 30 faculty, up to 10 visitors, up to 6 support staff, and approximately 100 postdocs and graduate students. This space needs state-of-the-art computing classrooms, conference rooms configured for video conferencing, and resources for teaching in flipped and virtual classroom settings. The new Life Science center which is planned for 2024, could be an ideal place where to house this new department, since it aims at spurring and developing acitvities in computational life science.

Another key point in the success of such a department is the influx of new ideas and people. In lieu of teaching specialists, we propose recurring funds to support 50% teaching activities of interdisciplinary postdoctoral researchers (balance supported by fellowships and research grants), as well as funds for a long-term visitor/recruitment program that would aim to have at least two long term faculty-level visitors in residence at any given time in order to inject new ideas. Combined, this will help to keep the unit current in terms of the latest computational methods and scientific problems, and will assist in the attraction of top talent to UiO.

Long term goals and sustainability. The overall goal of this department 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. This will be realized by the securing of Center-level funding (as well as many single- or few-PI grants), as well as the creation of a coherent academic program with large undergraduate and graduate enrollments. We anticipate that each PI will bring in grants that sustain graduate students, post-docs, travel and other associated expenses. In order to ensure the success of these efforts, the proposed department must be financially sustainable. Continued 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.

Proposed steering committee (2018)

1. Institute for theoretical Astrophysics and Rosseland Center for Solar Physics: Mats Carlsson and Viggo Hansteen

2. Bioscience: Tom Andersen, Marianne Fyhn and Lex Nederbragt

3. Chemistry and Hylleraas Center for Quantum Molecular Sciences: Michele Cascella, Trygve Helgaker and Simen Kvaal

4. Geoscience: John Burkhart, Joe Lacasce and Thomas Vikhamar Schuler

5. IFI Bioinformatics: Torbjørn Rognes

6. IFI Imaging and Biomedical Computing (coupling to Simula): Andreas Austeng, Xing Cai, Joakim Sundnes and Simon Funke

7. Math and Mechanics: Karsten Trulsen and Kent-Andre Mardal, Andreas Carlsson

8. Math and Computational Finance, Statistics and Risk Analysis: Arne Bang Huseby and Geir Olve Storvik

9. Math and Cmputational Mathematics: Geir Dahl, Ragnar Winther, Knut Mørken, Martin Reimers, Michael Floater

10. Physics and Center of Computing in Science Education: Morten Hjorth-Jensen and Anders Malthe-Sørenssen

11. SIMULA research lab: need people/names

12. Medicine: need people/names

13. UV: Possible person: Anders Kluge?

14. Social Sciences: Possible persons: Kjetil Storsletten and Halvor Mehlum?

15. Humanities: need people/names

Summary of Timeline.

1. Establish a center called **Center for Computing across Disciplines** by Fall 2018 and co-locate with the new Center for Computing in Science Education

2. Establish a department called **Department of Computational and Data Sciences** by Fall 2020.

3. New Master of Science Program on Computational Science starts fall 2018

4. New Master of Science Program on Data Science starts fall 2018

5. Establish a cross-college PhD program in Computational and Data Sciences, start fall 2020. This PhD program will be a collaboration between the Natural Sciences, Humanities, Social Sciences, Medicine and Education.

6. Develop a corresponding cross-college MSc program in Computational Science and Data Science by fall 2020.

7. An undergraduate program in Computational and Data Sciences tailored to various disciplines by fall 2020

8. Develop courses and course modules in Computational Science and Data Science for the private and the public sectors by fall 2019.

9. 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 by fall 2021.

10. Submit an application called **Computing Across the Disciplines** for a Marie Curie training network by spring 2019, 15 PhD positions

11. Submit an application called **Computing Across the Disciplines** to the Norwegian Research council by Spring 2019, 10 PhD and 10 PD positions

12. Prepare first draft for an SFF application by spring 2020

Centers and Departments at other universities

In Norway it is only UiO which offers a Masters program on Computational Science and Data Science. All other universities have only Master programs on Computer Science. The University of Bergen has a Masters program on Applied Mathematics while UMB has only a Masters on Bioinformatics and Data analysis. These are limited and more focused programs. Nationally, UiO is the only university which offers broad programs in Computational Science and 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.

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, Sweden and Switzerland.

The goal in Oslo is to establish a department which covers both Computational Science and Data Science across colleges and disciplines. The department will

be responsible for these educational programs and oversee that a coherent and modern selection of courses is offered and developed. The courses should reflect the needs of society at large as well as the specific research projects. This will give UiO a unique position in Norway.

Educational programs at other universities

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