**Scientific Computing I, II, III**

Course syllabus

**Basic information**

<table>
<thead>
<tr>
<th>Program of study</th>
<th>Applied Computing in Engineering and Science (Master’s Degree)</th>
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<tbody>
<tr>
<td>Semester</td>
<td>First+Second (Year 1)+Third (Year 2)</td>
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<tr>
<td>Course credits</td>
<td>6+6+6 ECTS</td>
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<tr>
<td>Language</td>
<td>English level B1 / Intermediate</td>
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<tr>
<td>Prerequisites</td>
<td>B. Sc. degree in Mathematics, Physics or Computer Science</td>
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</tbody>
</table>

**Course Instructor**

Tsarev S.P., D.Sc in Mathematics, Web-pages:

https://scholar.google.ru/citations?user=dey5ZnMAAAAJ&hl=en
https://www.researchgate.net/profile/Sergey_Tsarev

Professor in Dept. of Applied Mathematics and Computer Security,
Siberian Federal University, Krasnoyarsk, Russia [http://www.sfu-kras.ru](http://www.sfu-kras.ru)
Office: Institute of Space and Information Technology, office 3-11
E-mail: stsarev@sfu-kras.ru

**Required knowledge**

The students who take this course should have basic knowledge of elementary calculus and linear algebra. Programming skills (any high-level programming language) would help, but is not required. Knowledge in computational algorithms is optional, as necessary algorithms will be discussed during the course.

Preliminary Reading:


**Computing**

Access to one of the computing algebra systems such as *SageMath, Reduce, Maple, Mathematica*, etc. is required in order to do the computer assignments. SFU has a license for educational use of Maple.

**Teaching**

The course will be taught mainly in lecture format along with class examples and demonstrations. Applied issues (Computer modeling, Biology/Genomics etc.) will be presented using demonstrations. Problems (Individual Tasks) will be assigned. At the end of each of three terms the qualification (oral examination) will take place.
Course description

This course is for those who wish to gain an understanding of fundamental symbolic mathematical methods in the physical and biological sciences, engineering, mathematics, finance, computer science, etc. as embodied in contemporary systems for symbolic mathematics (e.g. SageMath, Reduce, Maple, Mathematica, etc.). Topics covered include: an introduction to a symbolic mathematical computation system; discussion of fundamental techniques in symbolic computation as illustrated by the solution of applications problems, methods for efficient solution of large problems, hybrid symbolic/numeric techniques. An integral part of the course is an extended discussion of modern algorithms in genomics (searching repeats in DNA etc., phylogenetic trees, assembly of DNA sequencing results etc.).

Course aims

The aim of the course is present an introduction to the up-to-date ideas, approaches and techniques for non-numerical mathematical model analysis. Also, the course is aimed to give students a critical understanding of current implementations of current methods and techniques, and to train student in the methods application.

Course objectives

The objectives of the course are:
1. to give students a detailed description of the concepts of symbolic algorithms;
2. to provide students with up-to-date knowledge on some methods and techniques…
3. to make students familiar with some software packages and toolkits used to implement the methods mentioned above into practiced in scientific computing.

Special Features

Scientific computation is an important tool in various areas of science ranging from biology to modeling of complex physical systems. It covers concepts and methods related to symbolic computation (“formula crunching”), other non-numeric algorithms (sorting and searching of information) as well as hybrid symbolic-numeric computations. Being a branch of modern mathematics, scientific computing has strong connections to applications and offers a chance to grow through a number of various specific fields of knowledge and expertise. A distinctive feature of the course is its tight integration with applied projects realized in cooperation with the School of Engineering Physics and Radio Electronics (joint research on mathematical models in global satellite navigation systems) and School of Fundamental Biology and Biotechnology (DNA sequencing, genomics of plants).

Learning Outcomes

At the end of the course, the student are expected to:

- master the main methods of non-numerical analysis of functions and processes;
- be able to use the modern algorithms for searching information in targeted areas (e.g. genomics) and the bases of algorithm construction and analysis;
- use symbolic software packages to perform engineering and science computations.;
- be able to apply these methods to academic and simple practical instances;
- develop the abilities to design and conduct advanced numeric and symbolic experiments appropriate for an applied mathematical model, analyze and interpret their results.
Outline of content

First semester:

1. Introduction to symbolic mathematics systems.
2. Effective use of symbolic mathematics systems and their limitations.
3. Exact versus approximate computation.
4. Use of symbolic mathematics systems to construct important mathematical examples, understand theorems, and to qualitatively and quantitatively explore various mathematical objects and their properties.
5. Key mathematical algorithms such as the Euclidean algorithm and the fast Fourier transform.
6. Integer and polynomial arithmetic.
7. Solution of systems of polynomial equations (introduction to Groebner Bases).
8. Applications of Groebner bases (digital signal processing, robotics).

Second semester:

1. Introduction to modular algorithms, their efficient implementation for fast symbolic/numeric computations.
2. Number theoretic algorithms in coding and cryptography.
3. Fast algorithms for multiplication of numbers and polynomials, fast matrix manipulation.
5. Fast factorization of polynomials.
6. Short vectors in lattices (LLL algorithm), applications for design of realistic optimal algorithms, in cryptography.
7. Resultants and subresultants.

Third semester:

2. Modern algorithms for sorting, searching and retrieving information with applications to genomic research and text processing.
3. Elements of algorithm design and analysis. Appropriate efficient data structures.
5. Quantifier elimination and applications to stability analysis and control theory.
6. Other applications based on student interests, joint project with other Schools at SFU.

Projects

Several homework problems/computational projects will be assigned during the semesters - expect there will be at least 3 and at most 5 of these projects altogether. They will be designed such that students have an opportunity to engage the skills acquired on various topics, preferably in areas of collaboration with School of Engineering Physics and Radio Electronics and School of Fundamental Biology and Biotechnology. The focus in all these projects will be on finding a computationally efficient alternative. This may mean coming up with good data structures and storage, a good algorithmic strategy or nice algorithm design etc. depending on the problem. The small projects should not take too long if the material in class is properly understood, larger applied project usually result in your Master Thesis.
Collaborative Work

Many people learn more effectively when they study in small groups and cooperate in various other ways on homework. We are very much in favor of this kind of cooperation so long as all participants actively involve themselves in all aspects of the work. When you hand in a paper with your name on it we assume that you are certifying it as your (joint) work and that you were involved in all aspects of it. Even if you work with others you should do its writing separately, and you should indicate the names of any collaborators for each part of it. However, we encourage you to make the final project a team effort with a joint presentation and write up, so please try to find collaborators early in the term for this work.

Course assessment

Note: Assessments subject to change. Below there is a tentative version of assessments. The final version will appear prior to start of the course.

<table>
<thead>
<tr>
<th>Assessment Type</th>
<th>Number per semester</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Computer Assignments</td>
<td>2</td>
<td>50%</td>
</tr>
<tr>
<td>Midterm</td>
<td>1</td>
<td>25%</td>
</tr>
<tr>
<td>Final</td>
<td>1</td>
<td>25%</td>
</tr>
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Attendance Policy

Students are expected to attend classes regularly, since the consistent attendance offers the most effective opportunity open to all students to gain command of the concepts and materials of the course. Meanwhile, excuses of various origin are permissible, in such a case students take a consultation and do the necessary class-work at home (or at their own). Such “hidden extramural” activity must not exceed a quarter of the total course time.

References


Academic Honor Policy / Academic Honesty:

The Siberian Federal University is built upon a strong foundation of integrity, respect and trust. All members of the university have a responsibility to be honest and the right to expect honesty from others. Any form of academic dishonesty is unacceptable to our community.

Note

The instructor reserves the right to make changes to this syllabus as necessary prior to start of the course.