TCPP EARLY ADOPTER FALL 2013

# Integrating TCPP curriculum into Computational Math in Russia

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## Project Overview

As a part of the proposed project implementation, it is planned to integrate TCPP curriculum with the curriculum for Bachelor's Degree in Applied Mathematics and Informatics at the department of Computational Math and Cybernetics (CMC) of the University of Nizhni Novgorod (UNN). The following modifications of the multiple undergraduate courses over multiple semesters will be made for this purpose:

(1) Renewal of the core computer science courses: CS101 Introduction to Computer Programming (1 semester, Fall 2013), CS102 Object Oriented Programming (2 semester, Spring 2014), CS103 Data Structures and Algorithms (3-4 semesters, Spring 2014).

(2) Structure adaptation of the core computer science courses (CS220 Computer Architecture, CS225 Operating Systems, CS230 Computer Networks, Spring 2014) in accordance with TCPP recommendations.

(3) Modernization of the main course on parallel programming CS338 Parallel Computing (5 semester, Fall 2014).

Curriculum for all the above mentioned courses will be published on the CDER courseware website. Lecture presentations for CS338 Parallel Computing course will also be published.

In addition, project results will be distributed among the members of Supercomputing Consortium of Russian universities (more than 50 Universities).

## Project Goals

The main goal of the project is to renew the curriculum for Bachelor's Degree at the CMC so that it corresponds to the requirements of the parallel computation world. Computer systems are becoming more parallel (supercomputers are expected to have billions of computational cores in the nearest future). That is why it is necessary to create new technologies for the development of parallel programming systems, develop new parallel algorithms, and create new parallel computational mathematics.

NSF/TCPP Curriculum Initiative recommendations fully correspond to the plans of curriculum renewal and for this reason may be used as the basis for completion of this task.

The proposed project will provide the basis for CMC curriculum quality renewal for next several years. All in all, it is planned to modernize 20 courses by adding parallel computing modules to them. The courses to be modernized are CS250 Computer Graphics, CS290 Software Engineering, CS314 Parallel Algorithms, etc.

## Background - Faculty of Computational Math and Cybernetics

Lobachevsky State University of Nizhni Novgorod is one of the leading Russian universities. In 2008 it was one of the first 12 universities that gained the status of national research universities.

Supercomputing technologies and high-performance computing are top-priority areas for the UNN development.

In 2013 a high-performance cluster with the peak performance of more than 500 Tflops will be installed in the UNN (it will be the second place among the Russian universities).

Computational Math and Cybernetics (CMC) department is the main UNN department that trains specialists in the fields of computational math, computer sciences and information technologies. There are 150 teachers and more than 1000 students at the department.

The UNN students have been taught parallel programming since 1995. The UNN learning materials on parallel programming were submitted for the European contest of the Informatics Europe association and won it. In 2011 the UNN student team was the best in the "Reaching Maximum Performance" section of the Student Cluster Competition that was a part of Supercomputing conference (Seattle, USA).

**Project Approach**

To implement the project, the team will follow these provisions:

1. Modules related with parallel computing should be presented in most of the courses based on the modern curriculum.

2. Materials that will be included in the renewed courses should be developed on modular basis.

3. Learning materials on parallel computing should follow the bottom-up (from simple to more complex) approach.

4. The courses should be renewed in accordance with the recommendations of the NSF/TCPP Curriculum Initiative project, the ACM-IEEE Computer Science Curricula CS2013 Strawman Draft report and theBody of Knowledge of Supercomputing developed as a part of Russian national project Supercomputing Education.

Master and postgraduate students will be engaged in the fulfilment of the project.

The proposed renewal of the courses will be discussed at the CMC teachers' committee.

**Details of Renewed Courses**

**1. CS101 Introduction to Computer Programming –** the course is an introduction to programming and as a result is oriented on computing algorithmization and algorithm implementation . In CMC, this course is given on the Pascal programming language. Floating point representation topic of the TCPP Curriculum has already been presented in the course.

The goal of the possible course development is, first of all, to introduce the field of parallel computing to students and motivate them for CS102 Object Oriented Programming course. For this purpose, students will be given modern multi-core processor characteristics and high-performance computer system examples. This will show that parallel and grid computing are necessary for reaching maximum performance (KA Cross Cutting and Advanced). Students will also be given examples of computational problems that may be solved only with the use of high-performance parallel computing.

**2. CS102 Object Oriented Programming –** this course is aimed at C/C++ learning and practical acquisition of object-oriented programming principles.

The goal of the possible course development is to teach parallel programming for the systems with shared memory. It is planned to use OpenMP technology as a basis.

The sections that will be added to the course will give additional information on modern multi-core processors that make parallel programming possible on the whole range of computer devices starting from cellphones and laptops and up to supercomputer systems. Students will be taught the basics of multi-threaded program organization: the concept of thread, thread independence and communication, communication problems (race conditions, excessive synchronization, performance loss), mutual exclusion techniques (critical section, semaphores, data localization).

The basics of the OpenMP technology (parallel sections, loop parallelization, data localization management, reduction) will be given to students to help them master and use the above concepts in practice. The OpenMP technology will be taught on the example of various computational tasks: matrix computation, data sorting, etc.

In general, the added learning materials correspond to the recommendations of the TCPP Curriculum on the parallel computing for the systems with shared memory.

**3. CS103 Data Structures and Algorithms**. The course is aimed at teaching classical data structures (stacks, queues, lists, trees, tables) and their use in algorithm development.

The goal of the possible course development is to teach parallel programming for systems with distributed memory. It is planned to use MPI technology as a basis.

The renewed course will give additional information on modern high-performance systems that provide huge (over petaflops) computational potential. Students will be taught the basics of multi-processor organization of programs: concepts of process and its difference from the concept of thread, process independence and communication, communication problems (overhead costs of data communication, data waiting locks, deadlocks) and message passing methods (point-to-point and collective operations, asynchronous data passing, communication complexity evaluation), presentation of a parallel program as a set of concurrently executed processes.

The basics of the MPI technology (processes and communicators, operations of sending and receiving of messages, typical communication operations) will be given to student to help them master and use the above concepts in practice. This technology will be taught on the example of various computational tasks: matrix computation, graph processing, Monte Carlo methods, etc.

In general, the added learning materials correspond to the recommendations of the TCPP Curriculum on the parallel computing for the systems with distributed memory.

**4-6. CS220 Computer Architecture, CS225 Operating Systems, CS230 Computer Networks**. These courses are the core computer science courses and they already contain the parallel computing learning materials recommended by the TCPP Curriculum. It is necessary only to restructure these courses so that they correspond the TCPP Curriculum structure.

**7. CS338 Parallel Computing.** This is the main course for student studying parallel computing. CMC has been giving this course since 1995. It is constantly modernized to cover all the new achievements in the field of parallel computing.

During this course students study examples and classifications of parallel systems, parallel computing performance metrics, computation and communication complexity of algorithms, advanced sections in OpenMP and MPI technologies, methods of development of parallel algorithms and programs on the example of matrix computation tasks, sorting, graph processing, optimization, etc. The peculiarity of the course is that it demonstrates the possibility to predict the efficiency of the developed parallel algorithms and to confirm their efficiency by computational experiments.

The course includes extended laboratory practicum. Upon completion of the course each student is to present an individual project.

The course will be renewed by adding modules connected with the development of parallel algorithms and algorithms for computational systems with hierarchy structure (many nodes with distributed memory, each node may be multiprocessor, each processor may be multi-core). For the development of parallel programs, these systems require combining of OpenMP and MPI technologies. To master this approach, students have to make a lot of effort and carry out a lot of computational experiments.

The course includes studying a lot of TCPP Curriculum topics and may be used as the basis for courses on parallel computing in advanced level.

**Project Evaluation**

Success of project implementation may be measured by evaluation to which extend the TCPP recommendations are presented in the renewed courses, whether new topics are reasonably distributed in the courses, and whether the difficulty of the learning materials is gradually increased when identical topics are used in different courses.

Students' success in mastering the subject will be measured by the results of lab assignments, exams, and course surveys.

Project results will be discussed by the Education Board of Classical Russian Universities at the meeting on computational math and information technologies.

**Budget**

Project team has an opportunity to use all the necessary computational resources. To implement the project, it is only necessary to support the completion of the activitie connected with the renewal of the courses listed in the project and to cover travel expenditures connected with the implementation of the project. Essential budget of the project is $2,500.

**Project Team**

**Victor Gergel** is the CMC dean, a Professor of Computational Science. His research interests are in the area of parallel computations for global optimization problems. He is a lecturer of the CS103 Data Structures and Algorithms and CS338 Parallel Computing courses. In the framework of project he is the principal investigator and responsible for updating CS103 and CS338.

**Alexey Liniov** is an Assistant Professor of Computational Science. His research interests in the area of parallel and distributed systems. He is an instructor of the CS225 Operating Systems and CS230 Computer Networks. In the framework of project he is responsible for updating CS225 and CS230.

**Iosif Meyerov** is the Vice-chairman of the Software Department and an Associate Professor of Computational Science. His research interests in the area of software development. He is a lecturer of the CS101 Introduction to Computer Programming and CS102 Object Oriented Programming. In the framework of project he is responsible for updating CS101 and CS102.

**Alexander Sysoyev** is an Associate Professor of Computational Science. His research interests in the area of parallel computations for global optimization problems . He is a lecturer of the CS103 Data Structures and Algorithms. In the framework of project he is responsible for updating CS103, CS220 and CS338.