

INFORMATICS EUROPE

2011 Curriculum Best Practices Award: Parallelism and Concurrency

Proposal

Title

Parallelism & Concurrency: Changing the Landscape of IT-Education

Team

This proposal presents results on a computing curricula developed under the direct influence of Parallelism and Concurrency ideas by a team of the two leading Russian universities – Moscow State University (MSU) and Nizhny Novgorod State University (NNSU).

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ACHIEVEMENTS

1. **Motivation.** Inevitable transition of the computer industry to the multi-core processor technology and wide use these processors for high-performance systems has defined the need of mass practical use of Parallelism and Concurrency (P&C). The significance of this problem determines an extremely serious challenge for higher education of rapid and wide-scale training in parallel computing.

2. **Approach.** The International recommendations on Computing Curricula (ACM/IEEE) and the Informatics Curriculum for Higher Education European (UNESCO, IFIP) may be used as a methodological basis for computing curricula development for a deep Parallelism and Concurrency study since P&C is an integral part of Computing and Informatics. As a result, instead of creating a few courses our team has concentrated on the following activities:

- We thoroughly analyzed the international recommendations for building the Computing and Informatics curricula, selected the sections (*areas*) related to certain aspects of Parallelism and Concurrency and defined a detailed structure of necessary knowledge and skills for these elements;

- Relying on the previous analysis we defined the necessary Curriculum for Parallelism and Concurrency study and developed most of the courses of the curriculum.

3. **Curriculum.** The main concept suggested in this project is the integrated approach to studying the Parallelism&Concurrency (P&C) at all levels of parallelism. It is based on the fundamental theoretical research of parallelism and takes into account the opportunities provided by modern technologies. The Body of Knowledge sections (*areas*) are defined according to the suggested concept. The areas are separate parts of the P&C curriculum and are further divided into smaller parts called *units*, which represent individual thematic modules within each area.

As a result of the executed analysis the following areas of the P&C Curriculum have been defined:

- Mathematical foundations of parallel computing,
- Parallel computing systems (computer system foundations),

- Technologies of parallel programming (parallel software engineering foundations),
- Parallel methods and algorithms,
- Parallel computations, large-scale problems and problem-oriented applications.

In corpore the Curriculum of Parallelism and Concurrency is given at <http://msu.hpc-education.ru/?q=node/51>.

4. **Courses.** The developed courses provide the integrated studies of the Parallelism and Concurrency (mathematical foundations and methods of parallel computations, technologies and tools of parallel programming, architecture of parallel computational systems, samples of practical use of the parallel computations potential for solving practical large-scale time-consuming problems).

The following courses have been developed (the content of the courses is presented briefly, the complete syllabuses of the courses can be found at the links given below):

- **Parallel computing** (V.I.Voevodin, MSU) - see <http://msu.hpc-education.ru/?q=node/52>.

Main topics: This course is an introduction to the diverse and fast growing area of parallel computing. It comprises four major parts. The introduction gives a flavor of supercomputers and supercomputing, shows various applications of parallel computing technologies in industry and science, reveals fundamental problems of the area. The next part describes parallel computers architectures, existing types and features, properties, discusses causes of performance degradation. The third part is devoted to parallel programming technologies. The last one gives brief overview of basic notions from the theory of algorithms and programs analysis. Knowledge and joint usage of the three parts: architectures, parallel programming technologies and structures of algorithms and programs form a strong basis for efficient solution of real-world large-scale problems.

- **High Performance Scientific computing: parallel programming model, tools and performance analysis** (N.N.Popova, V.A.Bakhtin, MSU) - see <http://msu.hpc-education.ru/?q=node/65>.

Main topics: Parallel programming models - shared address space and message passing programming models. Advanced features of the MPI and OpenMP such as parallel IO, remote memory operations, dynamic process management, hybrid MPI/OpenMP. Main steps in creating parallel programs: decomposition of algorithms into parallel tasks, load balance and synchronization, partitioning and mapping processes to processors are studied and demonstrated on typical linear algebra problems. Scalable methods of performance measurements and analysis with special focus on high-performance computing environments and on emerging computing technologies are studied in the course. Different tools such as PAPI, TAU, HPC Toolkit, SCALASCA and Intel Parallel Studio are studied and used in practice during projects carrying out in the frame of the course.

- **Introduction to Parallel Programming** (V.P.Gergel, NNSU) - see <http://hpc-education.unn.ru/?id=999>

Main topics: Overview of parallel computer architectures. Modeling and analysis of parallel computations. Parallel algorithms and software design. Technologies of parallel program development. Parallel algorithms for solving time-consuming problems (linear algebra, sorting, graph methods, differential equations in partial derivatives, global optimization).

- **Parallel programming tools** (V.P.Gergel, I.B.Meyerov, et al. NNSU) - see <http://hpc-education.unn.ru/?id=1000>

Main topics: 1. Introduction into debugging parallel programs for systems with shared memory (purpose, error types, their characteristics and methods of debugging). Mastering

with Intel Thread Checker (ITC). 2. Introduction into profiling and optimizing parallel programs for systems with shared memory (purpose, profiling methods, problems of performance degradations, their characteristics and ways to recover). Mastering with Intel Thread Profiler (ITP). 3. Developing parallel programs for systems with shared memory using the library Intel Threading Building Blocks (TBB). Objectives of the library, a content of the library, principles of using the library, advantages and disadvantages. Components of the library, main constructions and principles of their functioning.

- ***New languages for parallel programming*** (V.P.Gergel, et al. NNSU) - see <http://hpc-education.unn.ru/?id=1001>

Main topics: Overview of parallel computers, principles of parallel programs development for systems with shared and distributed memory, parallel programming languages in case of the partitioned global address space (UPC, CAF, Chapel, X10), technologies of developing parallel programs for new processors of new architectures (CUDA, OpenCL, technologies for Cell and ClearSpeed), parallel computations in mathematical packages (MatLab), parallel numerical algorithms for solving computationally intensive problems (parallel numerical algorithms of linear algebra, parallel data sorting, parallel graph processing).

The developed courses include extended laboratory trainings. The authors created and published the textbooks (see below) for the courses, these courses are supported by Internet resources with a wide presentation of the required and complementary teaching materials.

The presented courses are accompanied by the *software system Parallel Laboratory (ParaLab)* which is an integrated environment for studying and analyzing the parallel algorithms for solving complicated computational problems. A wide set of features for visualizing the process of carrying out an experiment and to analyze the obtained results allows to study the parallel method efficiency on various computer systems, to make conclusions concerning the scalability of the algorithms and to determine the possible parallel computation speedup – see also <http://hpc-education.unn.ru/?id=1018>.

An Internet portal of the collective bank of exercises and tests on parallel computing *Sigma* (<http://sigma.parallel.ru>) is one of the important elements of the learning process for different courses. The Sigma system is a collective bank of tests, questions and exercises for testing knowledge on different fields of parallel computing. Everyone can use a ready-made set of questions, or make up your own test based on a particular course, or take part in the collective work of experts on drawing up shared bank of questions and exercises, or self-test knowledge on any topic of courses. These are the tasks for which the system has been created. The tests offered to students to pass are prepared by teachers who made them up from the questions drawn up by a large group of experts-professionals and checked by the system editors. The questions are grouped according to the structure of the P&C curriculum. The set of questions is dynamic and rapidly developing involving more and more new specialists, therefore the base of tests is continuously supplemented by new material. At the moment Sigma system contains around **200 exercises** and more than **1000 students** from a dozen of Russian universities passed tests using this system.

The developed courses can be widely used as a basis for enhancing curricula in various specific areas of studies by Parallelism and Concurrency: computational mathematics, physics, chemistry, bioinformatics and bioengineering, etc.

5. **Textbooks.** To provide teaching and make learning easier all developed courses are accompanied by textbooks. The following series of textbooks has been published.

- **Voevodin V.V. Voevodin V.I. *Parallel Computing*.** - SPB.: BHV-Petersburg, 2002.
- **Antonov A.S. *Parallel Programming Using MPI*.** - M.: MSU, 2004.
- **Antonov A.S. *Parallel Programming Using OpenMP*.** - M.: MSU, 2009.

- Voevodin V.V., Zhumatiy S.A. *Computing Technologies and Cluster Systems*. - M.: MSU, 2007.
- Gergel V.P. *Theory and Practice of Parallel Computing*. – M.: Intuit, 2007.
- Gergel V.P., Meyerov I.B. and et al. *Parallel Programming Tools for Shared Memory Computers*. – M.: MSU, 2010.
- Gergel V.P. and et al. *Technologies of Parallel Programming for New Architectures Processors*. – M.: MSU, 2010.

A brief overview of these textbooks is given at the Section “Evidence of Impact” of the proposal.

6. **Classes.** The developed courses are actively used at the faculties of computational mathematics and cybernetics in MSU and NNSU. The courses are included into the curriculum of bachelor and master studies for three specialties:

- Computational mathematics and informatics,
- Fundamental informatics and information technologies,
- Applied informatics.

Every year **more than 400 students** of MSU and NNSU are studying the courses mentioned above.

To demonstrate the results of the training it should be noted that the students’ team of NNSU won the second place in 2009 at the world’s final of the international contest Imagine Cup held by Microsoft company (76 teams of 76 countries took part in the final). In 2010 the students’ team of NNSU took part in the Student Cluster Competition at the world leading Supercomputing conference (New Orleans, USA – see <http://sc10.supercomputing.org/?pg=studentcluster.html>). In 2011 the NNSU student team took the 5-th (Silver Medalist) place at 35th Annual World Finals of the ACM International Collegiate Programming Contest, the MSU student team – the 10-th place.

7. **Advanced Studies.** Apart from using the courses in the “classical” University learning process, these courses can be applied as the basis for forming special educational programs, which is a very specific feature of the developed course collection. Our team used the developed courses to organize the following (see also Section “Evidence of Impact” of the proposal):

- *Special-purpose intensive training for students:* students in the groups are from various faculties (mathematics, physics, bioinformatics, etc.) which are interested in practical usage of the high performance computing potential for solving their large scale problems in various areas of science and applications. This kind of training makes it possible to arrange an interdisciplinary training for students in the sphere of Parallelism and Concurrency. It also makes it possible to graduate within the limited time highly qualified specialist who are capable of developing and using efficiently the potential of modern high performance computational systems to carry out fundamental and applied research and bring this knowledge into the economics and industry - see also <http://hpc-education.unn.ru/?id=1012> . Every year **more than 70 students** of MSU and NNSU are studying in the framework of this innovative form of studies.

- *Youth educational schools:* participants are selected based on the entering contest/examination (2-3 candidats per a position). All of them are talented students, holders of a Master’s degree, postgraduate students, young scientists and specialists. These schools provide advanced trainings in different areas of Parallelism and Concurrency. **More than 250 participants** from various Universities of Russia participated in the schools organized by our team in 2010-2011 in MSU and NNSU – see also <http://hpc-education.unn.ru/?id=1013> .

- Youth research and practical seminars and conferences.

8. **Project Based Teaching.** During of training in the sphere of Parallelism and Concurrency a serious attention is paid to the individual work of students. To organize it the developed courses contain extended laboratory practical works and sets of tasks for individual

works. One of the examples of this form of training is the educational practical course given in March – April 2011 to the students of the fifth year, the graduation year of the faculty of computational mathematics and cybernetics in MSU: the course on practical usage of linear algebra methods and setting up the efficiency of problems on the supercomputers BlueGene/P and SKIF-MSU “Chebyshev”. (<http://angel.cs.msu.ru/~popova/assignment.pdf>). About **250 students** completed projects to study scalability of the methods to solve systems of linear equations using thousands of processor cores. The course is aimed at the C&P studying applied to perspective exaflop computers and development of parallel algorithms for them.

The educational system ParaLab contributes to the practical study of these issues. Using ParaLab it is possible to simulate a target computing system, set problems, choose a method of solving the problem and carry out a computational experiment monitoring the parallel computations on a screen.

To control the acquired knowledge the developed courses contain tests and questions. The collective Internet bank Sigma makes it possible to check of knowledge of trainees on a large scale.

It is immensely important for the high quality of the training that the students have an opportunity to use the most high performance computational systems in the country in their practical works – supercomputers «Lomonosov» (510 Tflops, in 2011 the peak performance will be extended up to 1.3 Pflops), «Chebyshev» (60 Tflops), BlueGene/P (28 Tflops).

Project-based approach for research and diploma thesis’s plays the major role in students’ individual work organization. The subject areas for the works/papers are, as a rule, focused on the latest current areas of applied mathematics, informatics, computer science, information technologies, practical applications. To complete the tasks and projects we form groups of 3-5 senior students, post-graduate students (for initial training students of the junior years can be involved into the groups). The works are supervised by the highly qualified professors and specialists of the University or of the IT companies that collaborate with the Universities. The results of the projects are discussed at department meetings and, as a rule, get published.

The list below shows scientific research projects that have been completed among others under supervision of our team members (see also <http://hpc-education.unn.ru/?id=1012>):

- The methods of developing parallel programs on the basis of machine learning (Ph.D. thesis).
- Research and development of the methods of scientific visualization for massive parallel computational systems (Ph.D. thesis).
- Creating educational library of parallel methods ParLib.
- The development of the cluster management system Metaccluster.
- The development and research in the field of VLSI design.
- Performance analysis of new parallel programming languages (Chapel, X10, Co-Array Fortran).
- Porting packages under Windows and their optimization for heterogeneous architecture (preparation of the students’ team for the participation in the Student Cluster Competition that took place within the international conference Supercomputing 2010).
- Plasma simulation by the Particle-In-Cell method on cluster systems.
- Simulation of light propagation in multi-layer environments by the Monte Carlo method.
- Developing the system DCS to support distributed computations, etc.

Every year **more than 100 students** of MSU and NNSU are carrying out research and educational projects.

Additional information on the results of our team can be found in sections “Evidence of Availability” and “Evidence of Impact” of the proposal

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EVIDENCE OF AVAILABILITY

Taking into account the high importance of education in the sphere of Parallelism and Concurrency (P&C), our team is making efforts to spread the information on the developed training materials among the University community and is actively contributing to using the materials in other Universities of Russia.

The developed materials are available for the Russian University community. It is possible due to several factors: availability of the published textbooks and materials on the Internet, realization of the advanced trainings for the faculties, holding seminars and schools for young scientists and specialists.

1. **Textbooks.** As it has already been noted above, our team prepared and published textbooks supporting trainings along the all developed courses. The textbooks published in 2010 were provided to Universities free of charge (50 textbooks to each University that is a member of the Supercomputer Consortium of the Universities of Russia that counts more than **35 Russian Universities**).

2. **Internet resources.** Most of the developed training materials are presented on the Internet: for MSU it is the Internet portal <http://parallel.ru> (section Training Materials), for NNSU it is the site <http://hpcc.unn.ru> (section Training).

The portal parallel.ru (the English version of the portal http://parallel.ru/index_eng.html) developed in MSU under the supervision of V.I. Voevodin contributes a lot to spreading the training materials on P&C. The portal is the main Russian Internet resource devoted to supercomputers and parallel computing. The main sections of the portal are Computers, Technologies, Research, Education, Conferences, etc. There are more than **3000 subscribers** for regular newsletters of parallel.ru.

The site <http://hpcc.unn.ru> contains training materials for **11 training courses** developed in NNSU that are devoted to the issues of P&C.

A significant part of the developed materials are presented on **the educational portal <http://www.intuit.ru>**. This portal is the resource of the Internet-University of Information Technologies and the main Russian Internet-resource in this area (more than **400000 registered users**). The portal contains training materials for **19 training courses** devoted to the issues of P&C.

The training course **“Introduction to Parallel Programming”** developed in NNSU is most widely presented in the Internet. The training materials of the course are fully presented on the site of the Nizhni Novgorod University software department - see <http://www.software.unn.ac.ru/ccam/?doc=14>. The course is included into the library of training materials at the Microsoft site in Russian – see <http://www.microsoft.com/Rus/Msdnaa/Curricula>.

There is also a complete version of the developed course in English. It is available in the library of training materials of the Microsoft company site <https://www.academicresourcecenter.net/curriculum/pfv.aspx?ID=6594> (in September 2007 this version of the training course became the second most downloadable training material of all the training materials of this educational resource).

One can study the course and take an exam remotely with the help of the Internet University of Information Technologies (<http://www.intuit.ru/departament/calculate/paralltp>) and within the system of distant learning of Nizhni Novgorod State University (<https://e-learning.unn.ru>). There

are also complete video versions of all the course lectures available (<http://www.intuit.ru/department/calculate/inparallprog/>).

3. **Training teachers.** Organizing various advanced trainings for teachers and faculties is an important contribution to wide usage of the developed training materials. In the frame of such educational programs it is possible to get familiar with the developed training courses, hold practical trainings, discuss possible ways to use the training materials for teaching students in various areas of computational sciences in Universities.

Advanced trainings for University teachers that are organized by our team cover current issues of developing high performance software. It is oriented at teachers and scholars who have basic knowledge and skills in the sphere of programming, who give or just plan to give classes in subjects related to high performance computing. It is also oriented at specialists in applied programming who want enhancing the theoretical basis and acquire additional skills in developing and optimizing the serial and parallel programs (see also <http://hpc-education.unn.ru/?id=1011>).

The training programs are held in MSU and NNSU (more than **50 teachers** per year) and in partner Universities (Perm, Vladimir, Tver, Belgorod, Arkhangelsk, Saransk and others).

4. **Teaching via Internet.** Organizing the Internet University of Supercomputing Technologies (<http://www.hpcu.ru>) is an interesting innovative form of spreading the developed training materials. Educational activities of the University are oriented at teaching a wide range of people (students, specialists, teachers) and presupposes the availability of various directions in training in order to take into account professional requirements in the sphere of supercomputing technologies (users, parallel programmers, engineers, applied researchers).

Technological basics of organizing an educational process are as follows:

- The educational process within the University is formed on the basis of the **distant education technologies** (presenting the training materials on the Internet, modular presentation of the materials, automated testing);
- **Video materials** are also widely used alongside with the traditional hypertext format of presenting training materials;
- **Holding classes in the form of video conferences** is an important part of the education. It helps significantly supporting the opportunities of the classical full-time education (training materials presented by a teacher, oral tests, an individual work under the supervision of a teacher).

There are more than **300 participants** every year at the University (see also <http://hpc-education.unn.ru/?id=1014>).

5. **Youth educational schools** organized and held by our team are an important element of the system of education and spreading the ideas in P&C – for details see Section “Evidence of Impact” of the proposal.

In addition, our team is actively using the opportunities of the Educational Committee of the Classical Universities for applied mathematics, information technologies, which brings together more than **60 universities** of the country to inform the community on the developments available. Besides our team is among the co-founders of the Supercomputing Consortium of the Universities of Russia (more than **50 members**), which also contributes to the wide spreading of our team experience and practical use of the developed training materials.

of presentation and perception of the material. Description is done using programming languages C and Fortran. Examples of complete parallel programs are given, they are available on the webpage http://parallel.ru/tech/tech_dev/OpenMP/examples/. At the end of each section control questions and tasks are given that can be used in the learning process.

- **Voevodin V.V., Zhumatiy S.A. *Computing Technologies and Cluster Systems*.** - M.: MSU, 2007. (<http://msu.hpc-education.ru/?q=node/54>)

Main topics: This book covers many problems which must be solved before, during and after a new computing cluster is installed. Is this cluster really needed? What it will be designed and installed for? What do you need to check and prepare before buying hardware? What kind of software do you need to install? These as well as many other questions a potential owner of the cluster must resolve are collected here. Book contains many practical recommendations on cluster building and usage stages. Skipping or forgetting any aspect of cluster building, installing, and other stages may lead to significant overheads. How to prevent forgetting or missing such important issues – this is the main goal of the book.

Materials for this publication are founded on 10-years authors experience, several real clusters usage in the Moscow State University, hundreds responses of users from Moscow and other cities. The book is free available via web-site <http://ClusterBook.Parallel.ru>

- **Gergel V.P. *Theory and Practice of Parallel Computing*.** – M.: Intuit, 2007. (<http://hpc-education.unn.ru/?id=1020>)

Main topics: The review of the principles for constructing parallel systems. The analysis of parallel computations efficiency for evaluating the acquired computation speedup and the usage of all computer hardware potential in parallel methods of solving problems. The general principles of developing parallel algorithms for solving complex time consuming problems. The MPI technology for developing parallel programs for distributed memory systems. Creating and developing parallel algorithms for solving applied problems in various spheres of practical applications.

- **Gergel V.P., Meerov I.B. and et al. *Parallel Programming Tools for Shared Memory Computers*.** – M.: MSU, 2010. (<http://hpc-education.unn.ru/?id=1015>)

Main topics: This tutorial describes methods and tools for developing, debugging and profiling parallel programs that target shared memory systems. It covers software packages Intel Thread Checker, Intel Thread Profiler, and Intel Threading Building Blocks. Introductory information is given on the Intel Parallel Studio package and the Intel MKL library. The entire workflow is demonstrated, including creation of a sequential version to be a baseline for comparison, preparing a parallel version, debugging it, profiling it and optimizing it. Instruction is based on sample problems not requiring specific domain knowledge. The reader is assumed to be familiar with programming fundamentals (the primary language used is C/C++), some problems require advanced mathematics knowledge (Dirichlet problem).

- **Gergel V.P. and et al. *Technologies of Parallel Programming for New Architectures Processors*.** – M.: MSU, 2010. (<http://hpc-education.unn.ru/?id=1016>)

Main topics: This guide is intended to present a review of programming technologies and effective usage of various types of parallel architectures, including modern graphics processors (GPUs), ClearSpeed accelerators and Cell BE processors.

In this guide the basic questions of accelerators usage are stated. A review of various architectural solutions and corresponding development tools is given, and performance of the presented solutions is analyzed by means of a simulation of a N-body system.

Special attention is given to a widely used today type of accelerators – graphics processors (GPUs), which have undergone significant changes and have turned to general purpose processors for last seven years. A review of existing GPU development tools is given and their advantages and disadvantages for solving various problems are discussed. The most relevant tools at the moment are discussed in detail: graphics APIs and shading languages (e.g. OpenGL and GLSL), NVIDIA CUDA and OpenCL.

All the textbooks are published in central publishing houses and are widely available (including via the internet shop <http://www.ozon.ru>). The textbooks published in 2010 were provided free of charge to Universities – 50 textbooks to all Universities that are members of the Supercomputing Consortium of Universities of Russia (more than **35 Universities** in Russia).

2. Youth educational schools. The youth educational schools held in MSU (<http://school.hpc-russia.ru>) are focused on the in-depth studying of supercomputing technologies, high performance computing, mathematical foundations of parallel computing, methods of developing large-scalable parallel programs, methods of carrying out large-scale computational experiments, ways of their practical use for solving the current problems of science and technology. The main focus in the school programme is practical study of supercomputing technologies. Participants of the schools are given an opportunity to carry out research projects on MSU supercomputers, including the most powerful supercomputer of Russia “Lomonosov”.

The youth school held in NNSU (<http://hpcc.unn.ru/hpc2010/>) is focused on studying the modern technologies of high performance computations and the ways of their practical use for solving the current problems of science and technology. The major subject areas of the school are: mathematical foundations of parallel computations, parallel algorithms for solving complex problems, new languages of parallel computations, Intel tools for parallel programming, high performance computations in scientific and industrial applications. The contest in program optimization and parallelization is held in the frames of the school.

It should be noted that these schools are highly ranked in the country. The participants are selected based on the entering contest/examination (2-3 candidats per a position). All of them are talented students, holders of a Master’s degree, postgraduate students, young scientists and specialists. **More than 250 participants** from various Universities of Russia participated in the schools organized by our team in 2010-2011 in MSU and NNSU.

3. Conferences. Our team is the initiator and the organizer of a number of annual scientific conferences devoted to the issues of P&C.

Russian Supercomputing Conference “Scientific Services and Internet” (<http://agora.guru.ru/abrau>) is the main scientific series of conferences in Russia focused on the problematics of the high performance computing and supercomputing technologies. The conference considers the following issues:

- computational systems of super-teraflop performance: design, constructing, maintenance;
- theory and practice of solving large problems on supercomputers and within distributed computational environments;
- program environments, methods and tools for development, optimization and debugging of parallel applications;
- multicore processors: architecture, programming technologies, experience of usage in the computational practice;
- parallel computing and education.

International Scientific Conference “Parallel Computational Technologies” (PaCT, <http://agora.guru.ru/pavt>) is focused on the issues of developing and using parallel computational technologies in various spheres of science and industry. The main objective of the conference is to provide an opportunity to discuss perspectives of developing parallel computational technologies and to present results obtained by the leading scientific groups in using

supercomputing technologies for solving real world problems of science and industry. Subject areas of the conference cover all the aspects of using high performance computations including applications, hardware and software, specialized languages and packages.

International Conference and Youth School “High Performance Parallel Computations on Cluster Systems” (<http://agora.guru.ru/hpc2010>) have been held annually since 2001 and are focused on the current problems in high performance computations in science and education:

- the principles of constructing cluster systems and the methods of managing parallel computations;
- parallel methods and software for solving complex computational problems;
- software environments, methods and tools for the development of parallel programs;
- problems of training specialists in the sphere of parallel computations.

More than **800 people** participate in the conference stated above.

4. Industry Collaboration. Important conditions to reach the high quality of specialists training on the basis of the developed educational materials are usage of the latest results of computer industry and demand for the qualified specialists in science, education and industry. Our team has agreements on the collaboration with the following companies: Intel, Microsoft, IBM, NVIDIA, T-Platforms, Teleca, etc. As a rule, these agreements presuppose creating Competence Centers or joint educational research laboratories. Two of the examples are given below.

The **Joint MSU-Intel center** (<http://msu-intel.parallel.ru>, see also <http://msu.hpc-education.ru/?q=node/57>) on high performance computing was opened in the Research Computing Center of Moscow State University in May 2007. The objectives of this center are:

- Active collaboration and coordination between scientific, industrial and educational organizations;
- Dissemination of the latest achievements in HPC within science and education community of Russia;
- Research on parallel computation systems, new methods of parallel programming, approaches and tools for software development, perspective computational technologies.

A significant number of research results are obtained, including both software and hardware testing. For example, the research on compiler-level optimization effectiveness, running on different platforms with various sets of custom compilation settings. The experiments aimed at revealing specific program behavior in different conditions are run, providing the basis for recommendations on what tools could be used and how user programs could be tuned.

The website of the Center regularly provides the latest news, research results, translated technical materials with useful comments based on the research activities. A number of events are being held: scientific seminars, trainings, master classes and so on, resulting in sharing of accumulated experience between teams and groups of Russian science and education community engaged in high performance computing. The last trainings on Intel Cluster tools were on May, 13 and May, 20, 2011.

Microsoft Competence Center for High Performance Computations in NNSU (<http://www.mic.unn.ru/mic/Cooperation/ms-hpcc.aspx>, see also <http://hpc-education.unn.ru/?id=1017>) is oriented at enhancing the usage of modern supercomputing computational systems on the basis of Microsoft technologies for solving complex time consuming scientific technological and industrial problems in companies, industrial organizations and in enterprises in science, industry and business. In accordance with this objective the Center must provide a significant enhancement of the training, re-training and advanced training, carrying out scientific research and applied works and providing all the necessary service in the sphere of high performance technologies.

Every year about **400 of graduates** of MSU and NNSU studying in the problematics of Parallelism and Concurrency get employed by companies in education, science and industry.

In 2006 to acknowledge the obtained results Intel presented the Honorary Diploma to MSU and NNSU for the outstanding results in training the specialists of the highest qualification in the sphere of information technologies. In 2005 Microsoft distinguished NNSU among the top 10 Universities of the world in the sphere of high performance computing. In 2006 the developments of our team were acknowledged among the winners of the Russian contest Intel Multicore Curriculum Program.

In recent years in 2009-2010 several General Agreements of Collaboration “NNSU-Intel”, “NNSU-Microsoft”, “MSU-T-Platforms” were signed. In 2009-2011 MSU jointly with Intel is held All-Russian contest on HPC projects. In 2011 CUDA Research Center was founded at NNSU.

5. Supercomputing Consortium. Our team is among the initiators of creating the Supercomputing Consortium of the Universities of Russia (<http://www.hpc-russia.ru>, see also <http://msu.hpc-education.ru/?q=node/60>). The Consortium significantly influences the development of the supercomputing education in Russia – at the moment more than **35 leading Universities** of Russia are the members of the Consortium.

The objective of the Consortium is to develop and to implement a set of events focused on the efficient usage of the higher education potential for the development and implementation of the supercomputing technologies into the Russian education, science and industry.

The activity of the Consortium is oriented at solving the following major issues:

- Coordination and organization of the interaction among the higher educational institutions of Russia in terms of using and developing the modern supercomputing technologies in education, science and industry,
- Coordination and organization of the interaction among the commercial companies, industrial enterprises and higher educational institutions of Russia in terms of developing and implementing the supercomputing technologies in high-tech sectors of economics,
- Development of educational programs to train highly qualified specialists, advanced training programs and re-training in the sphere of supercomputing technologies and high performance computations.

6. National Supercomputing Education. Our team is among the initiators of the national scientific educational project "Formation of the Highly Qualified HPC and Special Software Specialist Training System" (<http://hpc-education.ru>, see also <http://msu.hpc-education.ru/?q=node/61>). This project was initiated by Rector of the Lomonosov Moscow State University academician Sadovnichy V.A. and was formed in the course of the Russian Federation Presidential Commission Project on modernization and technological development of Russian's economy.

The strategic objective of the project is to create a national system of training highly qualified specialists in the sphere of supercomputing technologies (SCT) and related software.

The most expected results of the project are as follows: the development of the educational programs of training highly qualified specialists in the sphere of supercomputing technologies, creating more than **25 textbooks**, developing **40 training courses**, training **500 specialists** etc. Beyond all doubts, the realization of this project will significantly influence the system of higher education in Russia in the sphere of supercomputing technologies.

To support our proposal there are recommendation letters: Prof. J. Dongarra, Prof. H. Meuer, Academician V. Sadovnichy (rector of Moscow State University, President of the Supercomputing consortium of Russian universities), Prof. A. Terekhov (Saint-Petersburg State University), Microsoft, T-Platforms (one of the leading IT-company in Russia), Russian Ministry of Education and Science, Prof. B. Glinsky (Novosibirsk state University) – first five of them are enclosed.

INFORMATICS EUROPE

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Reference List

Courses

- *Parallel computing* (V.I.V.Voevodin, MSU) - <http://msu.hpc-education.ru/?q=node/52>.
- *High Performance Scientific computing: parallel programming model, tools and performance analysis* (N.N.Popova, V.A.Bakhtin, MSU) - <http://msu.hpc-education.ru/?q=node/65>.
- *Introduction to Parallel Programming* (V.P.Gergel, NNSU) - <http://hpc-education.unn.ru/?id=999>
- *Parallel programming tools* (V.P.Gergel, I.B.Meyerov, et al. NNSU) - <http://hpc-education.unn.ru/?id=1000>
- *New languages for parallel programming* (V.P.Gergel, et al. NNSU) - <http://hpc-education.unn.ru/?id=1001>

Textbooks

- Voevodin V.V. Voevodin V.I. *Parallel Computing*.- SPB.: BHV-Petersburg, 2002. (<http://msu.hpc-education.ru/?q=node/53>)
- Antonov A.S. *Parallel Programming Using MPI*.- M.: MSU, 2004. (<http://msu.hpc-education.ru/?q=node/55>)
- Antonov A.S. *Parallel Programming Using OpenMP*. - M.: MSU, 2009. (<http://msu.hpc-education.ru/?q=node/56>)
- Voevodin V.V., Zhumatiy S.A. *Computing Technologies and Cluster Systems*.- M.: MSU, 2007. (<http://msu.hpc-education.ru/?q=node/54>)
- Gergel V.P. *Theory and Practice of Parallel Computing*. – M.: Intuit, 2007. (<http://hpc-education.unn.ru/?id=1020>)
- Gergel V.P., Meerov I.B. and et al. *Parallel Programming Tools for Shared Memory Computers*. – M.: MSU, 2010. (<http://hpc-education.unn.ru/?id=1015>)
- Gergel V.P. and et al. *Technologies of Parallel Programming for New Architectures Processors*. – M.: MSU, 2010. (<http://hpc-education.unn.ru/?id=1016>)

Conferences and youth educational schools

- MSU youth educational school <http://school.hpc-russia.ru>
- NNSU youth educational school <http://hpc.unn.ru/hpc2010/>
- Russian Supercomputing Conference “Scientific Services and Internet” <http://agora.guru.ru/abrau>
- International Scientific Conference “Parallel Computational Technologies” <http://agora.guru.ru/pavt>
- International Conference and Youth School “High Performance Parallel Computations on Cluster Systems” <http://agora.guru.ru/hpc2010>

Industry Collaboration

- Joint MSU-Intel center <http://msu-intel.parallel.ru>, see also <http://msu.hpc-education.ru/?q=node/57>

- Microsoft Competence Center <http://www.mic.unn.ru/mic/Cooperation/ms-hpcc.aspx>, see also <http://hpc-education.unn.ru/?id=1017>

Education

- Supercomputing Consortium <http://www.hpc-russia.ru>, see also <http://msu.hpc-education.ru/?q=node/60>
- National Supercomputing Education <http://hpc-education.ru>, see also <http://msu.hpc-education.ru/?q=node/61>
- The portal parallel.ru http://parallel.ru/index_eng.html
- Microsoft library of training materials <http://www.microsoft.com/Rus/Msdnaa/Curricula>, <https://www.academicresourcecenter.net/curriculum/pfv.aspx?ID=6594>
- Training teachers <http://hpc-education.unn.ru/?id=1011>
- Teaching via Internet <http://www.hpcu.ru>, see also <http://hpc-education.unn.ru/?id=1014>
- Curriculum of Parallelism and Concurrency <http://msu.hpc-education.ru/?q=node/51>
- Software system Parallel Laboratory <http://hpc-education.unn.ru/?id=1018>
- Collective bank of exercises and tests <http://sigma.parallel.ru>
- Special-purpose intensive training for students <http://hpc-education.unn.ru/?id=1012>