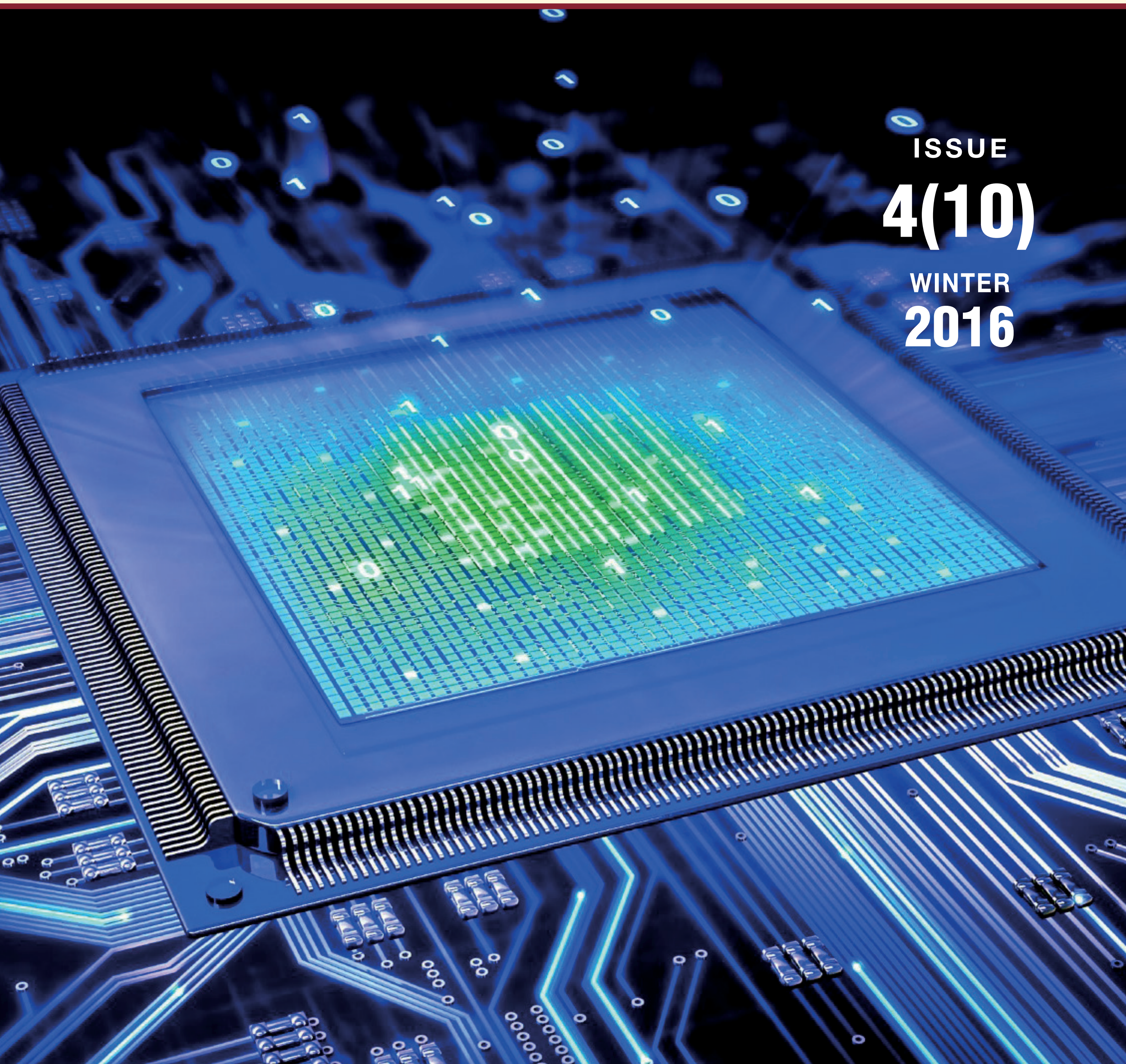
HERB

Higher Education in Russia and Beyond

Computer Science: History of Emerging Discipline



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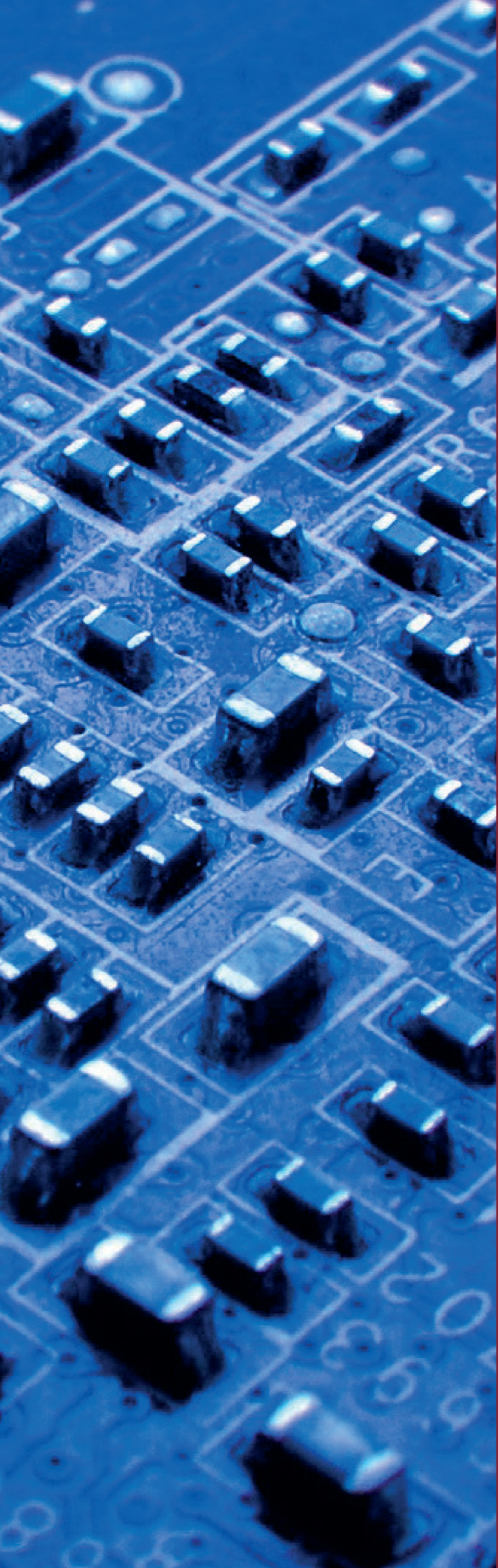

Dear colleagues,

We are happy to present the 10th issue of Higher Education in Russia and Beyond, a journal that is aimed at bringing current Russian, Central Asian and Eastern European educational trends to the attention of the international higher education research community.

This issue is dedicated to contemporary computer science education in Russia, which exhibits some interesting trends. Part one of the issue describes the rise of computing hardware and information technologies in the USSR. This topic is still relevant because in the Soviet times, expert evaluations of the situation in this sphere were rarely made public. Soviet legacy is still tangible in other ex-Soviet countries, for example in Belarus, which is one of the world's leaders in the sphere of IT outsourcing but maintains a largely Soviet-style higher education model.

The second part covers university education. Many comprehensive universities respond to the latest market trends by opening IT education departments and launching new programs in computer science. However, many higher education institutions in Russia are facing a serious problem: the most talented young people from their regions prefer to go to Moscow or Saint Petersburg to study.

The dynamics of IT industry presents another challenge: academic institutions cannot always keep up to date with the changes.

Part three of the issue is dedicated to further education projects and describes the newest approaches to working with high school students, university students and recent graduates used by HEIs, research organizations and commercial companies.

The facts that the educational landscape is very diverse and salaries in industrial companies are high lead to university graduates' lack of interest in post-graduate studies, so in the final part of this issue you can learn more about how research institutes can work with students and universities in the current context.

Higher Education in Russia and Beyond editorial team and guest editor Sergey Zavarin (Analyst at the Faculty of Computer Sciences, National Research University Higher School of Economics)

National Research University Higher School of Economics

National Research University Higher School of Economics is the largest center of socio-economic studies and one of the top-ranked higher education institutions in Eastern Europe. The University efficiently carries out fundamental and applied research projects in such fields as management, sociology, political science, philosophy, international relations, mathematics, Oriental studies, and journalism, which all come together on grounds of basic principles of modern economics.

HSE professors and researchers contribute to the elaboration of social and economic reforms in Russia as experts. The University transmits up-to-date economic knowledge to the government, business community and civil society through system analysis and complex interdisciplinary research.

Higher School of Economics incorporates 49 research centers and 14 international laboratories, which are involved in fundamental and applied research. Higher education studies are one of the University's key priorities. This research field consolidates intellectual efforts of several research groups, whose work fully complies highest world standards. Experts in economics, sociology, psychology and management from Russia and other countries work together on comparative projects. The main research spheres include: analysis of global and Russian higher education system development, transformation of the academic profession, effective contract in higher education, developing educational standards and HEI evaluation models, etc.

Center for Institutional Studies

The Center for Institutional Studies is one of HSE's research centers. CInSt focuses on fundamental and applied interdisciplinary researches in the field of institutional analysis, economics and sociology of science and higher education. Researchers are working in the center strictly adhere to the world's top academic standards.

The Center for Institutional Studies is integrated into international higher education research networks. The center cooperates with foreign experts through joint comparative projects that cover the problems of higher education development and education policy. As part of our long-term cooperation with the Boston College Center of International Higher Education, CInSt has taken up the publication of the Russian version of the "International Higher Education" newsletter.

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The Development of Computing in the USSR in Comparison with the USA and Other Western Countries

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There is a wide spread opinion — both among general public and in literature — that the USSR lived through a "golden age" in the development of computing machines. Some believe that it ended with the collapse of the Soviet Union, others — that its decline began with the start of mass production by IBM (big and medium-sized computers) and DEC (small computers) clones. Yet, proponents of either point of view tend to exaggerate the real (though often indeed prominent) achievements of Soviet computing and to explain the fact that the USSR was lagging behind the West, which had already become obvious by the early 1980s, not by objective factors (common for all Soviet industries) but by "CIA special operations", "fifth column conspiracy", etc.

Unfortunately, the history of Soviet computing is mostly researched by journalists. Usually they receive information not from archives, but former developers directly. Developers, in their turn, recall the past nostalgically and often subjectively. In Russia, there are only few works, which use documentary sources.

Moreover, one should understand that during the confrontation with the West Soviet state propaganda used to exaggerate the country's real achievements while the existence of any problems wasn't just hushed down but actually denied. Therefore, it is now impossible to understand the real picture based on official Soviet sources only. For example, front page of Pravda newspaper for 27 November 1953 contains an article about "Soviet constructors' important achievement": namely, the creation of T-5 tabulator. The article mentioned that the new tabulator was made of 110,000 pieces, contained 5 km of cables, etc., but of course it did not mention the fact that the new machine was inferior to its western analogues built some 15-20 years earlier, i.e., before the war (for example, T-5 could not perform multiplication and division functions). The main goal of such publications or news on radio and TV was to make the audience believe that Soviet computing was prospering.

Documents describing the situation objectively (various reviews, reports or private letters to the highest party and state organs) were classified. Most of them still remain unpublished.

It is difficult to write the full history of the development of Soviet computing in one short text, especially since its top inventions were indeed world-level achievements (e.g., Sergey Lebedev's BESM-6) or had no analogues abroad at all (Nikolay Brusentsov's Setun ternary computer, Israil Akushsky and Davlet Yuditsky's modular computers). So the current paper presents an attempt to analyze various expert opinions on the real state and level of Soviet computer.

The "Short Review on Computing Machines" (which was classified) is probably the first such document. It was released in April 1953 by Special Design Bureau № 245 (SKB-245) of the Soviet Machine Building and Instrument Making Ministry; SKB-245 developed the country's first computer of serial production — Strela. The document contains a rather detailed description of the functional scope of computers and of both Soviet and US developments. I will cite several conclusions made by the authors of the review:

"The Soviet Union has created a base for research, construction and production of domestic mathematical machines… Several types of mathematical machines are currently being developed: those are machines for both universal and specialized use. The analysis of comparable technical parameters shows that there are machines with cutting edge technical parameters are being developed in the Soviet Union. In some cases our constructors choose their own unique ways by creating machines with radically different structural schemes".

It might seem that everything is fine though the authors are not entirely sincere when they write about "cutting edge technical parameters" and do not mention the fact that Soviet engineers often had to find new ways due to severe lack of equipment. Nevertheless, the review continues like this:

"On the whole, the state and tempo of mathematical machine development in the Soviet Union cannot be called satisfactory due to the following reasons. The scale of machine construction is obviously not large enough. There is not enough research… The capacity of the Machine Building Ministry plant involved in the production of mathematical machines is not big enough. The capacity of the plants affiliated with the Ministry of Electrical Power Stations and Electrical Industry is not big enough in terms of the development of certain elements and devices…"

At the end of the review it was mentioned that only some Moscow- and Leningrad-based research centers would be equipped with mathematical machines. Distribution plans did not mention any other of the country's major research or industrial centers.

The document also contains the following figures: in the USA there were 20 machines of 16 types in use; machines of 10 more types were under development. At the same time, in the USSR there were two computers in trial use (one in SKB-245 and one in Lebedev's Institute of Precision Mechanics and Computer Engineering (IPMCE)). It was planned that SKB-245 would develop and produce 9 more machines by 1955 but by 1957 it had managed to produce and install only 7 machines.

A similar review (dated 2 March 1955) was written by Professor Dmitry Panov of IPMCE, who sent it to the Department of Science and Culture of the Central Committee of the Communist Party of the Soviet Union. This classified document contained a detailed description of US computing machines of various types and comparative analysis of Soviet and American machines. The expectations listed in the 1953 review did not come true: by the time the 1955 report was written the USSR only had 4 machines of 4 different types while the US had 2284 electronic computers, including 60 big and 110 medium-sized ones. This led the authors to some rather non-optimistic conclusions:

"The gap between the USA and the USSR in terms of developing digital computing machines and control devices continues to grow. We are behind both in terms of the number of such machines and their parameters, we are also behind in terms of technology and use of computing devices, particularly in the military sphere. The gap in analog machines is smaller… Still, we are behind in this sphere as well in terms of the development of new principles and technologies".

Despite the fact that the number of computing machines in the USSR was growing, the situation in the following years did not change much, and the problems that existed were actually getting worse. In 1967 famous Russian researcher colonel Anatoly Kitov sent an analytic report to Leonid Brezhnev, General Secretary of the Central Committee of the Communist Party, titled "On the State of Electronic Computing Equipment in Our Country." The paper gave a very realistic description of the situation:

"The state of electronic computing equipment development in our country is currently very bad. Our lagging behind the USA and other capitalist countries is not getting any better — on the contrary, it is quickly getting worse. Nowadays there are nearly 30,000 highly reliable computers in the USA, they are equipped with all the necessary external devices and a well-developed system of mathematical software. In our country the development and production of computers is still spread across several ministries whose works in not in any way coordinated; there is unhealthy hidden competition between ministries. We have slightly more than 1000 computing machines, many of which are outdated and inefficient. We have no data input and output devices which would meet demands of the modern world and which are necessary for economic use of computers. Machines are produced without relevant mathematical software and therefore cannot be used efficiently. The situation with magnetic tapes, which are unreliable and cannot ensure long-term data storage, is catastrophic. Still, even such tapes are produced in insufficient quantities… The memory of the machines that are produced is small…"

Such assessment could not be published in mass media of course but on the whole, the country's professional community did understand that despite all official optimism there was absolutely no parity with the US in terms of computers. I would like to cite a curious statement by one of the country's leading researchers that I heard approximately in 1979 at a rather high-level discussion about military use of computers: "There has been a positive trend recently. The rate of our lagging behind the US has stabilized!"

It is widely known that in the post-war years the USSR managed to reach parity with the US in terms of nuclear weapons development and to compete with the US in the sphere of space research until mid-1960s. Yet in the area of computers the USSR was always trying to catch up. For a long time computers were not considered to be crucial for national development; it was believed that this industry was important but lacked independent value.

In the beginning, the development of new-generation computing equipment (i.e., electronic) did not go easily. Even many professionals were skeptical about its prospects, while the industry's management believed that the lack of machines could be compensated by additional resources, i.e., people equipped with arithmometers and desk calculators. So, the first stages of research were conducted by teams of self-motivated scientists who had to operate despite lack of financial and material resources.

When scientists finally convinced the country's leadership that a number of computing machines would be required for the development of nuclear weapons and means of nuclear delivery, anti-ballistic missile systems and missile attack warning systems, such machines were indeed created. The country had enough resources, including scientific talent, to maintain parity with the US in these crucial areas.

There was, however, no parity whatsoever in terms of civil use of computing equipment. There were no economic or social conditions for the promulgation of cheap yet high quality computers in the USSR, so computer revolution of the late 1980s caught the country unawares. Serious social cataclysms that followed soon afterwards led to the fact that the gap with the West in the sphere of computer development was removed from the agenda for a long time.

Some articles on Soviet computing

Crowe G. D., Goodman S. E. S. A. Lebedev and the Birth of Soviet Computing // IEEE Annals of the History of Computing. 1994. Vol. 16. № 1. Pp. 4-24.

Brusentsov N P., Ramil Alvarez J. Ternary Computers: The Setun and the Setun 70 // Perspectives of Soviet and Russian Computing. IFIP AICT, vol. 357. Springer, 2011. Pp. 74-80

Malashevich B. M., Malashevich D. B. Modular: The Super Computer // Perspectives of Soviet and Russian Computing. IFIP AICT, vol. 357. Springer, 2011. Pp. 164-173.

Davis N. C., Goodman S. E. The Soviet Bloc's Unified System of Computers // Computing Surveys. 1978. Vol. 10. № 2. Pp. 93-122.

How Is the Success of Belarusian IT Industry Related to Higher Education System Development?

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Cooperation between industry professionals and academics is nearly universal. Industry leaders representing various scientific fields work together with educational systems in order to find highly qualified young staff for their companies. In this respect, the Republic of Belarus is a particularly interesting case.

Belarusian IT industry products, such as World of Tanks, Viber and MSQRD, are well-known all over the world; applications released by Apalon are continuously high-positioned in App Store, Google Play and Amazon Marketplace. Besides that, Belarus is one of the world's leaders in terms of IT outsourcing. The country's IT companies rank high in global ratings. Six Belarus-based developers (Ciklum, EPAM, IBA Group, Intetics, Itransition and Bell Integrator) were ranked in the 2016 Global Outsourcing 100 by IAOP. In 2015, 9 Belarusian IT companies were mentioned in the Software 500 rating published by Software Magazine, one of the most influential periodicals in the world of global hi-tech industry.

At the same time, unlike the country's IT industry, its educational system — in particular, in the sphere of IT education — is not that famous or successful. We cannot say that Belarusian IT education is of low quality, of course, but it has not achieved the same success as the country's professional industry.

Belarus State University (BSU), for example, is the country's only higher education institution listed among 978 other HEIs in THE World University Rankings 2016-2017. BSU ranked 801+. The results of many international rankings show that former Soviet countries cannot really be called global higher education leaders. However, speaking of HEIs located in the Community of Independent States (CIS) and Belarus' other neighboring countries, THE World University Rankings 2016-2017 also included 2 Lithuanian, 2 Latvian, 2 Estonian, 4 Ukrainian, 9 Polish and 24 Russian HEIs. THE BRICS & Emerging Economies Rankings 2016 top-200 lists Lithuanian, Polish, Estonian and Russian HEIs but none from Belarus. QS ranking offers similar results. Only 2 Belarusian HEIs were listed in QS World University Rankings 2016-2017: BSU (ranking 354) and Belarus National Technical University (ranking 701+), while neighboring countries were better represented (2 HEIs from Estonia, 4 from Lithuania, 6 from the Ukraine, 6 from Poland, and 22 from Russia). In QS University Rankings EECA 2016 the country's best HEI (BSU) was listed 39th — below 10 Russian, 3 Polish, 2 Estonian, 1 Ukrainian and 1 Lithuanian universities.

Belarusian IT education can hardly be called a driving force of the country's academic community. 1 Estonian, 5 Polish and 7 Russian universities are listed in the top-500 of QS Computer Science Ranking but no single Belarusian one. THE Computer Science Ranking Top-100 includes 2 Russian universities.

Naturally, the results of international rankings do not allow us to judge definitively on the quality of higher education but at least let us draw some conclusions on HEIs' visibility and academic performance.

Speaking of the latter, in 2006-2016, scholars with a Belarusian affiliation published 1314 Scopus-cited papers of the following types: Article, Article in Press, Book, Book chapter, Conference Paper, Review. Just to compare: during the same period there were 1838 Latvian, 2405 Estonian, 2858 Lithuanian, 9784 Ukrainian, 26929 Russian and 36582 Polish papers published.

Belarusian higher education system does not compare favorably to those of its neighbors. Therefore, it is only reasonable to ask: is the success of Belarusian IT industry related to the performance of the national higher education system? Or is it defined by totally other factors whatsoever?

In order to answer these questions, we can identify several key factors of IT industry development and try to assess their impact by analyzing expert statements by the representatives of IBA Group, winner of 2016 EOA Awards. IBA is listed among The Global Outsourcing 100 and Software 500. The company also has first-hand knowledge of the national higher education due its cooperation with BSU, Belarusian State University of Informatics and Radioelectronics (BSUIR) and Francisk Skorina Gomel State University (GSU).

Soviet IT System Legacy

Ivan Piletski (PhD in physics and math, Chief Specialist of the Department of Data Processing IBA IT Park and Scientific Director of the joint laboratory of IBA-BSUIR) believes that the basis for IT industry development in Belarus was laid in the Soviet era. "Even back in the Soviet times information technologies were a kind of "trademark" for the Byelorussian Soviet Socialist Republic. Specialized IT departments and faculties were created at leading Belarusian universities more than half a century ago. In 1964, a specialized HEI — Minsk Institute for Radioelectronics (now BSUIR) was founded", — says Piletsky. IBA founders (established in 1993) included, besides IBM (which left in 1998), the country's major IT organizations — all going back to the Soviet times, such as Research Institute for Electronic Computing Machines (known by its Russian abbreviation NII EVM) and Minsk Plant of Calculating Machines named after S. Ordzhonikidze.

After the collapse of the USSR IT industry in Belarus ceded ground. However, it was approximately at the same time that a number of companies now famous in Central and Eastern Europe were founded, including EPAM, IBA and — later — Itransition, System Technologies and others, which began working in IT outsourcing and became a king of "life safer" for the country's IT specialists, many of whom were then basically unemployed. That was probably the moment when Belarusian IT started to work in a new direction, namely IT outsourcing for the West, and when the industry's revival — which could also be called a birth of a "new formation" of Belarusian IT industry — began.

Support from the State

Inna Igontova, IBA Head of Corporate Marketing Department, agrees that the state has contributed a lot to the development of national IT industry: "Belarusian IT is a national brand, it shapes our country's image. It is one of the few industries which, being a global exporter, managed to keep the volume of output and output growth at the same level despite the global economic crisis. Our nation's economic development has to rely mainly on intellectual resources, which Belarus has always been rich in, but poor in natural resources."

Belarusian IT sector has indeed been receiving substantial support from the state. In the early 2000s, discussions about establishing a kind of local Silicon Valley began and in 2006, Hi-Tech Park (HTP) was opened. Its residents are free from corporate taxes and customs duties, while individual income tax rate is 9% for private persons (vs 13% in the rest of the country) and 16% for self-employed entrepreneurs.

Low Salaries in Other Sectors

According to Belarus National Statistics Committee (Belstat), face gross average wage for January–September 2016 was 713.9 Belarusian rubles (about USD 373), while in the IT sector this indicator equaled 3504.6 Belarusian rubles (about USD 1834.6), i.e., five times more than national average. IT is the most well-paid sector in Belarus.

Is it reasonable to assume that Belarusians, whatever their educational background is, try to find employment in IT companies and that in the end quantity becomes quality? In any case, IBA representatives disagree that this might be the major reason for the industry's success. "IT industry is indeed one of the most attractive sectors for Belarusians looking for a job. However, it would not be right to think that the industry is thriving due to lack of competition in other sectors," – says Piletsky. He continues: "No one — be it in Belarus, Russia or in the West — will just offer you a big salary. HTP residents' main customers are Western companies. IT industry works for specific customers, on specific tasks".

Higher Education

Belarusian higher education system bears a substantial Soviet legacy, so many people believe it is rather outdated. Belarus only joined the Bologna Process in 2015, for example, while Russia did it in 2003, Ukraine — in 2005, and Latvia and Lithuania — in 1999. Belarus is one of the few post-Soviet states where the system of obligatory job placement for HEI graduates is still in place. After graduation those whose education was paid for by the state have to work for two years for their alma mater's partner organizations (public or private, depending on their field of study). Moreover, university curricula feature a lot of non-core subjects, such as national ideology, history of universities and higher education, etc.

Still, IBA representatives do not fully agree. They believe that the fact that the country has joined the Bologna Process is indicative of national higher education system's competitive ability. Piletsky wonders: "What's bad about the system of obligatory job placement, when young professionals get a chance to apply and multiply their knowledge instead of losing skills while looking for a job?" He continues: "With the system of obligatory job placement young professionals get guaranteed employment and professional experience. Non-core courses are indeed often part of the curriculum. This can be regarded as extra workload, which is not good and which students are not happy with. On the other hand, no knowledge can ever be useless. It is necessary to optimize university curricula but through a balanced approach".

Olga Bogdel, IBA Head of Human Resources and Staff Adaptation Department, believes that the company's demand for young professional is fully covered by Belarusian HEIs: "Our cooperation with the country's leading HEIs includes establishing joint labs, training students, providing HEIs with Internet equipment, providing training in the use of new technologies and products at a discounted price, organizing joint workshops, participating in the educational process, doing trainings for HEIs' academic staff, etc. As part of the cooperation with BSU, BSUIR and GSU IBA Group has founded 7 computer labs, opened teaching and research labs, founded Academic Center for Technological Competencies at BSUIR, where IBM technologies and products are taught, and launched the joint BSU-IBA Center. We support BSU's membership in SAP University Alliances — a global partnership program between SAP and HEIs. All of this helps students broaden the knowledge they acquired during their studies".

IBA representatives largely do not agree with a negative view of Belarusian higher education. To counter Scopus data, they cite the results of international coding competitions, such as ACM/ICPC. Belarusians traditionally rank high in such competitions: for example, BSU team finished 2nd in 2012-2013, 14th in 2014, 15th in 2015, while BSUIR team took the 3rd and 17th places in 2012 and 2016 respectively. The total number of participating teams varies between 120 and 128.

Still, IBA leadership acknowledges the fact that there are some problems: "On the whole, our HEIs are of rather high quality though not devoid of problems, just like in other CIS countries. One of the main issues is ageing academic staff. It is yet unclear how this could be solved in the current situation, given the fact that IT professionals who could teach prefer working in the industry due to differences in salary levels. This is why IT companies, which are interested in new, highly qualified young staff, participate in the educational process. We spend a lot of efforts on this. We believe that the situation with staff turnover here in Belarus is no worse than at our neighbors".

On the whole, the question of cooperation between higher education and professional industry is rather broad and requires extended research before one can draw substantiated conclusions. Nevertheless, Belarus is an interesting case because it has managed to develop world-level IT products and create its own "Silicon Valley" despite the fact that it has no MIT, Stanford or Harvard.

How to Launch an IT Faculty at a Comprehensive University: Case of Higher School of Economics

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National Research University Higher School of Economics (HSE) is well-known both nationally and internationally for its achievements in the sphere of economics and social sciences. For example, according to QS World University Rankings by Subject 2016 HSE became the best Russian university in such fields as Economics & Econometrics, Sociology, Business & Management Studies, and Accounting & Finance.

In March 2014 HSE — together with Yandex, major Russian IT company — opened its new Faculty of Computer Science (FCS). This came as a result of structural reforms in the university aimed at expanding existing faculties and creating "big" ones that would be responsible for the delivery of educational programs. So, FCS united several previously isolated departments that had to do with informatics, applied mathematics and software engineering. Создание факультета стимулировало предложение Яндекса — в наличии у компании имеется большой опыт взаимодействия с российскими вузами, а также реализации собственных образовательных программ.

A number of basic questions need to be answered when creating a new faculty: whom will it train? What should students be taught and how? What spheres will alumni be sought after in? How can one recruit the best students and academic staff?

The issue of developing a competitive educational program is so extensive that there is a separate paper about is. We will try to answer all the other questions in the present paper using FCS as an example.

Who Does FCS Train?

Many young IT students in Russia start working in their third year already. It is therefore reasonable to ask: why study for four years at all? Indeed, training a "coder" takes two years but such a professional would only be able to solve basic tasks and could only start studying some specialized field.

FCS aims at training research engineers and software developers, i.e., specialists with deep knowledge in one of the areas of computer science who would be able to find new solutions and develop new algorithms. FCS alumni are expected to obtain a number of competencies that can be summed up as follows:

1. Coding skills, i.e., the ability to develop an elaborate software product both individually and as part of a team;
2. Knowledge of the branches of mathematics that are fundamental for computer science and ability to handle mathematical concepts;
3. Mastery of a specific area of expertise and ability to solve tasks within a specific application domain;
4. Fluency in English that is necessary for professional work in an English-speaking environment.

The first two mentioned items are definitive in terms of the learning basis that the students have to master first. Together with the English language this constitutes the core of what undergraduates study in the first two years. Years three and four are dedicated to specialized courses and research skills. Some of the courses can be taught in English, which allows students to gain practical experience in another language.

Understanding this logic makes it rather obvious who FCS aims at training. FCS alumni would be sought after in the IT industry as well as by other companies with large research or processing departments (banks, telecommunication providers, etc.). Such selection allows one to map out the companies whose vacancies could be analyzed when outlining requirements for alumni.

How to Recruit Talented Students?

Face-to-face contact is very important when working with prospective students. No leaflet will ever have the same effect as, for example, an open lecture by one of the academic staff where prospective students can see everything for themselves and ask all the questions they want.

In Russia, high school students who are good in math, informatics or physics traditionally show their best during various Olympiads and competitions — most of them but not all because not everyone has a taste for competitions. Therefore, when the new faculty was launched, we promoted it not only during Olympiads, summer schools, camps, conferences, math tournaments, etc., but also organized presentations at math-oriented schools that were not part of any specific events. What is challenging about such work is that prospective students aren't too interested in a typical presentation of any undergraduate program. In order to grab their attention, we told them about some real-life problems that are solved with the help of machine learning, algorithms and other scientific fields and that are taught at our faculty in particular.

Besides presentations we also used other ways of reaching our prospective students, such as publications on relevant websites (codeforces.com, groups in social media) which are often visited by our target audience. We organized our own events for prospective students too, such as Computer Science Days (offering a broad range of lectures and workshops by industry professionals) and Open Days (when we talk in detail about our undergraduate programs, our students' prospects, etc.).

It is also important to talk about our faculty not only with prospective students themselves but with people who have a significant impact on them too — i.e., their parents and school teachers. Parents need to understand what our alumni's career prospects are — regarding both those who want to work in the industry and those who want to do research.

We were trying to work closely with the media in order to build up a brand within the university that at the time was not yet known well enough in the sphere of computer science and had to compete with such titans of engineering education in Russia as Moscow State University and Moscow Institute of Physics and Technology.

Moreover, we organize our own conference for teachers from regional schools where we talk about modern technologies. It is important that our students participate in the conference and hold workshops for the teachers so that the latter can see who their current students will be studying with — should they be admitted to our faculty.

It has already been mentioned above that we work with high school students who participate in Olympiads and other kinds of competitions. We also work with school teachers who have helped organize such events and who teach the country's best young people. We listen to their feedback about our ideas and about the way FCS educational process is structured and try to incorporate it in our work. We believe it is the best way to show that our faculty is willing to evolve and improve its quality.

How to Find Academic Staff?

The task of finding academic staff can be split into two subtasks: finding "theoreticians" — those who would teach math and theory of informatics, and "practicians" — those who would teach coding and applied courses in computer science. These are two quite separate tasks. Luckily, there are quite a lot of highly qualified theoreticians in Russia and in Moscow in particular with proven experience in academic advising and a desire to teach. Such people can either teach courses that are part of the curriculum or work within separate research groups and labs.

HSE has an efficient system of bonuses that are paid for articles published in leading international journals. Staff members whose students win in research competitions and who are awarded Best Teacher title as a result of student vote receive similar remuneration.

Experts working in the practical field are more difficult to engage into teaching process. Highly qualified professionals are usually employed in the industry or in centers of applied research, therefore it is difficult to get them to agree to regular classes. The university should be willing to provide comfortable working conditions for such people, i.e., employ them part time or offer contract work and understand that these people are not very keen on writing academic articles and can only devote limited time to teaching.

In this sense, what works well is the system of specialized departments that exist at various faculties and are founded by academic institutes or commercial companies. Practice-oriented teaching staff are seeking to create a group of active students who would be interesting to work with and who could be engaged in the former's ongoing real-life projects. Our experience shows that some of the industry people have a drive for teaching and actually feel enthusiastic about it. It is pure luck when we manage to find such people and offer them a moderate teaching load in their area of interest.

What is common about the two subtasks mentioned is our students' qualifications and their motivation to study the field they have chosen. Keen teachers are interested in working with students who are able to understand and to master what they are being taught. If a teacher encounters students who do not understand what they are being taught or do not want to study, no additional stimuli, including financial ones, will help keep him or her within the faculty for long.

In other words, by recruiting talented students we also to a large extent solve the problem of finding highly qualified academic staff.

Results

FCS currently has two undergraduate and four master's programs. FCS is expanding: in 2016 we enrolled 370 freshmen vs 324 in 2015. The number of academic staff has nearly doubled in the past year and reached 150 teachers. In total, there are over 1200 students (including master's and postgraduate) enrolled at FCS in the academic year 2016/2017.

It is also important that we now have better qualified students. For example, in 2014-2016 per subject GPA of the freshmen enrolled at Applied Mathematics and Information Science program for the Unified State Examination grew from 93.1 to 94.2 to 96.5 respectively, while at Software Engineering program it grew from 92.4 to 92.0, to 94.9.

Each year there are more and more winners of various Olympiads among the freshmen, and we work quite a lot with them. In 2014, FCS admitted 13 of the winners of the final round of the All-Russian Olympiad in Informatics, Physics and Mathematics, 14 in 2015, and 22 in 2016. Same goes for first-level Olympiads winners: in 2016 we admitted 96 such applicants, in 2015 — 101, and in 2016 — 141.

Applied Mathematics and Information Science: How to Develop a New Educational Program in Computer Science

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When developing a new educational program, it is vitally important to study similar curricula already in place at other universities, both Russian and abroad. When it comes to computer science (CS) — there is another important source of information, namely Computer Science Curricula recommendations by the Association for Computing Machinery (ACM) and Institute of Electrical and Electronics Engineers (IEEE). These recommendations cover the courses that are believed to be crucial for CS education. The curricula have to be checked against the requirements set for the alumni eventually.

We will use bachelor's program Applied Mathematics and Information Science offered at the Faculty of Computer Science of Higher School of Economics as an example to show in what ways Russian CS programs differ from international ones, how such differences can be used to strengthen one's competitive position, how to manage the problem of freshmen's level of qualification, and how to arrange efficient project work.

The Particularities of Russian CS Education

Comparative analysis of Russian and foreign CS programs reveals several interesting differences. First of all, Russian programs imply a much higher workload than most foreign ones, which allows more time for extra study courses and other components, so Russian students also earn significantly more ECTS-points. Secondly, Russian programs are traditionally much more math-oriented: the country's leading CS programs take roots in mathematical departments, so the time spent teaching such classical disciplines as mathematical analysis or linear algebra has remained more or less the same. If at Stanford the obligatory part of the curriculum is half math, half computer disciplines, at Russian universities the total volume of computer disciplines is the same while math workload is twice higher.

A lot of math subjects is a significant advantage but this is not necessarily the case in practice. Actually, basic training in computer science has to differ from professional mathematicians training yet this is not always true for some Russian programs. Our goal was to bring this advantage to life in the first years of study by prioritizing math disciplines most relevant for computer science, e.g., discrete math, probability theory and mathematical statistics. At the same time, we manage to teach enough computer disciplines in accordance with Computer Science Curricula recommendations thanks to the fact that our program encompasses more than many foreign ones.

Elective Courses

Another important difference between Russian and foreign programs lies in the range of elective courses. Each area of computer science requires a specific set of courses, so the curriculum for the final years of study has to be as flexible as possible.

Traditionally in Russian universities curricula are department-based, i.e., one department within a given faculty is responsible for one particular educational specialization and, therefore, develops relevant curriculum. At CS programs, in addition to the courses offered by specific departments there are usually also some general obligatory and elective courses, with little time allocated for them. Another typical situation is when obligatory courses do not match departmental specialization due to the fact that it is impossible to find courses that would match all specializations.

In American universities, however, curricula are composed for each student individually. Students have to earn a certain number of credits, they have a wider choice of disciplines and are allowed substantial flexibility in deciding when to take which course.

Such flexibility is possible due to decreased obligatory workload requirements, lower contact hours, and a decrease in the number of courses to be taken simultaneously. The way of teaching is usually more intense and course duration is usually shorter (about 2 months).

We found a compromise by combining specialized (i.e., department-based) courses with a lot of elective courses. The former are given the same amount of time as the latter. Elective courses are divided into spring and fall blocks, so students can choose to take them either in their third or fourth year. The number of obligatory courses is minimal.

Final Projects

US university curricula always include a final project, which is similar to bachelor's thesis in Russia. Students also have to work on various yearly projects for many classes. Besides final projects, Russian curricula sometimes include interdisciplinary yearly projects that are not related to any specific discipline. There is also a system of research workshops which students are assigned to when choosing a specialization or academic supervisor.

When should students start to engage in research? There is no unique question to this answer. Higher School of Economics believes that it should be done as soon as possible, so even freshmen already have to complete a yearly project. Our experience shows that very few first-year students are capable of doing research in computer science due to lack of theoretical knowledge and practical skills. By the end of the first year students learn enough to be able to code. Interest for research develops when they choose a specialization. We have adopted the following system: second-year students have to complete a programming project, while third- and fourth-year students have to do a yearly project and bachelor's thesis respectively; they can choose between applied and research-related topics.

First-years' Varying Level of Qualification

Another important feature of the Russian education system that needs to be taken in account while planning curriculum is heterogeneity of first-year students in terms of their level of qualification. The system of high school math training in Russia, which dates back to the Soviet times, is traditionally very good: there are quite a lot of special math-oriented high schools where respected scientists often teach; many high school students participate in various Olympiads. Soviet — and later Russian — high school has always been well represented at numerous international competitions. On the other hand, many regular high school graduates who have not had special training in math successfully pass university admission exams.

This means that freshmen's entry level varies significantly: graduates of math-oriented schools often know most of the university curriculum for the first two years, while other have to start from scratch when it comes to math. It is therefore difficult to teach the two groups together because they actually need to be taught different things.

We have tried two solutions to this problem with Applied Mathematics and Information Science program students. First, with identified a "pilot" group of students with advanced understanding of math among 2014 freshmen. In order to be selected, students had to do a test. All the students took the same lectures but the pilot group could attend separately organized practice-oriented classes where they were offered more difficult tasks. Such a solution helped us optimized the process of teaching but could not solve the existing problem in full. When all the students take the same lectures, there is little flexibility when it comes to deciding the sequence of topics to be discussed. Moreover, it turned out to be difficult to make the lectures equally interesting both for specially-prepared and regular students.

Later we tried another approach: we formed several pilot groups, who had their own lectures, which made it easier to adapt the contents to students' needs. Such an approach gives students more flexibility in choosing what they want to study more deeply. Pilot groups can differ in terms of the practice-oriented classes they are taking.

It is also possible to identify groups that would go for in-depth study of parts of the curriculum. This is actually makes a lot of sense at our program: we formed an advanced math & informatics pilot group, an advanced math group, and advanced informatics groups. The first and the second groups take the same lectures on math, while the first and the third groups share the same lectures on informatics. Our experience shows that this approach works best.

Such a system has another advantage: students have more freedom in choosing their priorities and, therefore, time management. It also allows us to handle well-prepared students more effectively. However, this implies more complicated logistics, especially scheduling.

Individual Projects

Since software development training is one of our program's goals, we can add project work to the usual computer science disciplines, so that the students get a chance to use their knowledge in practice, to see whether it is relevant in real life, and to identify the areas where they see room for improvement for themselves.

We believed from the very beginning that students should be involved into project work as soon as possible, in their first or second year already, and as often as possible. The idea was that by giving only classical homework one can only test basic skills. Let's draw a comparison: architecture students are given separate home tasks to design rooming plans, electricity schemes, etc., while in real life one has to design all the systems and details at once. One cannot learn to develop a complete product within the framework of traditional higher education, which does not include project work, by only designing separate elements.

We use the following approach: in their second semester first-year students get to develop an individual software product under the supervision of a mentor who represents either the industry or academic circles. In the end, they have to develop a program with an interface that can be used anywhere by anyone, i.e., in the browser, on the smartphone or just in command line. In any case, the product has to imply some interaction rather than just be some project report.

Our students have been developing both research- and industry-oriented projects in the sphere of neural networks and machine-based learning. The results of their work include games, financial apps, social media analysis, synthetic vision systems, bioinformatics, etc. One of the most impressive examples is our first-year students' AlphaGo-similar project: an end-to-end system that teaches itself backgammon. We believe that the quality of projects is rather high but we have postponed the start of project work to the second year so that the students can learn more before they begin.

Team Projects

We have recently decided to expand the scope of project work. As of this year, third- and fourth-year students can also participate in team projects as an alternative to the traditional yearly projects. Team projects proposals come from IT companies, who are therefore really interested in their success. The companies also assign team mentors who understand how industrial team programming is organized. Mentors will help students with managing their work, teach them team work principles and skills, and monitor and review the results.

We were initially planning to start this as a small experiment with 4-5 companies launching projects for 4-5 participants each. The companies turned out to be much more responsive than we had expected, so in the end 10 such projects were launched in November 2016. It is still too early to say anything about the results but the interest on behalf of both IT companies and students is quire surprising. We believe this is very beneficial for our faculty.

First of all, we get a chance to introduce team work in realistic conditions as part of the educational process, which would have been difficult to organize otherwise. Secondly, participation in such projects provides students with a small extra income, so they have less need in working alongside their studies, which can often be harmful for their academic performance. Finally, this is a wonderful opportunity to introduce our students to IT companies, to show their real qualifications and to attract the attention of potential employers. This has a positive effect both on our graduates' career prospects and our reputation.

Results

Our program aims at training researchers, R&D engineers and product engineers in the sphere of theoretical and applied informatics. It was developed based on the experience of EPFL (Switzerland) and Stanford University (USA), as well as Yandex Data School, which focuses on data mining and big data processing, machine-based learning, etc.

Our program was only launched two years ago, which is of course too little to make any substantial conclusions about whether we have managed to reach our goals or not. Our students often become interns at famous companies like Yandex, Facebook or Google, and participate in international CS conferences. This, together with the industry's interest in project work with students, gives us a signal that we are going in the right direction.

Institute of Mathematics and Computer Sciences at the Ural Federal University: Outflow of Applicants to Moscow and Saint Petersburg

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Russia is characterized by an important feature that has vast influence on education and other spheres of life — namely, uneven territorial distribution of population. According to the Federal Statistics Service (Rosstat), 70% of the population of Russia, which equals 146.5mln people, live in the European part, which in its turn equals only to one-fifth of its territory.

It is worth noting that 1/8 of the overall population is accumulated in just two cities: Moscow (12.3mln according to Rosstat data for March 2016) and Saint-Petersburg (5.2mln). This is official data, which means it does not include illegal migrants and people from regional towns who travel to the two major cities every day.

This trend is also mirrored in educational processes. Most university applicants from regions of Russia tend to be admitted to higher education institutions of Moscow and Saint Petersburg. Thus, according to the Monitoring the Quality of Enrollment in Russian Universities conducted by National Research University Higher School of Economics (HSE), in 2014 the share of non-local first-year students in Saint Petersburg was the biggest in Russia – 68%. Moscow took the second place in this list. At the same time, only the 2% moved out from Moscow and Saint Petersburg to study.

Subsequently, one of the most important tasks of regional higher education institutions in Russia is to keep applicants in their region. Applicants for IT disciplines are no exception from this trend, and they reflect it very vividly. In 2016 there were eight universites in Moscow and Saint Petersburg offering public funding to students among the top-10 in terms of enrollment quality for the group of programmes related to business informatics, seven for computer science, and another eight for information security.

Apart from this, there are more career opportunities for graduates in the two main cities, which is also a great incentive to stay. According to CNews, one of the most cited and competent IT-related news portals in Russia, only 17 out of a hundred most profitable IT-companies in Russia have their head offices outside Moscow or Saint Petersburg, and out of 30 most profitable — only one.

This article explains the outflow of university applicants within the sphere of IT to Moscow and Saint Petersburg using the example of the Institute of Mathematics and Computer Sciences (IMCS) of the Ural Federal University.

In 2016 IMCS was ready to admit 210 students to IT programs. Average Unified State Examination (USE) score per subject was 81.6 out of 100. The most popular program this year was Fundamental Informatics and Information Technologies. It attracted 60 applicants, whose average USE score was 87.3. For a regional university this is a very good result despite the fact that in leading higher education institutions of Moscow and Saint Petersburg (such as Moscow State University, Saint Petersburg State University, Moscow Institute of Physics and Technology, etc.) this indicator usually varies from 90 to 95.

Yekaterinburg is an informal capital of the Ural region, a city of advanced industry and a relentlessly growing population (currently 1.4mln). There are quite a lot of IT companies in the city, which creates good employment opportunities for IMCS graduates. Moreover, companies are interested in employing new minds, so they organise various Olympiads for university and high school students together with IMCS and participate in teaching.

Educational process there is based on very strong fundamental training in mathematics. As a result, those who meet the standards and manage to graduate (usually approximately 70% of the students) gain very strong competitive advantages for their careers. Also there are reputable professors working for IMCS, such as Mikhail V. Volkov (one of the few professors participating in the grant program of the Ministry of Education) or Arseniy M. Shur (one of the world leading specialists in string processing), as well as highly qualified international guest lecturers and professors (for instance, one of the creators of the CSS standards Håkon Wium Lie, Chief Technology Officer of Opera Software).

There are also a lot of opportunities for IMCS students to test their skills: regional team programming championships, local individual programming championships, information security competitions. Students are successfully involved in scientific work: they publish in respected scientific journals and participate in international conferences.

To prepare for IMCS, secondary school students in their 7th year or later can attend the School of a Young Mathematician. There is also School of Olympiad Programming and IMCS holds an annual regional team Olympiad for high school children.

However, despite such extensive work and even though IMCS attracts many bright students from different parts of the Ural region, there is still an outflow of applicants that is quite hard to fight.

In 2016, seven senior year high school students won diplomas of the regional round of the All-Russian Academic Olympiad for School Students in informatics, and only three of them chose IMCS, while the others left the region. In 2015, 16 senior year high school students won similar diplomas but only nine stayed at IMCS.

According to the data of the Specialised Science and Learning Center of the Ural Federal University, in 2016 only 105 of the Center's senior year students chose Ural Federal University, which is only 48.6% of the Center's students. It is known that 40% of them moved to study to Moscow and Saint Petersburg.

Looking at other good schools of the region it is possible to conclude that roughly about the half of all students their choose one of the two aforementioned regions. However, together with this outflow, there is an inflow of applicants from different parts of the Ural region: many good students still find it reasonable to stay closer to home.

It is hard to determine what groups of applicants in terms of specialisations they choose are more inclined to move to Moscow or Petersburg as too many factors are at play: streams of applicants may often be heterogeneous within one specialization or one region. This question requires further research. Moreover, such factors as the universities' level of selectivity, their approach to working with applicants and educational formats (applicants from Moscow usually have higher financial ability to pay for education in comparison to applicants from other regions) can be significant. For instance, at Higher School of Economics, which offers 34 educational programmes, Muscovites admitted in 2016 made 52% of the overall number of first-year students, 43% of the total number of state-funded freshmen and 59% of self-funded freshmen.

Among the students admitted to the Faculty of Computer Sciences (teaching Applied Mathematics and Informatics, and Software Engeneering), Moscow was represented by 44% of first-year students, 32% of state-funded freshmen and 56% of self-funded freshmen.

On the other hand, at Moscow Institute of Physics and Technology that only offers education in mathematics, physics, and informatics, the number of students from Moscow admitted to the first year rarely exceeds 20%, which, however, might in part be explained by the fact that it is located in Moscow region, outside Moscow city, which officially constitute two separate regions.

Consequently, the only thing that is certain is that Moscow and Saint Petersburg remain attractive for applicants from all over Russia, mostly because of university brands there and bright career prospects. Are other motivational factors significant? Do IT applicants differ in their behavior? Both questions are open for debate.

Computer Summer School: Bringing School Teachers, College Teachers and IT Industry Professionals Together

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IT industry advances very fast: it often happens that by the time young people find a job, the information they learnt at school or college is already outdated. This is why IT companies often offer internships to retrain young staff. They also have to participate in secondary and post-secondary education, otherwise they would soon experience staff shortage.

Colleges are often disappointed with the applicants' level of qualification too. One of the major reasons behind this is lack of interaction mechanisms between secondary schools, colleges and employers. The concept of a summer school actually implies cooperation between school teachers, students, college professors and industry professionals, which allows them to find common ground, if only on a small scale.

There are various summer schools on a wide range of topics but they often follow similar organizational principles. Secondary school students have to write an application; if it is successful, the applicant can join the summer camp. There are classes every morning. At the end of the summer school the participants have to take a test.

Computer Summer School (CSS) is aimed at 12-17-year-olds who want to learn coding.

How CSS Is Organized

CSS takes places in the countryside at a recreation facility; there are two 21-day-long sessions. At each session there are about 250 participants of varying qualifications: some are beginners in coding, some are the country's smartest students.

CSS applicants have to fill in a special form and solve an admission test. In the application one has to indicate what topics he or she is familiar with and what algorithms he or she can already write. The way the problems presented in the admission test are solved indicates how well the applicants actually know the topics they have mentioned.

CSS is conducted in Russian but this is the only restriction for participation: secondary school students from all over the world are welcome. Traditionally participants come from all over Russia as well as from other former Soviet countries. There have also been participants from Bulgaria, Sweden, Italy, U.K. and U.S.

Participation costs about 40,000 rubles (650USD) per session. Those who cannot afford to pay the fees in full can apply for a partial waiver, which is possible thanks to CSS sponsors.

Education at CSS

Computer science is the core of CSS educational program: it includes algorithms, data layout, methods of data organization and analysis, skills for writing reliable code and testing it.

The fact that school teachers, professors and industry professionals work together allows to split the participants by level and field of study: they are divided into three parallel groups upon admittance. Group D is for beginners, they study easy topics: Euclidean algorithm, binary search and quadratic sort. Group A is for the most qualified students, e.g., participants of the International Olympiad in Informatics. Group A studies, for example, suffix arrays and Dinic's algorithm for computing the maximum flow. Besides the two algorithm groups there is also group P with a focus on industrial software engineering. It is a small start-up. During CSS session group P works on its own unique project. Participation in group P helps train teamwork skills and provides an opportunity to work on a real task.

In the morning, before lunch, there are compulsory classes: two hours of theory and two hours of practice. Computer labs stay open from lunch till dinner so that the participants can further work on their projects. In the first two hours after lunch there are optional courses: short lectures on a broad range of topics which usually aren't directly related to CSS curriculum, e.g., physics, math, medicine. Lectures are organized by CSS guests and by representatives of the sponsors. After that students can take part in recreational activities: join the drawing club, guitar club or movie club. There are 3-4 optional courses and 3-4 different clubs every day, so the participants are free to choose what they find interesting. After dinner there are extra activities where everyone can participate: games for the brain, campfire, theater, social dance, etc. Various sports competitions (from volleyball and football to chess) are also organized during each CSS session

In the end the participants have to take a theoretical test and a practical one. They get two days to prepare for the test. In this period there are no classes; yet, computer labs stay open, and the students are free to seek advice from CSS academic staff. It is often in this very period or even during the test that the students finally get to understand the topics discussed during classes.

Some secondary school students and their families believe that CSS is aimed at training students for coding Olympiads. Formally this is not a goal for CSS, unlike special Olympiad training camps. CSS participants' success at coding Olympiads is rather a consequence of their hard work. In the end, CSS alumni perform very well at various Olympiads, and the students who take part in such Olympiads strive to come to CSS.

CSS Goals

CSS was launched in 1999. Originally it was just a summer camp for the students of one particular school based in Moscow but it started expanding very soon. First, students from neighboring regions started coming, and in 2004-2005 the school reached national scale: there were participants coming from all over the country, from Saint Petersburg to Barnaul, as well as from abroad.

CSS role has changed over time. In the early 2000s, CSS was basically the only place where young people – especially those coming from rural areas – could learn coding at a high level. Nowadays, as access to the Internet has grown and there are online courses and testing systems available, everyone has an opportunity to learn. CSS is now aimed at kindling interest in young people and creating stimuli for their further unsupervised work. Another goal is to bring together young people who share similar interests so that they can get to know each other. Three of our alumni, for example, who became friends at CSS have launched their own startup in Portugal.

Nearly all CSS academic staff have participated in and/or organized coding Olympiads; many of them are jury members at the Olympiads of various levels, including the final stage of the All-Russian Olympiad of School Students. Many staff members work in leading IT companies (such as Google, Yandex, VKontakte and others).

Companies support CSS because first of all, they can directly see where the money is going, and secondly, many CSS alumni later start working for these companies. Their employees can organize both session-long courses and short optional courses.

It is worth noting that cooperation between school and college teachers and industry professionals within one educational project is very fruitful. In addition to the facts that have already been mentioned above (CSS alumni's success at various Olympiads, chance to find employment with the leaders of Russia's IT industry), CSS has another very important effect. Experience shows that CSS actually sets standards in the sphere of IT education in Russia. In 2011, for example, CSS started teaching the youngest groups in Python because it turned out to be very efficient. At the time, nearly no one in Russia was using Python when working with school students. Nowadays many of Russia's leading schools use Python, and their number is growing every year.

Computer Science Center: Why Computer Science Students Need More Than a University Degree

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IT is one of the fastest growing industries, so relevant universities and departments have to be very dynamic too. In practice, it is not always the case. Due to bureaucracy and lack of funding universities often cannot keep up with the latest developments and offer students outdated curricular. Therefore, in the 2000s, many Russian IT companies and research institutes came up with various educational initiatives.

One example of such initiative is Academy of Modern Software Engineering (AMSE), based in Saint Petersburg, which introduced evening classes for engineering students in 2005. AMSE curriculum, based on the international educational standard in software engineering (SE2004), was complementary to university education and included courses generally missing from the program.

Two years later Computer Science Club (CS Club) was founded at the Saint Petersburg branch of Steklov Mathematical Institute of Russian Academy of Sciences. It was available to everyone. The goal of the club was to introduce students and IT specialists to modern theoretical computer science and encourage them to do research in that area.

At the same time, in 2007, Yandex (Russian IT company) launched Yandex Data School (YDS), a two-year computer science program, featuring data mining courses rarely found on the university curriculum. Just like AMSE, YDS was designed to be complementary to university education.

In 2011, YDS decided to expand and open a branch in Saint Petersburg. By that time AMSE and CS Club were already well established, and most of the staff were involved in both. However, there was no conflict of interests: AMSE was specifically targeting university students, who were accepted on the competitive basis, whereas CS Club was not selective at all. Therefore, the idea of launching yet another education project looked unreasonable as it would increase the competition for both students and teachers among the institutions.

Thus, AMSE, CS Club and YDS decided to join forces and created Computer Science Center (CS Center) offering several educational tracks, with CS Club responsible for the Computer Science track, YDS for the Data Mining track (a local YDS branch now), and AMSE was transformed into the Software Engineering track. Since AMSE was to a large extent supported by JetBrains, the latter is now responsible for the Software Engineering track.

In the following we will describe the target audience of CS Center, the structure of its educational process, and finally, the motivation of both the students and organizers.

The first CS Center students had to choose a track and follow a fixed syllabus, just like it had been at AMSE and YDS. With time it became obvious that software engineering students could be interested in data mining as well, while data mining could benefit from courses in theoretical computer science, etc. Nowadays the syllabus is more flexible: in addition to the core courses students can choose from a wide variety of electives, based on their personal interests.

There is indeed quite a broad choice as CS Center is constantly on the lookout for new enthusiastic IT specialists willing to share their knowledge and skills with students. Currently CS Center offers 40 permanent courses. Most of them are taught on the annual basis, others — once every two years, depending on the demand.

Most of the courses were recorded and are available online. To reach a wider audience, CS Center launched an online initiative in programming basics in cooperation with Saint Petersburg Academic University of the Russian Academy of Sciences (SPbAU). The program introduces the students to programming and offers 12 courses, each running from 2 to 3 months. 129 people completed the online program in 2016, many of them coming from cities other than Saint Petersburg. The audience included both current students and working professionals from other fields, who wanted either to switch careers or learn how to solve their field-specific problems with the help of programming.

Since 2011, over 500 students have enrolled at CS Center. Of them, 116 have graduated and 185 are currently studying. The workload averages about 20 hours per week. Not everybody can cope with that, and the dropout rate is quite high. Often having faced with a lack of time the students choose to focus on university education or their job. Another, albeit not that widespread, reason for dropping out is a lack of commitment.

Most students appreciate the high quality of education offered by CS Center and gladly recommend it to their peers. This “through the grape wine” kind of advertising seems to be working very well. The number of applicants tends to increase every year. When asked about their motivation, most applicants reply that they feel the need for real-world projects, which is not fulfilled by the university. By participating in applied and research projects CS Center students learn how to solve problems they will encounter later in their professional lives. These projects are an important part of CS Center’s approach to education. Successful completion of a number of projects is a graduation requirement. Therefore, CS Center is always looking for new challenging projects to engage their students.

Summing up, the three main goals pursued by CS Center are as follows. Firstly, to select highly motivated students and through a two-three-years program give them a solid foundation in both theoretical and applied aspects of computer science. Secondly, attract highly-qualified specialists in different IT fields and encourage them to share their expertise with the students. Finally, to create online opportunities for professional development for people from outside Saint Petersburg. CS Center is working towards these goals steadily evolving to meet the industry expectations and demands.

The remaining question to be addressed is how educational projects such as CS Center benefit its organizers and students. Recent university graduates are usually offered an internship, which requires a lot of supervision from more experienced employees. This could be inefficient both in terms of time and costs given that some of them could leave the company shortly after the end of their internship. Students graduated from CS Center, on the other hand, are much better prepared for work and are typically able to get up to speed quicker as they have hands on experience of real-word projects and are familiar with engineering culture. Additionally, CS Center graduates tend to be aware of their own professional interests and therefore are more likely to stay with the company after the internship. Thus such educational projects appear mutually beneficial.

The rapidly evolving IT industry requires educational institutions to be flexible, which is often a challenge for universities. CS Center could help bridge this gap by focusing on the latest trends and giving the students the skills which are currently in demand. CS Center alumni are young IT specialists with work experience in real-world projects, vast technical background and deep interest in the field.

Why Do Students Need Programming Contests? Case of ACM/ICPC

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The ACM International Collegiate Programming Contest (ICPC) is the largest and most famous programming contest for post-secondary students. The first competition took place in 1977 during ACM Annual Computer Science Conference. Since then it has been organized annually under the auspices of ACM (Association for Computing Machinery).

ACM/ICPC is a team-based competition with certain requirements to the participants: only post-secondary students and first-year post-graduate students no older than 24 are eligible; each team consists of three members. One can participate in the finals no more than twice and in the regionals no more than five times.

Participating teams have to solve as many problems as possible within limited time. Before the finals there are several rounds of regionals (quarter- and semi-finals); universities representing a certain region may send as many teams as they want. However, only one team from a given institution may advance to the World Finals. Every year the finals are held in a different country.

Russian universities took part in ACM/ICPC for the first time in 1993 when the organizers expanded ICPC geography by creating the Eastern Europe Region. Russian teams have won 11 times since 2000: Saratov State University team won once, Saint Petersburg State University team – four times, and ITMO University – six times. The performance of other Russian teams is traditionally high too. In 1996, for example, Moscow State University team advanced to the finals for the first time. After that the team managed to finish world second five times and was awarded gold medals; it also once won silver medals and six times bronze medals.

Naturally, participation in world-level competitions requires a lot of time and efforts – that is, alongside regular studies. Moreover, some students also work. What motivates them to take part in international programming contests and what competitive advantages can such experience bring them?

At most universities the core of the preparation process is solving competition-level problems. At Higher School of Economics, for example, such a process is built in the following way: the best students sit one or two training sessions where all ICPC rules are observed and where they solve problems from earlier competitions. After that they go through the problems in detail or analyze other people's original solutions. Those with less experience also take classes where cases of practical application of various algorithms are studied. There is a number of problems that students have to solve for each class, and if they have any questions, they can ask for advice.

Students who participate in competitions have to work really hard. Many of them gather together several times a week for 5-6 hours and later spend their own extra time on solving problems. Several times a year they also go to bootcamps where they work intensively every day. Many of the ICPC winners started programming while still in high school and performed well at various Olympiads for high school students.

Why do young people need such competitions at all? Even if we disregard such nice things as a chance to travel and meet like-minded people, even if we put aside such factors as passion for programming and competitive spirit, participation in such contests returns some important dividends.

First of all, competitions stimulate and motivate people to code a lot, so they learn to do it quickly and flawlessly. This is very useful for future professional work. Job applicants are often asked to solve the same problems as those offered during competitions, and those who have relevant experience have higher chances of getting a job.

Secondly, ACM/ICPC achievements are indicative of one's advanced intellectual abilities. ACM/ICPC participants learn to find optimal solutions for relatively difficult problems, which later helps them process large data sets that come up in real-life projects. Of course there are also a lot of smart people who are used to spending a long time thinking thoroughly over problems. They are capable of solving difficult research problems but competition format allows little time for that, which people without relevant experience often find stressful.

Thirdly, it is of course prestigious. ACM/ICPC participants spend a lot of time and efforts but earning a medal is a great achievement; winners become more attractive for potential employers. IBM, for example, is one of the ACM/ICPC finals regular sponsors; it provides cash prizes for the winners and offers gold-winning team members internship or employment opportunities.

All of the above makes contest participants more competitive on the labor market.

Speaking of university life, there is a wide-spread belief that collegiate programming may be harmful for one's academic performance. It has indeed happened that top competition participants were expelled for underperformance. However, such cases are rather rare. Moreover, the situation is the same with any other kinds of contests or university-unrelated student activities. It is quite obvious that if a student starts having problems at university, his or her own bad time-management is to blame rather than the fact that he or she participates in coding competitions.

As for university education, competitions help students learn more about dynamic programming, string algorithms, data structures and other topics that often aren't covered well enough by university curricula.

Finally, many universities hire former participants of programming competitions as teachers or team trainers, so this is another employment opportunity in addition to working in IT companies. Many of the participants find it important that after graduation they will be able to develop professionally in their area of interest.

Who's the Best in Computer Science? Analysis of Top Conferences Using Scopus

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Introduction

Computer science (CS) may be the hottest field of R&D at the moment but it is also one of the most difficult to evaluate using standard bibliometric tools like journal impact factors or WoS paper counts. The reason is that conferences, not journals are the main scholarly communication venue for most branches of CS (Meyer et al 2009, Godoy et al 2015). Major conferences serve as gatekeepers of quality, providing rigorous peer review and achieving citation rates comparable with those of respected journals in the other fields of science (Freyne et al 2010).

The quality and impact of various CS conferences differ greatly. Top conferences are regarded as the most prestigious way of presenting new research and enjoy very high international visibility. Accordingly they have low acceptance rates and strict peer review (Meyer et al 2009) and can be considered as a CS publication core in Bradford's and Garfield's sense. This emphasis on quality makes them a good proxy of both scientific productivity and impact. In this paper they are used to measure relative standing of top nations and Russia in the field of computer science. Country-level analysis is followed by data on Russian universities producing top CS papers.

Methods

To make conference paper count as a meaningful metric two goals have to be achieved: to find a suitable list of top conferences and to ensure acceptable bibliometric data quality. There are several conference rankings produced by various parties cross the world (Singh et al 2016). Judging from our research management experience and personal communications with senior CS scientists, the most elaborate and substantiated ranking is produced by the Computing Research and Education Association of Australasia (CORE, an association of university departments of computer science in Australia and New Zealand). According to CORE, its rankings "are determined by a mix of indicators, including citation rates, paper submission and acceptance rates, and the visibility and research track record of the key people hosting the conference and managing its technical program". [1] As we are interested in top international conferences across the whole spectrum of CS, we have included all the 62 conferences ranked A*, which means "flagship conference, a leading venue in a discipline area". The most recent 2014 edition of the rankings was used.

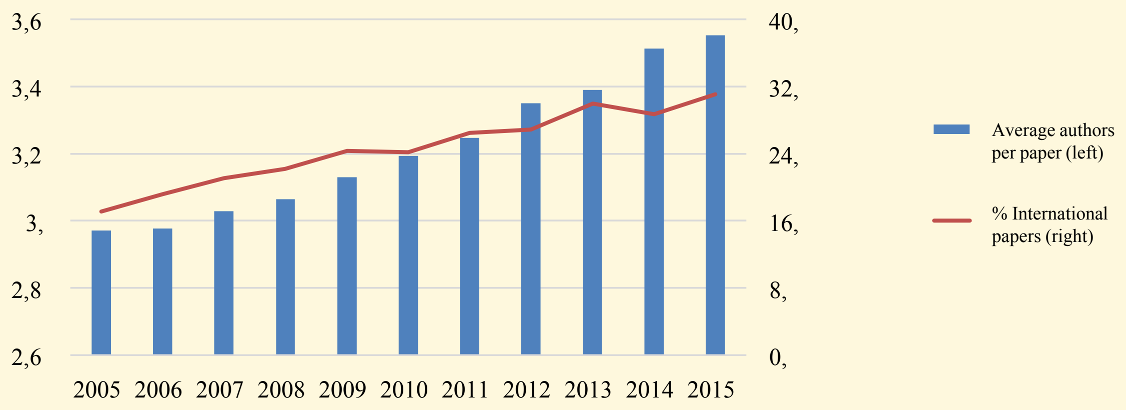
The choice of bibliometric database was based on a combination of coverage and analytical power. Scopus beats Web of Science in terms of coverage in engineering sciences (Harzing and Alakangas 2016), while offering much more detailed country- and institution-level analysis capabilities and better data quality than Google Scholar (Falagas et al 2007). Luckily, according to a personal communication with Elsevier staff, Scopus is basing its CS conferences list on the CORE ranking.

For each conference on the list we have manually built a search query in Scopus using various field tags and operators, searching both by "conference name" and "source name" fields. Conferences with names similar to A* conferences were specifically tracked and excluded. We have also excluded "workshop," "adjunct", and "companion" proceedings using conference name and source name filters. This was done to increase the uniformity of expected peer review quality for resulting publication set. An important drawback of our approach is the lack of discrimination between full oral talks and posters because of the lack of such data in Scopus. The publication window chosen was broad: 2005-2015, although Scopus coverage for the recent years is somewhat better than for pre-2010's period.

Results: World

We have identified proceedings of 61 conferences with almost all years' proceedings in our publication window covered by Scopus. [2] The only conference not indexed was Usenix Security Symposium, and for the majority of the rest the coverage was varying from good to excellent, with tens to hundreds of papers indexed each conference year for each conference. In total we have analyzed 67,873 Scopus conference proceedings records. Their importance for the field is matched by their combined citation count: 765,506 at the time of writing this paper in Scopus and much more in Google Scholar. Yearly publication counts in our set grew from 5,491 in 2005 to 7,747 in 2015.

The following graph shows overall dynamics of the main collaboration metrics: average authors per paper and share of international papers. Both are steadily increasing, which arguably reflects the growth of the scope and complexity of modern CS research and overall globalization of academia and business. The share of international papers among top conference papers is much higher than the world average for all Scopus-indexed CS conference papers: 31% to 18% in 2015.



There are 112 countries mentioned in author affiliations of our set but only one dominates: the United States account for more than 52% of all papers. The USA is also the only country to have some of their national conferences on the list. Next table shows absolute & relative output and growth rates for the top 10 countries by total publication count in 2005-2015 plus Russia.

Rank by N	Country	N	% of world	% growth (2005-2006 to 2014-2015)
1	United States	34759	52	25,8
2	China	5813	8,7	431,3
3	Germany	5214	7,8	99,8
4	United Kingdom	5127	7,7	95,7
5	Canada	4228	6,3	23
6	France	3433	5,1	70,4
7	Japan	2472	3,7	12
8	Israel	2453	3,7	22,3
9	Australia	2324	3,5	134,8
10	Singapore	2061	3,1	151,1
35	Russian Federation	113	0,17	166,7

Profound shifts in country presence for top CS conferences lead to decrease of world shares for a group of established leaders – USA, Canada, Japan and Israel. Europe is now performing much better but such a rise could be partly due to change of focus of EU researchers form local conferences to global/American venues. The biggest gainer is China with its Tsinghua University already occupying 11th place globally, just behind Google, and a multitude of other universities and research centers in the world top 100.

The main difference between CS and traditional basic sciences on the level of organizations is the role of corporate players. According to our data, they publish on par with the largest universities. This corresponds well with the steady stream of industry news of both established university professors and younger stars moving to research positions at Google or Facebook or Baidu. Judging from our publication set, the older Microsoft and IBM take the lead. The next table shows top organizations by publication counts in 2005-2015.

Organization	N
Microsoft Research	3495
Carnegie Mellon University	2373
IBM	2062
Massachusetts Institute of Technology	1720
Stanford University	1313
UC Berkeley	1192
University of Illinois at Urbana-Champaign	1091
National University of Singapore	1069
Georgia Institute of Technology	963
Google Inc.	938

It is worth noting that Microsoft and other corporations have big research units in China and other non-US locations. Especially productive is Microsoft Research Asia situated in Beijing.

Results: Russia

Russia is virtually non-existent in global CS according to our data. Just 113 papers with Russian affiliations were indexed in 2005-2015. Nevertheless, the dynamics is good: there is a clear rise in papers starting in 2013, and 2015 was the best year in Russian history so far with 27 papers. In line with global trends it is big IT companies and select universities that lead the way. Yandex — a Russian Google-style Internet giant — has 155 researchers but it is ranking the first high mainly thanks to Pavel Serdyukov, a young researcher with conference track record unparalleled for Russian CS (SIGIR, WWW, ICML, WSDM are all A*). Yandex researchers authored 8 papers in our set in 2015. The two leading academic organizations are Higher School of Economics (HSE) and SkolTech, which are mentioned in affiliations of 8 and 4 of the 27 Russian papers in 2015 respectively, and the Russian Academy of Sciences with 7 papers. Moscow State University, which was a leader in the 2000s, has mostly lost its ground, partly due to migration of top scientists to HSE, Yandex, Microsoft and foreign research centers. It had 2 papers in 2014 and zero in 2015. It is worth noting that a handful of papers were produced by small and medium Russian innovative regional IT companies, like Magenta Technology from Samara and Itseez from Nizhny Novgorod (recently acquired by Intel).

Judging from conference names and author keywords the spectrum of Russian CS research is fragmented but mostly connected with machine learning and data mining (Yandex, HSE, SkolTech) and foundations of CS (mathematics, a traditionally developed area, mostly RAS).

To sum up, top CS conference proceedings are a promising tool for measuring quality research output. They allow us to monitor performance of local and global actors on the top international level. A combination of Scopus and CORE rankings seems to produce plausible results. The USA dominates research landscape with roughly half of all surveyed proceedings having American affiliations and 9 organizations in top-10 but China, EU and a score of other nations are showing much faster growth.

Speaking of Russia, these results are both appalling and encouraging: our output is drastically low but new centers of growth are emerging. Their research agendas are much more oriented towards hot topics in applied CS, which is a welcome addition to more traditional theoretical CS areas where we were at least somewhat noticeable on the global scale. Still, Russian CS research has a long way to go to become world-class in scope and quality, and this way clearly goes through top international conferences.

Notes

[1] Detailed methodology and ranking tables are available online at http://www.core.edu.au/conference-portal

[2] The list is available online at http://portal.core.edu.au/conf-ranks/?search=A&by=rank&source=CORE2014&sort=atitle&page=1*

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The Institute for Information Transmission Problems: Cooperation Between Research Centers and Universities

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A new trend started in Russian higher education institutions (HEIs) and research centers in 2010: HEI graduates are losing interest for post-graduate studies and academic careers. According to the Federal State Statistics Service, in 2010–2015 gross enrolment to post-graduate programs in Russia decreased from 54,558 to 31,647 and the rate of post-graduate students who managed to defend their dissertations dropped from c 28.5% to 18%. In this context, research institutes' outreach towards HEI students is becoming of greater importance. The Institute for Information Transmission Problems (IITP) of the Russian Academy of Sciences is one of the most active research centers in terms of cooperation with universities in the sphere of computer science. IITP has seven joint educational programs with partner universities.

In this paper I will use the example of IITP to talk about the ways of cooperation between research institutes and universities, how they manage to survive in the competition with IT companies for students, and why such centers and students themselves need this at all.

In the early 1960s, IITP became the first Soviet center specializing in fundamental communications research. Alexander Kharkevich, famous scientist and engineer, masterminded the institute and was appointed as director.

The emergence of modern communications, large-scale logistics and computers in the middle of the 20th century made math, for the first time in its history, directly applicable in the sphere of technologies. Mathematicians with their theorems and concepts suddenly became engineers' immediate partners. Before that engineers had to talk to mechanicians, chemists or physicists, who used math in their research. The area of engineering that we now call "computer science" developed at this crossroads of various sciences.

IITP's main activities include fundamental and applied research in the sphere of data transmission and processing, information processes in technical and living systems, computational linguistics and bioinformatics. As it has already been mentioned, IITP has seven joint educational programs with partner universities: two at Moscow Institute of Physics and Technology (MIPT, known in Russia as "Phystech"), one at the Faculty of Bioengineering and Bioinformatics at Moscow State University (MSU), one undergraduate and one master's program at the Faculty of Mathematics at Higher School of Economics (HSE), and two master's programs at HSE Faculty of Computer Science (Mathematical Methods of Optimization and Stochastics; Data Analysis for Biology and Medicine).

The question of bringing together scientists from various fields and forming a consolidated and functional team arose in the early years of IITP's work already. It was particularly important when biologists first joined IITP: information transmission and processing are very efficient in living systems, so understanding the way they work would mean learning a lot in the technological sphere too. An answer to the question was found when MIPT graduates started coming to IITP. MIPT is a flagship technological university; education there is based on two main principles: a broad scope of disciplines (that is how MIPT began training biophysicists back in the 1950s) and the famous "MIPT System," when MIPT "outsources" education and research beyond the first two or three years of study to various research and technical partner organizations (known locally as "bases"). When "at bases," students not only do lab work but also take classes given by researchers of such organizations rather than MIPT professors.

The "MIPT System" includes an educational part and is therefore more intense than traditional internships. This kind of symbiosis between science and education can be compared with Unités mixtes de recherche — labs of the French Centre national de la recherche scientifique that are founded in partnership with universities. However, the "MIPT System" is based on educational units rather than research ones, i.e., departments rather than labs.

In the USSR the "MIPT System" was in use not only at MIPT but also at Novosibirsk State University, Novosibirsk being the country's largest research cluster outside Moscow. In the post-soviet times the "MIPT System" was successfully implemented at other fast growing universities too. Such a system was formalized in the 2012 law on education, where "specialized departments" are described as a unique form of educational cooperation between HEIs and research centers. This system helps students better adapt to labor market demands by working and studying at leading research centers and commercial companies.

MIPT students come to IITP in their third year already; first — once a week, then more often. In the end they write bachelor's and master's theses. Top students "assimilate" fast and start working either at the institute itself or one of its spin-off tech companies. Some MIPT students want to do their master's at IITP even if they haven't finished their bachelor's there but this is rather unusual.

IITP-HSE partnership is organized differently. HSE leadership aims at attracting prospective master's students from all over the country, so master's programs are in a way "disconnected" from undergraduate education. However, two years is not enough to train a good researcher. This is why our partnership with HSE is different: HSE students come to do their master's at IITP and if they succeed, they move further to post-graduate programs, which gives them in total 5-6 years of training.

IITP partnership with Skolkovo Institute of Science and Technology (Skoltech) is expected to follow the same model. Skoltech is a new technological university aimed at training specialists in tech innovations. It was founded several years ago with MIT as a major developmental partner.

Speaking of MSU, its whole Faculty of Bioengineering and Bioinformatics is IITP's partner. This fosters fruitful cooperation with future colleagues from their very first years of study.

In the context of collaboration with universities IITP has to respect their policy of sorting students. Some young people are given free choice to decide their own futures, others are advised to join research centers at their university's choice.

IITP is a modern center for research, education and innovations. It has various spin-off companies that work in the sphere of data mining, mathematical modeling, professional communications, synthetic vision systems. For our researchers cooperation with HEIs is a chance to train future generations of academic staff. University staff and researchers in specialized centers often perform similar yet quite different roles. The former teach and do research as a means of professional development, while the latter do research and teach because they need to train their own successors.

Successors are difficult to find and even more difficult to retain: globalization stimulates competition for human resources with commercial companies and research centers from all over the world. Academic work requires individual selection; research or lab teams usually have few members. However, no one — neither students nor their supervisors — can ever predict whether their collaboration will be successful. So the flux of students going through IITP has to exceed the organization's internal demand for new employees. But where do those who leave go?

IITP operates in the sphere of computer science and information & communication technologies, so the nature of its work means that research results have to be translated into the industry. Such transfer is possible when doing research commissioned by industrial companies or when creating spin-off companies (known in the Russian legislation as "small innovative enterprises") aimed at further development and commercialisation of technological prototypes that come as a result of fundamental research.

Thus, motivated students who use IITP educational opportunities available at their own universities have a rather comfortable career choice between fundamental research and work in the industry.

Institute for System Programming: How to Train Research Engineers for IT

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The existence and development of modern society are closely tied to technological development. Systematic innovations — socialized and imbedded in a relevant technological niche for active implementation — are crucial for it. Such innovational development is only possible when social institutes of research, industry and education function coherently. Relations between science and technology are often presented as a chain of knowledge transfer described by Francis Bacon (Figure 1).

Fundamental science → Applied science → Technologies

Figure 1. Technological development according to Francis Bacon

Although there has been a number of suggestions on improving the components of this scheme, e.g., by including inverse links, although the development of each element is usually inspired by internal processes and only rarely involves the results or knowledge of others [2], and the characteristics defining the fundamental/applied divide are rather heterogeneous [3], no serious researcher questions the necessity of the three elements' coherent development for stable long-term progress. It is therefore also important to consider the relation between science and innovations on the one hand and educational institutions, which train new generations of researchers, on the other while designing a strategy on training researchers.

Sources and Principles of Training Research Engineers

The issue of training research engineers is one of the main challenges for creating a self-reproducing mechanism of developing innovations. Research engineers belong to the middle element of the aforementioned scheme, so they are responsible for coherent scientific development. As this problem was recognized during the industrial revolution, specialized technological universities were founded. They were aimed at training professionals who would be able to invent new technologies. École Polytechnique (established in Paris in 1794) is an important example of such a university. Though formally it is believed to be the first university of such type, its position can be challenged by the School of Mining established in 1735 in Selmecbánya (then Hungary), which trained mining engineers (and which can be considered a predecessor of the contemporary Hungarian University of Miskolc), and Technische Universität Braunschweig founded in 1745. However, École Polytechnique was the first to use the essential principles of training research engineers, "high-class engineers" who would be able to apply latest research in their real-life work and to do research themselves in the areas where they were lacking knowledge necessary for designing efficient solutions. These principles included:

1. Integration of academic studies, deep understanding of fundamental disciplines and real practice;
2. Orientation towards using university knowledge for solving practical tasks that arise in the industry, military sphere or administration;
3. Step-by-step systemic selection of the most talented and well-performing students (irrespective of their socioeconomic situation);
4. Elitism in teaching which allows to maintain high quality standards for decades.

These very principles were reproduced by Wilhelm von Humboldt in the course of higher education reform in Prussia and while designing Berlin University in 1810, which was later given his name [4]. Moscow School of Mathematics and Navigation founded by Peter the Great in 1701 became Russia's first engineering school. A number of the École Polytechnique principles were also used in the Institute of Railway Engineering Corps founded in 1810 by Agustín de Betancourt on the order of emperor Alexander I (now Saint Petersburg State University of Communication).

The "MIPT System"

In the 1950s, when post-war Soviet economy needed speedy revival and at the same time when new science-driven industries needed to be developed, the country's top scientists (P.L. Kapitsa, M.A. Lavrentiev, S.A. Khristianovich, S.A. Lebedev) initiated the establishment of Moscow Institute of Physics and Technology (MIPT, also informally known as "Phystech") [5, 6]. One of its founding principles stated that in order to train highly qualified professionals, students have to take part in the work of research teams dealing with practical industry-related tasks. This became an underpinning principle of the so-called "MIPT System", as part of which students in their third year and later have a chance to listen to lectures of scientists actively involved in research project of strategic importance and to step into such projects themselves.

As a result, MIPT alumni are actually ready for independent professional research, so for them post-graduate education is not just an introduction to research but the most academically active period that leads both to a mature dissertation and practical application of research results. The efficiency of such approach is proved not only by the achievements of the Soviet military-industrial complex but also by the fact that MIPT alumni's work is highly appreciated by the international academic community and the Nobel Committee in particular.

The world's most famous technological universities (Stanford, MIT, Berkeley, Carnegie Mellon) cooperate with the industry too by collaborating with R&D departments of commercial titans (such as Microsoft, IBM or Intel) and public research centers such as INRIA system in France or Fraunhofer in Germany. The complexity of integrating education and research and achieving substantial results, especially in the newest and fast-growing technological fields, makes it difficult to train highly qualified professionals within traditional university education framework.

ISP RAS: Integrating Research, Education and Technologies

The Institute for System Programming of the Russian Academy of Sciences (ISP RAS) has also been using the "MIPT System" for more than 20 years already in order to train research engineers. ISP RAS was established in 1994 drawing on the experience of Lebedev Institute of Precise Mechanics and Computer Engineering of the Russian Academy of Sciences and the Institute of Cybernatics of the Russian Academy of Sciences which were both using the same model.

ISP RAS's work is best described as "industrial research," i.e., work aimed at translating research results into the industry (or other sphere of application). This means that the institute's other activities are focused on making sure that the technologies, software products and system programming problem-solving methods developed meet all modern requirements and are ready for application.

Therefore, the main emphasis is on the central element of the chain that connects fundamental science and application of new technologies. However, the other two elements can be found at ISP too in order to ensure long-term operating capacity of innovation design mechanism.

Fundamental research, exploration and experimentation are necessary to ensure that the institute's development is in line with the most recent ideas and nascent technologies. Ideas for new projects also originate from fundamental research. As technologies are tuned to become true innovations and brought to active real-life implementation they are also adapted for software products and services that can be used in practice too.

ISP RAS: Results Implementation Principle

ISP RAS does not launch start-ups because despite it would create a higher concentration of practically implemented technological discoveries, it could also destroy the institute's research team and hinder the process of training new specialists.

Instead, the institute prefers to implement its inventions through big industrial and research organizations, which at the same time often exploit new technologies themselves and act as ISP's partners in promoting its achievements for mainstream use. Our foreign partners in the sphere of innovative activities are Samsung and Linux Foundation; Russian partners include State Research Institute of Aviation Systems and Kvant Research and Production Enterprise.

Besides research and technological work, we also solve the issue of stable and smooth team development. Stability allows us to build long-term relationships with partners and customers, otherwise it would be difficult to reach and maintain a high technological level of R&D. Such stability is based on the existence of a school of thought that includes the institute's leading researchers. This allows new employees to smoothly step into the team and embrace both formalized knowledge and skills, and informal rules and behavioral patterns in order to work productively with other colleagues and to conduct high-level research.

ISP RAS: Reproducing Research Engineers

Manpower replacement is facilitated through participating in education. Each year 30-40 undergraduates from MIPT, MSU Faculty of Computational Mathematics and Cybernetics and — since recently — HSE Faculty of Computer Science join the system of departments organized under the auspices of ISP RAS. The system was chaired by one of the institute's founders and RAS member prof. V.P. Ivannikov until his death in November 2016.

They join the course in their third year of study and attend lectures (3-4 per week) by ISP RAS staff, participate in research workshops and get acquainted with the work of various ISP RAS departments. One year later they start participating in specific research projects. Many students already have academic publications and actually become real specialists in their field by the first or second year of their master's. Over the course of their post-graduate studies they continue accumulating practical experience and deepen their understanding of their chosen specialization.

Besides that, post-graduate students also start teaching. They lead workshops and lab classes for students, read specialized courses, supervise students' yearly projects and bachelor's theses. Systematic accumulation of knowledge and experience over the years allows to regularly train truly mature high-class specialists who possess valuable skills and have achieved substantial results.

Trying to separate practical specialists from teachers often results in the fact that the students who have "successfully" mastered the curriculum are not actually ready for real research work. They are good at solving well-formulated problems but cannot overcome real-life difficulties in a situation when success depends on being able to find the right solution and to correctly formulate the task at the same time. In the Russian context excessive preoccupation with research mobility (in terms of topics and workplaces) often leads to the fact that new employees lose time "growing roots" in a new team and underdeliver.

Research projects that are directly relevant for industry needs allow ISP RAS to offer its employees competitive salaries comparable with high tech IT companies. Of course sometimes people change jobs or even move abroad but the institute manages to avoid massive "brain drain" due to high professional level of research.

So, people who are interested in cutting-edge research are just enthusiastic about working at ISP RAS. Having an interesting job means working on truly challenging problems, which implies that one has to understand ground-breaking technologies and to be able to look beyond the boundaries of existing knowledge. Moreover, true science means openness of results and "visibility" of their authors, which often contradicts IT companies' corporate policies. For ISP RAS, on the other hand, openness of results and usage of open software code both stimulate quality and help promote new technologies that are being developed. Openness means that even young professionals working in big teams become famous within the international IT community and build up reputation as world-class experts in their specialized fields.

Training research engineers is one of the most important ISP RAS activities, all of which are closely integrated and share a lot of inverse links; each component is important for the effectiveness of others. Here are some examples of such links:

- Research projects require efficient professional training;
- Training high-level researchers requires projects with important real-life tasks that allow their participants to master and develop cutting-edge technologies;
- Research that ends in the development of new technologies needs industrial projects to help demonstrate verifiable efficiency of its results;
- Attracting new customers and partners and gaining new resources for development depends on research success.

ISP RAS organizational model may seem cost-inefficient. One could substantially cut the resources spend on teaching, participation in conferences, organization of various academic events or academic publications, concentrate on financially profitable projects and abandon unprofitable ones but that would cause institutional degradation. Current model enables smooth long-term institutional development, it helps build up capacity for solving new system programming problems and training world-class experts.

Apparently, such model is not universally applicable, it would be difficult to reproduce in many organizations. However, it facilitates successful reproduction of research engineers who are able to systematically produce new technologies and implement them in practice in the industrial field.

Training Research Engineers

To sum up, there are three key elements to the strategy of training research engineers for IT. First of all, such a strategy should be developed bearing long-term goals in mind. Educational success criteria should be based not on formal procedural criteria but on an expert community evaluation of whether graduates are mature and efficient enough as researchers. Adequately training a highly qualified specialist who has both broad knowledge in IT and deep understanding of their own specialization requires 8 to 10 years.

Secondly, active participation in cutting-edge research projects aimed at solving practical problems and teaching younger generations is core to research engineer training. All this helps develop an important set of competences that cannot be measured according to formalized criteria (such as citation index or other bibliometric indices). It is also important that by studying within a vivid school of thought with several generations of active researchers students have a chance to witness a broad range of behavioral patterns at various stages of academic careers and adapt them to consciously build their own careers.

Finally, one has to understand that when students shape up their personal curricula individually (lacking broad professional knowledge) and often change the subjects they study, which of course helps improve academic mobility indicators, it is impossible to neither train mature high-quality experts nor meet the country's and economy's long-term needs in various specialists. What should probably be seen as a strategic goal is supporting teams that create an appropriate environment for training such specialists, i.e., schools of thought and research centers that systematically build up research and practical work and train new academic and engineering specialists.

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