Research Statement

My main research interest is computational complexity theory and its relations with other areas of theoretical computer science. The topics I would like to work on include barriers in computational complexity, circuit lower bounds and parameterized complexity, and I am also eager to learn some new areas.

I believe that the University of Chicago, with its very active theory group, is a perfect place to pursue these topics. I would very much like to work with Prof. Alexander Razborov (I find his research in circuit and proof complexity to be very inspiring: actually, it is after reading his paper, „Natural Proofs", several years ago that I decided to focus my interests on complexity theory), Prof. Lance Fortnow (I liked very much his talk on the *Logical Approaches to Barriers in Computing and Complexity* conference in Greifswald, and parameterized complexity is only one of many topics he tackles that interest me deeply), Prof. Ketan Mulmuley (learning geometric complexity theory is one of my greatest goals for graduate studies), Prof. Stuart A. Kurtz (working with him would give me an opportunity to expand further my interest in the Isomorphism Conjecture) or Prof. Robert I. Soare (while complexity is currently my main research interest, computabily stands a close second and I would very much like to have an opportunity to do some research on this subject).

Research experience

My first research experience was proving PSPACE-completeness of Kropki[1] – an idea given to me by Prof. Mikołaj Bojańczyk. Proving that fact involved merging approaches of two papers on complexity of Go and inventing a convenient combinatorial "gadget".

I had an opportunity to get involved in more serious research in 2009, when I started working with Prof. Łukasz Kowalik on proving hardness of subexponential approximation of various problems. We assumed ETH (Exponential Time Hypothesis) and utilized special reductions (SERF-reductions, introduced by Impagliazzo and Paturi in [1]) to show hardness of gap versions of certain approximation problems. We focused on VERTEX-COLORING and MAX-CLIQUE, trying to show that they are inapproximable within a constant factor. At first, we tried using simpler, combinatorial approaches. We noticed that the proof of NP-hardness of $(2-\varepsilon)$-approximation of coloring uses a strong (linear) reduction, which gives us also inapproximability of this problem (within a factor less than 2) in subexponential time, assuming ETH. We tried to expand the techniques used in that proof to higher factors, taking advantage of more powerful SERF-reductions, but we encountered some obstacles we have not yet overcome. We were also studying various PCP-based approaches to hardness of approximation.

In 2010 I collaborated briefly with an emerging Fixed Parameter Tractability research group at my university comprised of Ph.D. students, who asked me to help them understand a new result [2] showing the impossibility to obtain small kernels for a large family of important problems.

Recently, I had an idea that using the mechanics of Scrabble one could implement gadgets necessary to show hardness of this game (i.e. value-assigning and value testing gadgets, used in reductions from SAT problem). I proved PSPACE-completeness of a deterministic model of the Scrabble game [3], which I wanted to make as close as possible to the standard Scrabble game (with the assumption that the sequence of lettered tiles drawn from the bag by each player is known *a priori*, to make the game deterministic). To this purpose I had to overcome several technical difficulties posed e.g. by the rule allowing the players to exchange letters. I plan to submit this result to the next *Fun with Algorithms* conference.

Currently I am working under the supervision of Prof. Iordanis Kerenidis from University Paris-Sud on lower bounds in communication complexity. While I was browsing recent papers in this area, a new model of communication, recently defined by Impagliazzo and Williams in [4], caught my attention and I decided to work on it. I reduced an open problem posed in that paper to showing that some problem, which can be computed by a deterministic protocol using $O(\log n)$ bits of communication and $O(\log n)$ rounds,

[1] a game similar to Go, popular in Eastern Europe, known also as Tochki or Dots.

does not admit a solution using $O(\log n)$ bits of communication and only a constant number of rounds. I devised a variant of Pointer Jumping problem that seemed to be a good candidate, and I proved that indeed it is such a hard example. I have also shown a reduction from this problem to Median – the problem of finding the median of a set of numbers which is partitioned between Alice and Bob, thus giving a partial answer to another open problem raised in that paper [5]. We are now trying to look at the other possible applications of my approach.

I have been invited by Prof. Benjamin Doerr from Max Planck Institute for Computer Science in Saarbrücken to join their Algorithms and Complexity department as a research intern for Spring 2011. I will be working with Prof. Manindra Agrawal, who will be visiting the department during this period, on several problems related to the Isomorphism Conjecture.

In Summer 2011 I will be doing an internship in Google Research with a group working on combinatorial optimization led by Vincent Furnon. I will be working on determining the complexity of certain versions of constraint satisfaction problem and on devising exact and approximate algorithms (both combinatorial and based on linear programming). I hope that during this internship I will gain much research experience in combinatorial optimization and constraint satisfaction problems.

Academic background

During my undergraduate studies I have focused on theoretical computer science courses. Since my first year I have attended 20 graduate and 5 undergraduate courses in complexity theory, algorithms and theory of computation, continuously receiving the highest grades. I have devoted much of my free time to expanding my knowledge in these areas, reading textbooks and recent monographs, browsing and trying to work on recent conference papers and generally striving to stay up-to-date with the trends and the progress in the area. With Mathematics as a Minor I have also gained enough mathematical background to understand various non-combinatorial (algebraic, logical etc.) approaches to problems in theoretical computer science.

At Ecole Polytechnique I am attending the 2nd Year of the Parisian Master of Research in Computer Science programme, which is comprised of one semester of elective advanced theoretical computer science classes, and one semester devoted to a research internship. The courses allow me to explore various areas in theoretical computer science which were not active in Warsaw, like algorithmic game theory, distributed algorithms or communication complexity. The lecturers usually assume the knowledge of classical results in the area and focus on recent approaches, aiming to give the students enough background to do research on the subject.

For many years now I have tried to spread interest in theoretical science among high school students (organizing and lecturing on a nation-wide workshop) and fellow undergraduate students (coordinating and giving talks on a students' seminar in complexity theory).

Goals

After finishing my Master's thesis I am planning to pursue a Ph.D. diploma in complexity theory, with a research career in academia as my long-term goal. I have to admit that the greatest expectation I have about my Ph.D. studies is meeting a mentor - someone who would show me which directions in complexity theory are worth pursuing and where my work could fit into a bigger program targeted at some important results.

Let me mention a few topics that recently caught my attention:

– circuit lower bounds – I have been interested in this topic for some time and the very recent result of Ryan Williams [6] doubled my enthusiasm. I plan to check in the near future whether the methods introduced there can be extended to prove some other results.

- barriers in complexity theory – Ever since I first read about natural proofs, the topic of barriers in computational complexity seemed extremely interesting. I believe there is still much work to do regarding the most recent barrier, algebrization [7]. During the *Logical Approaches to Barriers in Computing and Complexity* conference in Greifswald I heard a talk by Antonina Kolokolova describing the axiomatic approach to this barrier [8], whose potential applications I would very much like to explore.
- sparsification of boolean formulas – In [2] it is shown that we cannot encode a d-CNF formula into an equivalent one having $O(n^{d-\varepsilon})$ clauses unless the polynomial hierarchy collapses, which gives lower bounds on different methods that could be used to produce such encoding, kernelization in particular. I really liked the methods used in this paper and I would like to try to solve some open problems raised there.

Of course, I am also very willing to try to do research in other topics suggested by my future advisor. In particular, I would very much like to get introduced to geometric complexity theory.

Ever since high school, when I first read about the halting problem, I knew that it is the *negative* results that fascinate me the most, and that the problems of computability and complexity appear to me as being of fundamental importance. My first attempts at research made me confident that I deeply enjoy trying to solve these problems. Graduate studies at University of Chicago would allow me to fully develop my potential.

References

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[4] Russell Impagliazzo, Ryan Williams: *Communication Complexity with Synchronized Clocks*, IEEE Conference on Computational Complexity 2010: 259-269

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