/ Preface to the Second Edition

The collection of algorithmic problems in this second edition of *Looking for a Challenge? The Ultimate Problem Set from the University of Warsaw Programming Competitions* was first published in 2012. On May 17 of that year, the University of Warsaw hosted the 36th World Finals of the annual ACM International Collegiate Programming Contest (ACM-ICPC). The team from St. Petersburg State University of IT, Mechanics and Optics was the overall winner.

The University of Warsaw team, comprising Tomasz Kulczyński, Jakub Pachocki, and Wojciech Śmietanka, placed second among 112 teams of the best student programmers selected from 8000 teams, coming from 2219 universities in 85 countries. Together with other Polish student competitive programmers, they participated in and co-organized numerous programming contests regularly carried out by the faculty, staff, and graduate and undergraduate students in the Faculty of Mathematics, Informatics and Mechanics of the University of Warsaw (MIMUW). These contests have provided students in Poland and around the world the opportunity to learn and hone their skills in algorithmic problem solving and programming, both core elements of computer science. For many participants, the MIMUW contests laid a path to further successes in the most prestigious programming competitions, and – more importantly – launched their outstanding scientific and professional careers.

Although the structure and contents of the book have not changed from the first edition, the editors, Tomasz Idziaszek, Jakub Łącki and Jakub Radoszewski, have made corrections and minor revisions in many places. The editors would like to thank careful readers whose comments led to these improvements.

To reflect the progression and highlights in their professional careers since 2012, we have also updated biographical notes of the authors of the solutions included in this book.

Szymon Acedański: academic teacher in MIMUW; founder and CTO of InviNets, a software company developing applications for the Internet of Things; member of the Main Committee of the Polish Olympiad in Informatics.

Marcin Andrychowicz: received his Ph.D. degree (cryptography) in 2016 from MIMUW; silver medalist of the ACM-ICPC World Finals in 2013; finalist of the Google Code Jam 2016; currently working at OpenAI in California.

Piotr Chrząstowski: academic teacher in MIMUW; member of the Main Committee of the Polish Olympiad in Informatics.

Marek Cygan: academic teacher in MIMUW; in 2018 received a post-doctoral degree (habilitation) in computer science; recipient of a Starting Grant from the European Research Council in 2015; co-founder of NoMagic.AI, a company specializing in robotics software.

Tomasz Czajka: developer at SpaceX since 2014, working on computer systems for the Falcon and Dragon rocket and spacecraft; the second-place winner of the 2014 Facebook Hacker Cup.

Krzysztof Diks: academic teacher in MIMUW; since 2016, Chair of the Polish Accreditation Committee; 20-time participant in the ACM-ICPC World Finals as a co-coach and academic advisor of the University of Warsaw competitive programming teams: between 2012 and 2017, teams from the University of Warsaw won two gold, three silver and one bronze medal, including two overall runner-up titles (2012 and 2017).

Andrzej Gąsienica-Samek: founder and president of the software company Atinea; creator and developer of the Insta.Ling and instaKod educational portals for teaching and learning foreign languages and programming.

Tomasz Idziaszek: received his Ph.D. degree (theory of infinite tree languages) in 2014 from MIMUW; currently working at Codility on developing algorithmic problems and testing programming skills; since 2013, Scientific Secretary in the Main Committee of the Polish Olympiad in Informatics.

Grzegorz Jakacki: co-founder (2008) and CEO of Codility, a platform for assessing the level of programming competency; among Codility customers are Amazon, Intel, Microsoft, Nokia, PayPal, Samsung, Slack, Tesla.

Tomasz Kociumaka: Ph.D. student in MIMUW; recipient of a competitive research grant from the Ministry of Science and Higher Education (2013); co-author of more than 50 scientific publications; silver medalist of the ACM ICPC World Finals (2013 and 2014); finalist of the Google Code Jam and the Facebook Hacker Cup (2015).

Eryk Kopczyński: academic teacher in MIMUW; enjoys continued success in programming competitions, including the 2017 finals of the Facebook Hacker Cup and the Yandex.Algorithm contest.

Marcin Kubica: academic teacher in MIMUW; member of the Main Committee of the Polish Olympiad in Informatics; since 2015, Chief Software Engineer at Codility.

Tomasz Kulczyński: software engineer at Google Warsaw since 2012; co-founder of CodiLime; finalist of the Facebook Hacker Cup (2013 and 2016).

Jakub Łącki: received his Ph.D. degree (dynamic graph algorithms) in 2015 from MIMUW; since 2016 working for Google Research in New York; since 2014, member of the Scientific Committee of the International Olympiad in Informatics.

Krzysztof Onak: researcher at the IBM T.J. Watson Research Center, Yorktown Heights, USA.

Jakub Pachocki: graduated in 2013 with a bachelor degree from MIMUW; received his Ph.D. degree in 2016 from the Carnegie Mellon University; since 2017, researcher at OpenAI; the winner of Google Code Jam 2012; the second-place winner of the Facebook Hacker Cup in 2013 and finalist in 2014 and 2015.

Paweł Parys: academic teacher in MIMUW; winner of the 2012 Cor Baayen ERCIM Award for a promising young researcher in computer science and applied mathematics; finalist of the Facebook Hacker Cup in 2013.

Jakub Pawlewicz: academic teacher in MIMUW.

Marcin Pilipczuk: academic teacher in MIMUW; in 2017 received a post-doctoral degree (habilitation) in computer science; recipient of a Starting Grant from the European Research Council in 2017.

Michał Pilipczuk: academic teacher in MIMUW; received his Ph.D. degree in 2013 from the Bergen University, Norway; winner of the 2016 Cor Baayen ERCIM Award for a promising young researcher in computer science and applied mathematics.

Jakub Radoszewski: academic teacher in MIMUW; received his Ph.D. degree (algorithms on texts) in 2012 from MIMUW; since 2016, vice-chair of the Main Committee of the Polish Olympiad in Informatics.

Wojciech Rytter: professor in MIMUW; member of the Main Committee of the Polish Olympiad in Informatics; active creator of challenging and inspiring problems for programming competitions.

Krzysztof Stencel: professor in MIMUW; member of the Main Committee of the Polish Olympiad in Informatics.

Wojciech Śmietanka: graduated in 2012 from MIMUW; co-founder of CodiLime; after working as a software engineer at Google Zurich, now in London at Quadrature Capital, an investment management company.

Tomasz Waleń: academic teacher in MIMUW; member of the Main Committee of the Polish Olympiad in Informatics; co-founder and developer at Codility.

Jakub Wojtaszczyk: works at Google Warsaw; creator and co-author of the system supporting programming contests in distributed programming; a judge in the ACM-ICPC World Finals.

Filip Wolski: between 2012 and 2016, employed by leading high-frequency trading firms, including Teza Technologies; since August 2016, AI researcher at OpenAI.

Presenting this second, revised edition, we hope that its collection of problems will continue stimulating readers to plumb the depths of algorithmics and programming. Furthermore, we trust that studying the solutions designed by the authors will yield valuable insights and allow readers to augment the skills necessary for tackling science and engineering challenges in their professional careers.

Krzysztof Diks,
Warsaw 2018

Introduction

This book outlines the most significant moments and achievements in the almost 20-year history of Polish algorithmic and programming contests organized or co-organized by staff and students of the Faculty of Mathematics, Informatics and Mechanics at the University of Warsaw. The history of competitions in Poland is all about the people—both organizers and contestants. The fact that Poland was chosen to host the International Olympiad in Informatics in 2005, and the 2012 World Finals of the ACM International Collegiate Programming Contest, says a lot about the quality of programming contests that have been held in Poland over the years.

Participants in Polish competitions have numerous international achievements on their résumés. The most important ones include: first place for Filip Wolski and Tomasz Kulczyński in the International Olympiad in Informatics in 2006 and 2007 respectively, as well as the two-time victory of the University of Warsaw in the World Finals of the ACM International Collegiate Programming Contest thanks to Tomasz Czajka, Andrzej Gąsienica-Samek and Krzysztof Onak in 2003 and Marek Cygan, Marcin Pilipczuk and Filip Wolski in 2007. Polish contestants have had their fair share of successes—including victories—in other competitions as well, such as TopCoder Open, Google Code Jam, Facebook Hacker Cup and Microsoft Imagine Cup. These achievements would not have been possible without the level of challenge presented by programming contests held in Poland, which have enabled talents to be identified and given adequate opportunity for development.

Competitions in informatics

The role of competitions in selecting and educating particularly gifted high school and university students cannot be overestimated. These educational events require knowledge and skills greatly exceeding what is taught in schools and universities. A good competition is one that relates to the core of the discipline it concerns, and knowledge and skills acquired through participation therein are

not volatile but constitute grounds for further field-related development. What is of even greater importance is for the competition to help participants develop skills that will be useful in their future professional lives: diligence, constant striving for success and self-development, self-discipline, hunger for knowledge, self-improvement, teamwork, honesty, ambition, eagerness to compete, dedication. Taking part in a good competition should pose an intellectual challenge to a young individual, whilst success should be a reason for pride and recognition.

Contest tasks say a lot about the quality of a competition itself. They should be original, engaging and of different levels of difficulty. Finding a solution should cause the contestant to feel great satisfaction, whereas being unable to solve a given task should encourage an individual to broaden their knowledge and develop new skills. This book contains the best tasks from algorithmic and programming competitions organized or co-organized by the University of Warsaw, together with their exemplary solutions. The selection of the tasks was undertaken by people who have played significant roles in the history of Polish algorithmic and programming competitions as their participants or organizers. All of the authors of the texts presented in this book are closely affiliated with the Faculty of Mathematics, Informatics and Mechanics at the University of Warsaw, whether as former or current students or as academic staff.

Each of the tasks presented and discussed in this book was used during one of the following events: Polish Olympiad in Informatics, Junior Polish Olympiad in Informatics, Polish Olympiad in Informatics Training Camp, Central European Olympiad in Informatics, Polish Collegiate Programming Contest and Algorithmic Engagements.

The **Polish Olympiad in Informatics** was established in 1993 by the Institute of Computer Science at the University of Wroclaw, then chaired by Professor Maciej Sysło. The main founders of the event included four staff members from the University of Warsaw: Piotr Chrząstowski-Wachtel, Jan Madey (director of the Institute of Informatics at that time), Wojciech Rytter and Stanisław Waligórski (who became the first chairman of the Main Committee of the Polish Olympiad in Informatics). Since the very beginning it was the University of Warsaw that facilitated the event, in terms of both scientific background and technical solutions. All authors of texts presented in this book were, or still are, affiliated with the Olympiad.

The Olympiad in Informatics is a competition for high school students. The first four winners of national programming competitions represent their countries at the International Olympiad in Informatics.

The Polish Olympiad in Informatics consists of three stages. The first stage is usually organized in October or November and attracts around a thousand contestants, who are presented with five tasks to be solved at home. Completed solutions are then sent for evaluation to the competition organizers over the Internet. About 400 contestants qualify for the second stage of the competition, which lasts for three days and is held in a few selected regional centers that cooperate closely with the universities that offer the best computer science programs in Poland. The purpose of the first day is to acquaint the participants with the rules and regulations of the contest. Over the following two days, participants are asked to solve two or three tasks on their own during a five-hour supervised session. The solutions are collected from all the regional centers in Poland and are evaluated in a common environment using the same checking methods. Around 80 authors of the best solutions will be selected for the Olympiad's finals. This third stage is organized in one place and lasts for five days: there are three competition days and two days for recreation and sightseeing. The finals are very similar to the second stage of the competition. The resulting four best contestants will represent Poland in international programming competitions, including the International Olympiad in Informatics.

To date, 19 meetings of the Polish Olympiad in Informatics have presented 15,000 students with a total of 300 tasks to solve.

The **International Olympiad in Informatics** takes place every summer and gathers together the best high school programmers in the world. The first International Olympiad in Informatics took place in 1989. Since then, Polish students have won 31 gold, 28 silver and 22 bronze medals.

Academic staff and students from the University of Warsaw have actively participated in organizing international programming competitions affiliated with the Olympiad in Informatics: the **International Olympiad in Informatics** itself (IOI 2005), three meetings of the **Central European Olympiad in Informatics** (CEOI 1997, 2004, 2011) and two instances of the **Baltic Olympiad in Informatics** (BOI 2001, 2008).

Each year, finalists in the Polish Olympiad in Informatics have the opportunity to participate in the **Polish Olympiad in Informatics Training Camp**, where they get to solve and thoroughly discuss algorithmic and programming tasks prepared mostly by older students from the University of Warsaw.

For the past six years, yet another event has been organized regularly, namely the **Junior Polish Olympiad in Informatics**—a competition for junior high school students. The idea for the Junior Olympiad came from the great teacher Ryszard Szubartowski, and the Institute of Informatics at the University of Warsaw was actively involved in launching and developing the contest.

Many finalists of the Olympiad in Informatics choose the University of Warsaw as the place to further their education in informatics. The University allows its students to develop their competitive drive by trying out for a spot in the team representing the University of Warsaw in team programming competitions, including the **ACM International Collegiate Programming Contest**. The ACM-ICPC is the oldest and most prestigious computer science competition in the world, and it is considered to be a world championship in team programming. Each team consists of three students representing a single university. Regionals are the first stage of the competition; a few dozen regional eliminations are organized on all inhabited continents. The best teams selected during the regionals (including winners and a few runner-up teams, depending on the strength of the region and the number of competing teams) advance to the finals.

Both regionals and finals have the same format: each team, composed of three members, is presented with one computer and given five hours in which to solve between eight and twelve tasks. The solutions proposed by the contestants are evaluated in real time, after which the teams receive post-evaluation feedback in the form of a short but clear communication: *accepted*; *run-time error*; *time limit exceeded*; *wrong answer*; *presentation error*. All tasks are evaluated individually and marked as accepted or rejected. The team that completes the most tasks successfully wins the competition. In the event that several teams complete the same number of tasks, they are ranked based on the total time spent solving the tasks, shorter times being better. However, each rejected submission of a completed task results in a 20-minute time penalty.

The history of the ACM-ICPC dates back to 1977 and is closely intertwined with the work of Bill Poucher, the originator and director of the competition. The contest was popularized among Polish students and academic staff by Professor Jan Madey, who formed the first team representing the University of Warsaw in the competition in 1994. The team was sent to Amsterdam to compete in the eliminations, and succeeded in getting through. As regional winners, these University of Warsaw students were invited to the finals in Nashville, where they came 11th. Ever since then, teams from the University of Warsaw have qualified for the ACM-ICPC World Finals every year, and have won the entire competition twice: in 2003 and 2007. In 2012 the University of Warsaw has the pleasure of hosting the finals of the ACM-ICPC.

It is worth mentioning that the University already has some experience in organizing large-scale events like this. Between 2001 and 2003 the University of Warsaw hosted the **Central European Regional Contest**—an event that serves as eliminations for ACM-ICPC. In 1998–2001 and 2011 the University organized the **Polish Collegiate Programming Contest**.

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In 2001, during the course of preparations for the Baltic Olympiad in Informatics, a new programming competition, Algorithm Busters, was launched. In 2005 it changed its name to **Algorithmic Engagements**. Algorithmic Engagements is an individual competition for any person of any age and professional status who is willing to sign up for it. The only things that really matter are each contestant's knowledge and skills. The competition consists of two stages. The first is organized via the Internet, lasts for about a week, and is divided into five or six rounds. During each of the rounds, contestants are asked to solve between one and four tasks. The level of difficulty increases from one round to the next. The top 20 participants from the first stage are invited to regular finals that have a format similar to those of the ACM-ICPC (the only exception being that the contestants solve tasks on their own rather than in teams). The winner receives the title of Algorithm Master of the Year. Algorithmic Engagements has become quite popular over the years; every year a few thousand people sign up for the event, and some of them even update their CVs with their competition achievements.

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As one may imagine, over the course of many competitions we have organized in the past, hundreds of original programming tasks have been invented and properly described. In order to "keep them alive", we do our best to upload as many of them as possible to an educational portal called **MAIN** (to be found at http://main.edu.pl*), which was created at the initiative of organizers of the Polish Olympiad in Informatics and is administered by academic staff and students of the University of Warsaw. MAIN's archive is integrated with the computer system of the Polish Olympiad in Informatics, called **SIO**, which enables solutions to tasks uploaded on the portal to be evaluated in real time, 24/7. Readers of this book can prepare their own solutions to tasks presented herein and then have them checked on the MAIN portal. Good luck!

About the authors

The authors of the texts presented in this book are closely affiliated with the University of Warsaw and have had a significant impact on the course of the history of algorithmic and programming competitions organized or co-organized by the University. Due to the nature of this book, we have limited ourselves solely to people who have experience in writing and solving competition tasks. The authors include lecturers and students, former contestants with international successes in programming competitions, educators and popularizers of informatics.

Each author was asked to choose the two tasks that they found the most interesting from competitions co-organized by the University of Warsaw, and to discuss their solutions. The choice was based on the level of difficulty of the tasks, the methods and techniques of solving them, their educational value or the particular author's personal memories of a specific task. Each task and description of its solution is preceded by a short biography of the author, illustrating the links between their careers and programming competitions as well as their scientific and private interests.

* Currently portal MAIN is not supported. The problem archive has been moved to portal http://szkopul.edu.pl.

Acknowledgements

In the pages of this book we have only been able to honor a mere 30 individuals who have had a significant impact on the development of programming competitions in Poland—thereby contributing at the same time to the popularization of informatics and the education of many talented computer scientists. However, I would like to extend my thanks to everyone who has made it possible for this book to be published. I wish to thank the authors of the texts presented in this book, who managed to submit their extracts despite a very tight deadline. Special thanks should go to those who not only authored some of the texts in this book but also used their subject-matter expertise to edit the whole publication: Tomasz Idziaszek, Jakub Łącki and Jakub Radoszewski. Without their engagement and editorial hard work this book would have had no chance of being published. During the preparation of the English translation of the book we received help from my daughter Justyna Diks and my friend Jerzy Jaromczyk, assisted by Neil Moore. For the copy-editing of the English version, my special gratitude goes to Richard Hallas, who was supported in his work by Grzegorz Jakacki and Marcin Kubica. I am also extremely grateful to graphic studio Podpunkt for the layout design of this book and for patience with editors during the process of typesetting material for publication. While creating this book we received a lot of support and encouragement from Rafał Sikorski—a lawyer with a keen interest in informatics.

Having this book published as it is—both in Polish and English—and released in a limited run of 1000 copies in each language would not have been possible but for the financial support of the Ministry of Economy, PKO Bank Polski and Fundacja PKO Banku Polskiego. I would like to take this opportunity to express my appreciation to the management of these institutions for acknowledging the significant educational value of this book and supporting such educational undertakings.

To all readers of this book: enjoy the read and the satisfaction of discovering the secrets of algorithms!

Krzysztof Diks