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Iranian National Olympiad in Informatics

Mohammad Ali ABAM[1], Abolfazl ASADI[1], Afrouz JABAL AMELI[1],
Saeed R. SEDDIGHIN[2], Farhad SHAHMOHAMMADI[3]
[1]*Sharif University of Technology, Iran*
[2]*University of Maryland*
[3]*Google*
*e-mail: abam@sharif.ir, abasadi@ce.sharif.ir, ajabalameli@ce.sharif.ir,
seddighin@ce.umd.edu, farhadsh@google.com,*

Introduction

Iranian National Olympiad in Informatics (INOI) is organized by Young Scholars Club (YSC), an entity organizing all scientific Olympiads on behalf of the ministry of Education (see logo of YSC, Fig. 1). YSC holds nation-wide contests to select top students in each field, representing Iran in international Olympiads. This includes Olympiads in mathematics, physics, computer, chemistry, and biology. YSC has appointed a committee for each Olympiad whose responsibility is to select and prepare the students for the national and international contests. One of these committees is the national committee of INOI. The INOI committee consists of different generations of IOI and INOI medalists. Three decades of experience has led the INOI committee to establish a multi-round selection system which we explain next in more details.

Fig. 1. Young Scholars Club is the host for Olympiads.

The First Round

Every February between five to ten thousand students at grades 10 and 11 participate in the 1st round contest nationwide, one thousand of which advance to the 2nd round. In the 1st round, the contestants answer thirty easy multiple-choice problems in three hours.

The goal of the 1st round is to examine the mathematical knowledge and creativity of contestants. Therefore, the problems are designed in a way that the basic mathematical knowledge is sufficient to solve them. Problems are divided into three main categories, namely combinatorics, preliminary graph theory, and puzzles. Most of them are mainly focused on enumerative combinatorics and simple optimizations.

The 1st-round committee starts the preparation process from December. The committee calls all former INOI medalists to submit their problems in order to form a long-list of problems. Afterwards, the committee selects the final problem set for the contest through several meetings, and turns them into multiple-choice problems. Finally, the committee asks three former INOI medalists to take the contest in advance to find any potential issues. To get more insight, we next explain a sample problem of the 1st round exam.

A sample problem. *Five police officers are seated around a table wearing sunglasses, which are either red, blue, or yellow. Each officer can only see the world through his own sunglasses, therefore rather than seeing the actual color of an object, he sees a combination of the object's color and the color of his sunglasses. For example, an officer wearing a red sunglass sees a blue object in purple. Keep in mind that an officer does not see other sunglasses in their actual color too. The following table shows how the combination of colors is.*

yellow	blue	red	
orange	purple	red	red
green	blue	purple	blue
yellow	green	orange	yellow

Captain Ilich asks each officer to report the set of colors when he sees the other four sunglasses. For example, suppose that the police officers wear red, red, blue, yellow and yellow sunglasses, respectively. The second officer says: "I see red, purple and orange *colors". For how many cases out of all* 3^5 *cases, Capitan Ilich can uniquely determine the color of each officer' sunglasses?*

1) 150 2) 153 3) 183 4) 213 5) 243

Solution to the sample problem. *The answer is* 243. *Let* S *be the set reported by an officer. If a primary color (red, blue or yellow) is in* S, *the color of his sunglasses is that primary color. Moreover, if two different secondary color (purple, orange or green) is in* S, *the color of his sunglasses is determined uniquely. Now suppose that* S *doesn't contain any primary color and contain only a single secondary color. In this case, the four other officers' sunglasses have the same color and Ilich can guess the color of their sunglasses, and so the color of the officer's sunglasses can be determined from this color. Therefore, Ilich can guess the color of sunglasses in all cases, and consequently the answer is* $3^5 = 243$.

The Second Round

The second round of INOI is held on two consecutive days in April. Each exam lasts for almost four hours. The first-day exam consists of twenty-five multiple-choice problems similar to the 1st-round exam, but more challenging. The second-day exam consists of four theory problems, mainly focused on graph theory, and combinatorics, similar to the problems in IMO. Contestants are required to provide a detailed proof, which can span over multiple pages.

Grading is done in two phases. First, all contestants are graded by their multiple-choice exam, and then roughly the top 300 contestants will be graded on their written exam. Each question is graded by two former medalists independently, and if the scores are different, they will grade it again for the third time together. The final score of each student is the sum of the contestant's scores obtained in both exams. Contestants may also object to their grades, should they decide any of their grades is below their expectation. Finally, the top 80 contestants advance to the 3rd round.

The preparation process of both exams is done in parallel by two separate committees. The head of each committee invites former INOI medalists to submit their problems. These problems are verified and categorized by their difficulty and subjects, and the committee selects the exam questions from them. Finally, three former INOI medalists take these exams and give their feedback to both committees to refine the problems.

As already mentioned, the 1st-round and 2nd-round exams mostly concentrated on theoretical computer science. This is mainly due to increasing the creativity of contestants and measuring their skills in computer science under a fair platform. Unfortunately, all students in the entire nation do not get the opportunity to learn the fundamentals of algorithms and programming. Therefore, including algorithmic and programming problems to the 1st and 2nd rounds would be in favor of a few students who have coding experience. We also believe by a solid background in combinatorics, students are more prepared to learn algorithms. Below, we present a sample written problem and a sample multiple-choice problem of the past 2nd-round exam.

A sample written problem. *Let $n > 2$ be an integer. Ilich has $3n - 2$ coins of weight 1 gram and 2 coins of weight 0.5 grams. He needs one of the 0.5-grams coins for shopping. Since all coins are identical in terms of shape, he had trouble finding the proper coin. He only has a magical machine that can help him solve the problem. At each step he can put two coins on the machine, and the machine shows whether or not the sum of the weights of the selected coins is an integer number.*

1. *Prove that Ilich can solve his problem by using the machine in at most $2n - 1$ steps.*
2. *Prove that Ilich can not design an algorithm which guarantees to solve the problem in less than $2n - 1$ steps.*

Solution to the sample written problem.

1. *Partition the coins into n groups $A_1, \dots, A_n$ such that for every $1 \leq i \leq n$, $|A_i| = 3$. Also denote the members of $|A_i|$ by a_i, b_i and c_i. For every $i < n$, use the machine for $\{a_i, b_i\}$ and $\{a_i, c_i\}$. Since there are only two 0.5-gr coins, if the result of both sums are integers then a_i, b_i and c_i are 1-gr coins. In this case call A_i a "`perfect" set. Otherwise you can partition A_i into two nonempty subsets $A_{i,1}$ and $A_{i,2}$ such that $|A_{i,1}| = 2$ and the coin in $A_{i,1}$ has different weight from coins in $A_{i,2}$. In this case define A_i as an "imperfect" set.*
   - *If at these $2n - 2$ steps, Illich finds out that he has two imperfect sets, namely A_i and A_j, then he can conclude that $A_{i,1}$ and $A_{i,2}$ contain the 0.5 gram coins.*
   - *If at these $2n - 2$, Illich finds only one imperfect set, namely A_i, then by checking a member of a previously determined perfect set by a member of this imperfect set he can compute the weight of the coins in the imperfect subset, and thus he can find at least one 0.5-gr coins.*
   - *If none of the above cases occur, then A_n has two 0.5-gr coins and a 1-gr coin. So by using a machine one more time for a_n and a member of a perfect set he can find a 0.5-gr coins.*
2. *To obtain a contradiction assume that Ilich has an algorithm which can solve the problem by less that $2n - 1$ steps. Also Assume that the magic machine at all steps shows integer sums. Construct a simple graph G which has $3n$ vertices which represent the coins and two coins are adjacent if and only if at one step Ilich use the coins to check sum of this two coins; Thus G has less than $2n - 1$ edges. Assume G has r connected components with $a_1 \leq \cdots \leq a_r$ vertices. Denote the set of coins of each component by $S_1, \dots, S_r$; Note that $|S_i| = a_i$ for every $0 \leq i \leq r$. Now since every component with t edges has at least $t - 1$ edges so r is at least $3n - (2n - 2) = n + 2$ components. So since $\sum_{i=1}^{r} a_i = 3n$, one of the followings cases occur:*
   - *$a_1 = a_2 = a_3 = 1$. In this case every pair of these three coins may be the two 0.5 gram coins and ilich can not guarantee the correctness of his algorithm.*

- $a_1 = a_2 = 1 < a_3$. *In this case since* $\sum_{i=1}^{r} a_i = 3n$ *and* $r \geq n+2$, a_3 *should be equal to two. So both coins in* $S_1 \cup S_2$ *and both coins in* S_3 *vertices can be the pair of the two 0.5-gr coins.*
- *If* $a_2 > 1$ *then we have* $a_2 = a_3 = 2$. *So there are two scenarios that Ilich can not distinguish between them. First scenario is that coins in* S_2 *are 0.5-gr and all other coins are 1-gr coins. Second scenario is that coins in* S_3 *are 0.5-gr and all other coins are 1-kg coins.*

So Ilich can not guarantee that his algorithm works which of course is a contradiction.

A sample multiple-choice problem. *Suppose that we have a table where* 0 *or* 1 *is written in its each cell. The set of four cells being in in the intersection of any two different rows and two different columns, and containing* 0 *is called a "Jabali" group. Also the set of four cells being in the same row and containing 1 is called a "Soltani" group. What is the maximum positive integer* n, *such that there is an* $n \times n$ *table with no jabali group and no soltani group?*

1) 4 2) 5 3) 6 4) 7 5) 8

Solution to the sample multiple-choice problem. *The answer is* 5. *See below table for* $n = 5$:

1	1	1	0	0
0	1	1	1	0
0	0	1	1	1
1	0	0	1	1
1	1	0	0	1

Now we prove that no such table exists for $n > 5$. *For the sake of contradiction suppose that* $n > 5$, *and there is a table not containing any Jabali or Soltani group. In each row there must be at least* $n - 3$ *cells with number* 0. *Thus, there are at least* $n \times \binom{n-3}{2}$ *pairs of* 0 *cells, such that the cells of each pair are in the same row. We have* $\binom{n}{2}$ *pairs of columns in the table. Since* $n > 5$, *we have* $n \times \binom{n-3}{2} \geq \binom{n}{2}$, *and according to the pigeonhole principle there are at least two same pairs of columns that have number 0 in their cells and a Jabali group is found. This contradicts our assumption, and therefore the proof is complete.*

The Third Round

The third round of INOI is an onsite programming contest which aims at evaluating contestants' programming and problem solving abilities, without requiring any background in formal algorithms. By holding this annual contest, the INOI committee tries to encourage students to get more familiar with computer programming before the summer camp, so that this camp can be more focused on principal computer science theory concepts. This contest is designed as a filter to eliminate the students with insufficient experience in computer programming, rather than a contest to identify the best students. Around top 80 students from the 2nd round are eligible to participate in this contest and about 40 of them will be qualified for the INOI summer camp.

The contest is held in two consecutive days and each contest consists of 3 tasks, each divided into 3 subtasks. The tasks are batch problems and do not require any I/O interaction. In addition, there are no time or memory limits for each task. The answer to each subtask is an integer number. To prevent cheating, a unique prime number is assigned to each contestant and the answer to each subtask is a function of this number. An online judging system is provided to the contestants to validate their answers instantly. Each contestant can use the judging system at most 20 times for each subtask. The first subtask of each task is usually solvable using a very simple program or even by hand. The second subtask is solvable without complex algorithms, usually by just brute forcing the problem space, and the third subtask requires finding an optimal solution for the problem. Below we present a sample problem from the past 3rd-round exam.

A sample problem. *Assume that* $\Delta = 19913$. *We call a pair of integers* (a, b) *k-friendly if and only if* a *and* b *have exactly* k *common divisors. For example, pairs* (3, 9), (10, 14) *and* (9, 3) *are three different 2-friendly pairs. We also call a pair* (a, b) *less than* C, *if and and only if* $a < C$ *and* $b < C$.

1. *Define* A *as the number of 1-friendly pairs less than* Δ. *What is the remainder of* A^4 *divided by* Δ?
2. *Define* B *as the number of 48-friendly pairs less than* Δ. *What is the remainder of* B^4 *divided by* Δ?
3. *Define* C *as the number of 48-friendly pairs less than 12299390. What is the remainder of* C^4 *divided by* Δ?

The Summer Camp

The most intense and important program of INOI is the summer camp. Students who advanced to this program, come to the country's capital Tehran from all over the country and live together for almost three months. All students who participate in this program receive a medal at the end of the summer; the top 8 students receive a gold medal and later participate in more training programs. The rest of the students receive silver and bronze medals.

The summer camp is very similar to a school of computer science. Four main courses are always included in this program, namely C++ programming, algorithms, graph theory, and combinatorics. In addition to this, an additional short course is added to the program. The goal of this short course is to make students familiar with a more advanced area of computer science. Each course has its own instructor and grading policy.

During the summer, many classes are held for each course and students are evaluated in the mid-term and final exams. Apart from this, every week there is a theoretical exam to evaluate the overall problem-solving skill of the students. Moreover, as students learn more about programming languages and algorithms, we hold some programming exams most of which have either two or three problems and last for five hours. The problems are relatively easier than IOI, since the students are new to programming, but as we approach the end of the summer, the programming exams intensify and get harder.

At the end, based on some written exams and programing exams students are ranked; the first top 8 students get a gold medal (Fig. 2), the next top 16 students get a silver medal, and the rest get a bronze medal.

Fig. 2. Gold medals!

The Gold Camp and the Team Selection

All 8 gold medalists of the summer camp enter the gold camp; 4 of whom will eventually participate in the IOI. The gold camp starts at the beginning of Fall and usually ends before Spring when the team-selection contests are held. In contrast to the previous training camps, the main focus of this program is on the algorithmic and programming problems. Most of this training program is online, though a few 1-week long camps are usually scheduled for onsite classes and midpoint evaluations.

In the online training camp, several problems are selected from various online programming platforms such as Codeforces, SGU, Topcoder, etc., and given to the student as weekly assignments. The students have a limited amount of time to solve the problems and submit their solutions to an online judge. They're encouraged to have discussion sessions and collaborate to find the solutions, however, students have to write their codes individually.

Students get their grade after the deadline for each assignment. These grades are not incorporated in the final team selection criteria, however, if a student exhibits a poor performance on the assignments, based on the decision of the INOI committee, he might be penalized or even disqualified from participating in the final team selection contests.

Every month, a 1-week onsite training camp is scheduled for the students both for educational and evaluation purposes. These camps are held and accommodated by YSC. The main focus of these camps is on training classes, mostly instructed by former INOI medalists. In addition to this, most onsite camps feature one or two programming exams to monitor the progress of the students. The results of these exams are incorporated in the final team selection process.

Following the training camps come the team selection contests. A few weeks before Nowruz (Iranian festival of spring), students come to Tehran to participate in these contests. The number of contests varies between 3 to 5, based on the decision of the INOI committee. The format of each contest is similar to the IOI contests. Each contest consists of 3 programming problems, designed by the committee and lasts for 5 hours.

The Team Training

The students who advanced to the IOI participate in a spring camp to further practice for the IOI. The main goal of this camp is to ensure that the syllabus of IOI is completely covered. The IOI team also get more familiar with advanced algorithms and data structures, not necessarily included in the IOI syllabus. This camp takes place in YSC and continues until the IOI contests. The format of this camp is based on practice contests. The team take at least 3 practice contests, in the same format as an IOI contest, every week. The contests are selected from the previous IOIs and the most recent CEOI and BOI contests. After each contest, the committee holds discussion sessions for each contest.

Fig. 3. Iran team in the IOI 2015.

Another important part of this camp is inviting former IOI medalists to share their experiences about the contest environments and unexpected things that can happen in the IOI contest, with the new team. Interestingly, these experiences have proven to be useful for the members of the new team and helps them to prevent common mistakes, caused by stress of the contest and the new environment that the students are put in.

M.A. Abam is a faculty member of the computer engineering department at Sharif university of Technology. He has been the chair of the INOI committee and team leader of Iran at IOI since 2011. He is also chair of the IOI 2017.

A. Asadi is a computer engineering student at Sharif and a member of the INOI committee. He is also a coach and problem maker at the INOI summer camps.

A. Jabal Ameli is a Sharif computer engineering graduate and a member of the INOI committee. He is also a coach at INOI summer camps, he used to be the deputy leader of Iran at the IOI 2016.

S. Seddighin is a Sharif graduate and PhD student at the University of Maryland and used to be a member at the INOI committee. He is also a silver medalist at the IOI 2007 and a Sharif team member at the ACM/ICPC in 2009.

F. Shahmohammadi is a software engineer at Google and a Sharif and UCLA graduate. He used to be a member of the INOI committee and a coach in the summer camps. He also used to be the deputy leader of Iran at the IOI 2013.