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Intelligent Management of Preparations for Programming Olympiads on the Basis of Swarm Intelligence Algorithms

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Abstract—As a rule, approaches to managing the preparation of learners for programming Olympiads are not intended for intelligent interactive support from learning management and the software tools based on these approaches do not allow efficient processing of information for shaping individual and team preparation trajectories and providing this information to learners. This study proposes a method of organizing the intelligent management of preparation for programming Olympiads, based on the system-level approach, organizational systems control theory, and implementation of the entire IT specialist training cycle, including the phases of planning, organization, control, and motivation. It is proposed to adaptively shape learning trajectories and adjust them on the basis of swarm intelligence algorithms modified to include features for managing the training of learners for programming Olympiads. It is proposed to shape individual learning trajectories for participants in individual Olympiads on the basis of a modified firefly algorithm and team learning trajectories for participants in team Olympiads on the basis of a modified fish school search algorithm. It is also proposed to supplement the training process with recommendations and exercises selected by the results of psychological testing and intended to develop the personal and psychological qualities of the learners. The recommendations are followed throughout the preparation process until the threshold values of personal and psychological qualities necessary for participation in an Olympiad are reached.

Keywords: Olympiads programming, contest, swarm intelligence algorithms, modified firefly and fish school search algorithms, online judge systems, individual and team learning trajectories

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INTRODUCTION

Programming Olympiads are an important stage in training successful programmers, because these contests encourage interest in IT, develop such qualities as goal commitment and personal leadership, creative ways of solving formulated tasks, skills for properly formalizing and solving tasks within a limited time frame, and testing, debugging, and teamwork skills [1, 2].

This work is aimed at analyzing the existing methods of managing the preparation for programming Olympiads, determining problems with organizing the intelligent management of preparation for programming Olympiads, and describing the features of the developed software set for this intelligent management.

1. APPROACHES TO MANAGING PREPARATIONS FOR OLYMPIADS

The practical training for participation in programming Olympiads involves regularly solving large numbers of tasks and solving tasks in groups trained by ranking-based contests [1]. Because the mastery of the minimal bulk of necessary theoretical expertise and the checking of task solutions are fairly labor-intensive processes, the application of e-learning technologies is gradually being expanded. Thus, for example, remote learning systems that contain study materials and check task solutions are broadly in use. In [3], M.S. Dolinskii describes a concept of remote learning system of preparation for participation in programming Olympiads. This concept was developed at the New IT Research Labs of the Francisk Skorina Gomel State University. The functions implemented in the system for individual and team users are results checks, score evaluation considering the time used to solve the tasks and make repeated solution attempts, and individual selection of task sequences on various topics.

Work [4] presents cases of successfully using for training purposes online judge systems designed for training programmers, automated executed task checks, and running programming Olympiads.

Work [5] describes the application of the Ejudge network system created at the Lomonosov Moscow State University (https://ejudge.ru) for programming education and participation in programming Olympiads. In this system, the learning process is based on solving sets of tasks combined in tours and on keeping student ranks.

Systems similar to Ejudge have been designed by M. Mirzayanov (https://codeforces.com), Yandex (https://contest.yandex.ru), the ITMO University in St. Petersburg (https://neerc.ifmo.ru/ trains/information/software.html), Ural Federal University (https://acm.timus.ru), Novosibirsk State University (https://olympiad.nsu.ru), and other institutions.

In work [6] the learner is offered to make up lists of exercises in the Online Judge System depending on their complexity (simple, medium, and hard); for this purpose, it is proposed to choose a desired theoretical section and a number of tasks on the list. The complexity level of each task is determined automatically on the basis of complexity estimates as indicated by learners in submitted task solutions.

In [7], it is proposed to use a trained neural network on the basis of the SCFH model for dividing the learners in to three classes, including risky, intermediate, and advanced; this is needed to create the feedback with their teachers on the basis of data from logs of the Online Judge System. The SCFH model uses four factors, including the number of correctly solved simple tasks (simple) and complex tasks (complex), frequency of student use of the online system (frequency), and number of help requests (hint).

Work [8] proposes to form recommendations for solving Olympiad tasks on the basis of a preliminary data processing strategy intended to detect fallouts by the number of student attempts to solve a specific problem. Such tasks are selected for hard problems with the help of fuzzy logic tools.

Work [9] describes the Ejudge project developed at the University of Valladolid, Spain, to integrate the UVA Online Judge (https://uva.onlinejudge.org) in the Moodle learning management system and the QUESTOURnament module. Moodle's main functions are searching for problem-plagued areas and poll and evaluating learners. The QUESTOURnament module creates various contests and generates adaptively variable training task sequences. In this module, questions, and tasks are classified by complexity using fuzzy production models, the structural parametric adjustment of which is conducted using a genetic algorithm [10].

Works [11, 12] propose various collaborative filtration techniques for providing recommendations in the Online Judge System by training task sequences.

Article [13] describes the architecture of the Aizu Online Judge platform (https://judge.u-aizu.ac.jp/onlinejudge/) for programming classes and holding competitions. This architecture was developed at Aizu University, Japan, and it is based on dividing the functions of data server, judge server, and client programs, and has been designed proceeding from the classification of the main acting parties. These parties are actors represented by learners and teachers who create tasks and evaluate learners, judging as a special program agent accepting task solutions and rendering verdicts, program agents for data handling, and researchers who analyze accumulated statistics. This architecture implies the management of learning objects, such as tasks, solutions, judicial verdicts, etc. The learning trajectory is a set of training tasks and materials. This set is determined by considering the strengths of individual learners in various categories and their preferences, as well as diagrams of learner assessment by tasks submitted for checking and composed on the basis of a recurrent neural network (RNN). This RNN is trained with the help of accumulated data on sequences of tasks solved by experienced users [14].

On the whole, the software tools used in preparations for Olympiads have the following features: support of various programming languages; archive of existing tasks (with conditions, landmark solutions, and tests) grouped by topics, complexity, score, and purpose (for training courses, credits, exams, competitive programming, Olympiad tours); archive of solutions sent by participants; training materials; forums and chats; maintenance of the participant rankings; and organization of online Olympiads with various scoring methods. These systems have fairly limited opportunities for programming classes because only a small part of these tools and systems can be shaped by individual recommendations for preparations for Olympiads.

The trends characteristic of modern learning systems include the use of adaptive learning and individualization of education trajectories [13, 15]. It is also necessary to consider that personalized training, taking into account individual student qualities, is widely used in very different domains. For example, work [16] proposes to shape the individual development and learning trajectories of corporate employees with the help of personal employee profiles compiled using the Sixteen Personality Factor Questionnaire (16PF) and the Holland Code (RIASEC) Test, list of key corporate areas of activity, desired course of employee development, classification of employee motivation types, and learning management systems (LMSs).

Work [17] notes that, in addition to the distribution of roles in teams (programmer, algorithm specialist, tester, ideologist, executor, and critic), the system of team preparation for Olympiads must consider the peculiarities of the mindset of each team member. In addition, the level of maturity of education competences, general cultural and occupational competences included, must also be considered. The training for participation in team Olympiads is organized on the basis of studying various methods, supported by solving a series of tasks ordered by complexity. However, the Olympiad preparation process does not contemplate any psychological correction of personal qualities for teamwork, and there is no description of the development of the team preparation trajectory, considering the features of each concrete team.

Thus, the existing program systems use various methods to elaborate recommendations (individual recommendations included) for programming Olympiad preparation. However, these systems have several weaknesses:

— In most cases, they do not allow efficient management of the development of personal education trajectories; in this work, an individual education trajectory is understood as a sequence of transitions among study courses, theoretical sections, topics, and Olympiad tasks. This sequence is individual for each single student or each team and adaptive, that is, it implies constant automated correction depending on the study results of a single student or team, the speed and quality of acquiring study material, and solving Olympiad tasks;

— but the personal and psychological qualities of learners are ignored. The consideration of these qualities is a significant aspect because the preparation for and participation in programming Olympiads are usually fraught with fairly high mental loads; in addition, the participation in team Olympiads requires perfectioning teamwork skills, which requires developing respective PPQs for having good results.

— The fact that Olympiads are divided in individual (personal) and team (with three or more participants) events is ignored. There are no existing methods of managing the development of trajectories of team preparation for programming Olympiads.

2. MATERIALS AND METHODS

The materials used for the study are the rules posted at https://acmp.ru and the peculiarities of preparation for and organization of programming Olympiads in Russia and Belarus. Individual education trajectories are developed using swarm intelligence algorithms, because these algorithms allow the most efficient solutions to be derived, have fairly low computational and implementation complexity (which is important because the generation of long sequences of study materials is a hard task [18]), and model pretraining is not required.

3. INTELLIGENT TRAINING MANAGEMENT

To organize an intelligent system for managing programming Olympiad preparations, it is proposed to use the IT specialist training cycle generated using the main provisions of the organization systems management theory [19–22], and the management of the Olympiad programming learning process with swarm intelligence algorithms [23].

The swarm intelligence algorithms in use are selected, considering the similarity in standard behavioral patterns of single learners and teams during preparation for Olympiads. For example, work [13] shows that the learning trajectory of experienced programmers is a good guideline for beginning programmers. This is why, the individual education trajectories were developed using a modified Firefly algorithm based on the firefly algorithm (F-algorithm) [23–25, 27] and adapted to manage the preparation for programming Olympiads.

To manage the development of team education trajectories, it is proposed to use a modified fish school search algorithm to describe the behavior of the participants with various types of expertise, skills, habits, and psychological characteristics during teamwork aimed at determining a rational strategy of Olympiad task solving [23, 24, 26, 27].

Olympiad preparation along developed and constantly corrected trajectories is supplemented by recommendations for developing learners PPQ with the help of psychological games and exercises. These trajectories are corrected depending on the rate and quality of the task solving. The recommendations are based on psychological testing and are used to achieve the threshold PPQ values necessary for participation in Olympiads.

The connections of the basic phases of the intelligent management of the individual education trajectory generation on the basis of the modified Firefly algorithm, considering PPQs, are shown in Fig. 1. First, each potential participant takes the general psychological test to identify PPQs that determine their capabilities for Olympiad programming. This testing includes the Amthauer intelligence structure (TSI) test, the Munsterberg selective attention test, the stress resistance test, the personal adaptability test (adaptivity multilevel personality questionnaire, E.E. Tunik's personal creativity questionnaire), the verbal creativity test (S. Mednik's RAT test), and tests of personal will and creativity potential together with other PPQ [20, 23]. At subthreshold PPQs, the learner is offered to fulfill a set of recommendations during the learning

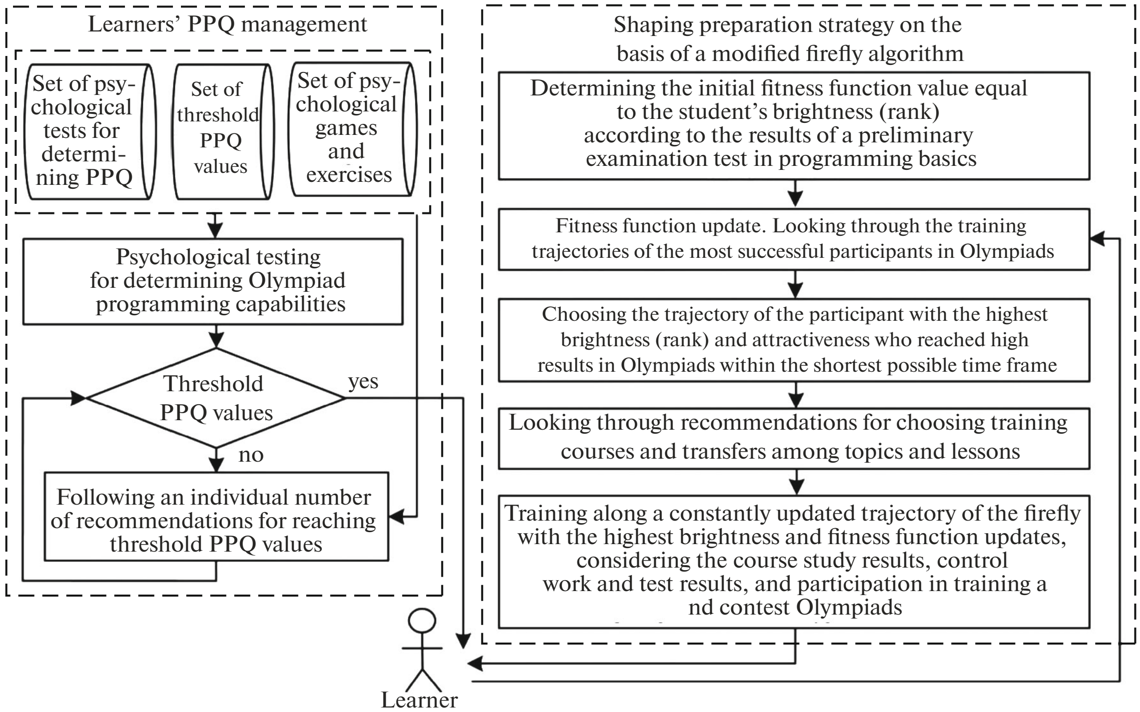

Fig. 1. Intelligent education trajectory generation management for preparation to individual Olympiads.

time to achieve threshold levels of stress resistance, adaptability, memory, attention concentration, and other such PPQs.

It is proposed that, in the modified firefly algorithm, the value of the fitness function $\varphi(X_i)$ should be equal to the value of the radiation brightness defined as the rank of a learner who is taking a chosen study course. The initial value of the fitness function $\varphi(X_i^0)$ for each learner is defined as their rank X_i with the result of a preliminary module test. It is proposed to run the firefly motion by reproducing the training course trajectories of the most successful participants in Olympiads (fireflies with the highest brightness (rank)). The sequence of moves made by each learner among the courses and lessons is saved in the system. The recommendations for individual learning trajectories are automatically generated on the basis of the constantly updated values of $\varphi(X_i)$ and taking into consideration the chosen study course trajectories of the fireflies with the highest brightness (rank) and attractiveness. The attractiveness of learner s_j for learner s_i is defined from [23]. The trajectories and ranks $\varphi(X_i)$ of the most successful participants in Olympiads are seen by all of the other learners. Incomplete task solutions are counted for scoring and the actual number of points is pro rata with the number of correctly passed tests by tasks (https://acmp.ru). The condition for terminating an algorithm's work is the achievement of desired successes in Olympiad programming or the termination of preparations for Olympiads.

For the connections of the main phases of the intelligent management of the team education trajectory generation on the basis of a modified fish school algorithm, taking into account the PPQs of a team of learners, see Fig. 2.

In addition to taking the general psychological test, the learners are tested to determine the PPQs characterizing their teamwork capabilities, such as communicative and administrative inclinations (KOS-2 test) [28], personality and administrative capabilities within an organized group (test developed by L.I. Umanskii, A.N. Lutoshkin, A.S. Chernyshov, N.P. Fetiskin) [28], and other teamwork capabilities. Then teams are lined up with three persons in each and tested for psychological compatibility by determining Seashore group cohesiveness index [28] and other qualities. During the learning process, team participants fulfill recommendations for improving their team communication capabilities when required.

Each team has an individual Olympiad preparation trajectory and an individual strategy of behavior during the Olympiad; the experience of other, even very successful teams, can be unsuitable for a specific team because each team has unique expertise, skills, and habits. In the fish school search algorithm, the best result in solving Olympiad tasks while constructing the preparation trajectory, that is, the maximal result per training Olympiad, is not determinative, because each Olympiad is unique. The team learns on the basis of the previous experience in solving training

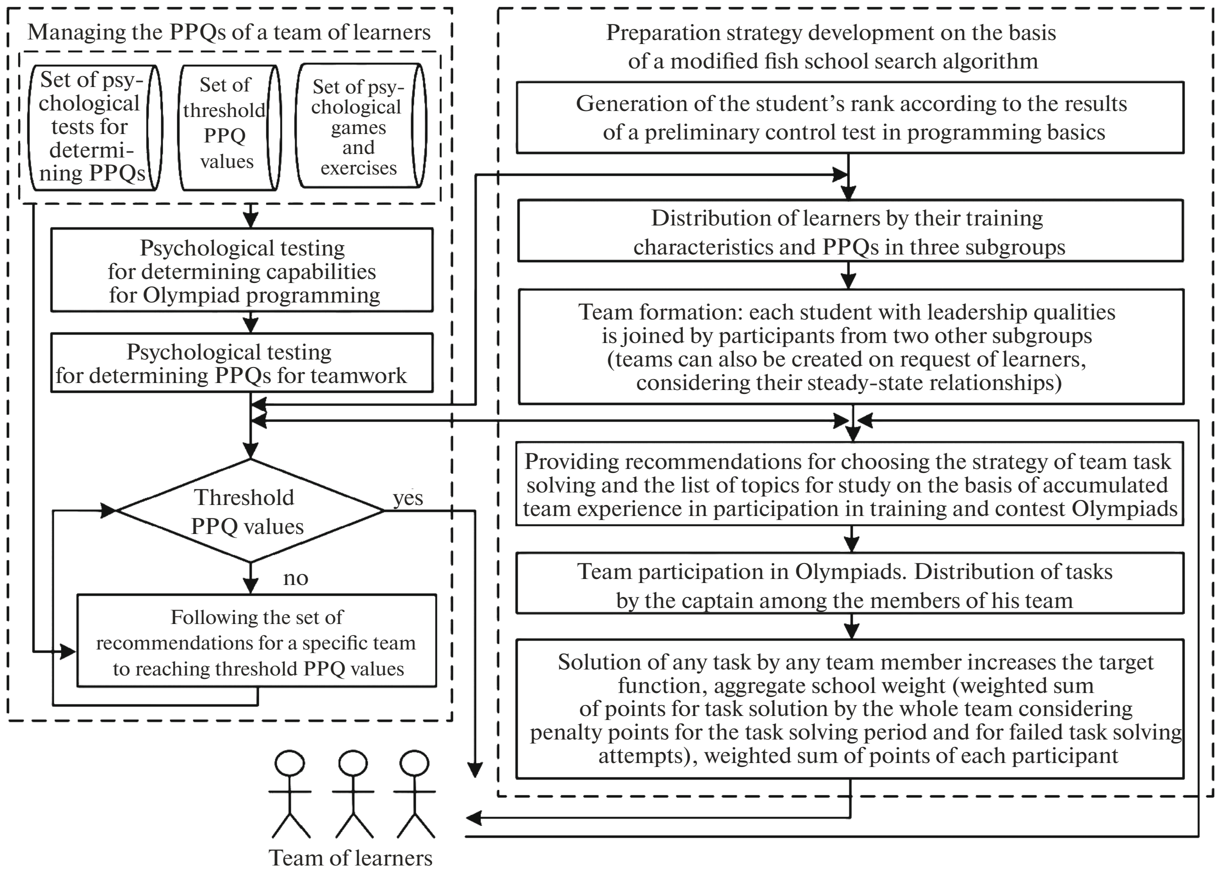

Fig. 2. Flowchart of the intelligent team education trajectory management for preparation for team Olympiads.

Olympiad tasks (the minimal number of Olympiads sufficient for this experience is 30) and thus develops a certain strategy for itself in the sequence of tasks it solves and distributes them by subject among the team members.

An iteration is the current phase in solving a set of tasks of a training or a contest Olympiad; in this case, each team member solves their own task or several team members solve a task together. When deciding on further actions, the fish school, that is, the team, proceeds from the current results of solving the tasks of the current Olympiad, that is, it relies only on the results of the previous iteration. During a new iteration the team solves one or several tasks of the tasks remaining in the tour.

The main distinct feature of the modified fish school search algorithm is the participation of the team captain in decision making. The team captain distributes the tasks among the other team members; in other words, this distribution is not random. The initial position or rank of each team member is determined by the results of solving the preliminary examination test.

The state of the team changes only when one of its participants finishes solving a task or the task is replaced by the captain; in other words, the random component is excluded. If the task has not been solved for a certain period, the team returns to its previous state and the captain can designate a different participant.

In each jth iteration, after any team member solves any task, it is necessary to consider not only the team results but also its penalty points, which is why it is proposed to calculate the target function as

$$\varphi(N_{r_i}) = \begin{cases} N_r, \ \forall K_i : \text{y } N_{r_i} = N_{r_j}; \\ N_r - BS_i/BS_{\max}, \ \forall K_i : \exists N_{r_i} = N_{r_j}, \end{cases}$$

where N_r is the number of tasks correctly solved by the ith team (which has passed all of the tests); BS_i is the penalty points of this team; $BS_{\max}$ is the highest number of Olympiad penalty points among all of the teams.

The successful solution of any task by any team member increases the weighted sum of points B_i (school weight) for the solution of tasks by the team minus its penalty points. The formula proposed for calculating this weighted sum of points is

$$B_i = \sum_{z=1}^{Z} B_{iz} + \frac{\sum_j (V_{ij+0.5} T_{ijz} \varphi(X_{ij+0.5}))}{\sum_j \varphi(X_{ij+0.5})} - \sum_{z=1}^{Z} (M_{iz} + A_{iz}),$$

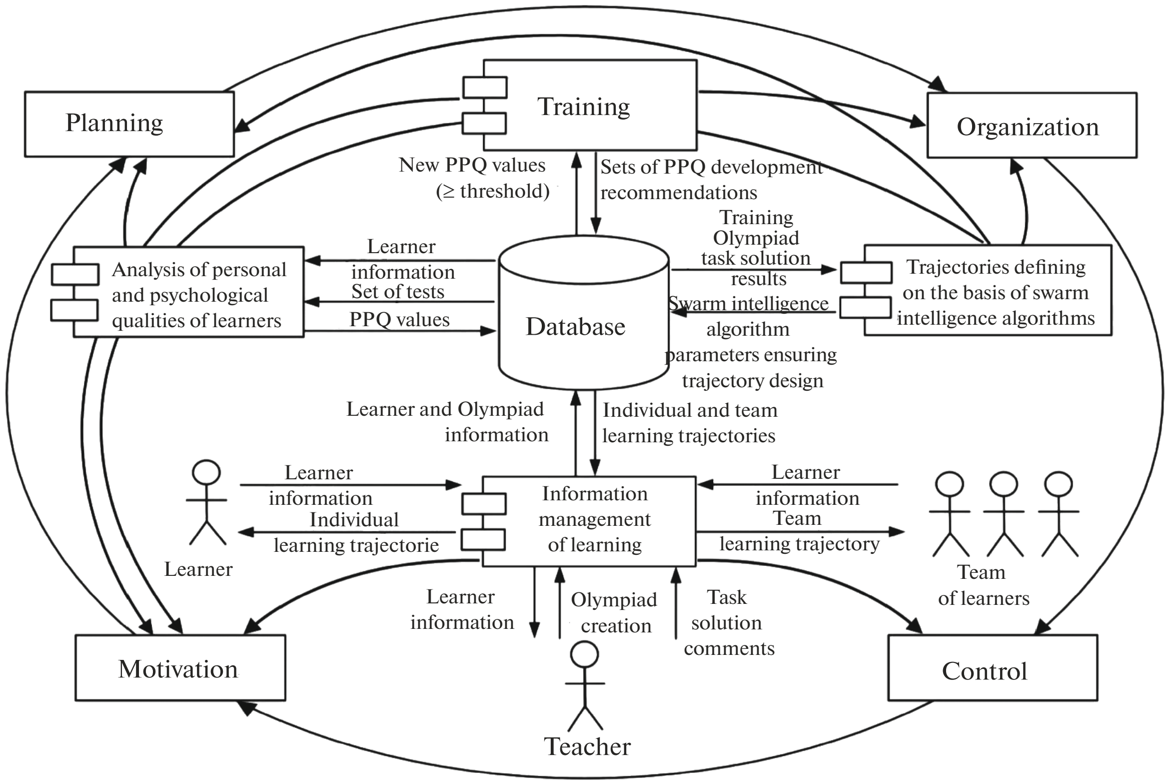

Fig. 3. Pattern of connections among the main elements of the cycle of automated management IT specialist training management and modules of the software suite.

where B_{iz} is the weighted sum of points scored by the *i*th team in the previous iteration;

$V_{ij+0.5}$ is the speed at which the *j*th learner from the *i*th team solves the *z*th task in the intermediate iteration with index $j + 0.5$ (during the intermediate iteration a regular task is solved);

T_{ijz} is the time for which task z is solved;

$\varphi(X_{ij+0.5})$ is the number of points in the intermediate iteration when the task is solved; these points are calculated as the product of maximal number of points $B_{\max}$ for the counted task solution and task solution probability $P(B)$: $\varphi(X_{ij+0.5}) = B_{\max}P(B)$;

M_{iz} is the time in minutes from the beginning of the tour to the credit after passing all of the tests to solve the *z*th task; M_{iz} is converted to points;

A_{iz} is the penalty points for each failed attempt to solve the *z*th task (https://acmp.ru).

Thus random data appear only during intermediate iterations.

The formula suggested for determining the weighted sum of points of each team member (intermediate weight of each fish) is

$$B_{ij+0.5} = B_{ij} + \frac{\varphi(X_{ij+0.5})}{\max(\varphi(X_{ij+0.5}))},$$

where B_{ij} is the weighted sum of points scored by the *j*th learner in the previous iteration.

The condition for terminating the work of the algorithm is the termination of preparations for the Olympiads.

Team trajectory recommendations include the automatic selection of Olympiad tasks for training and topics for study and are generated for each team depending on the speed and quality of solving tasks by topics in the course of learning.

4. GENERAL DESCRIPTION OF THE PROGRAM SUITE

The Olympiad training software is a set of program modules developed in Python (Fig. 3). The integration of modules within a program suite ensures the intelligent management of preparation for individual or team programming Olympiads.

The software structure is developed so as to execute the main phases of the IT specialist training management cycle (planning, training process management organiÿation, control, and motivation of learners).

The module *Analysis of personal and psychological qualities of learners* fulfills the following functions:

—taking of a set of psychological tests. The variants of test sets for individual learners and teams of learners are contained in the database of the suite;

—assessment of personal and psychological qualities necessary for participation in individual (personal) Olympiads;

—assessment of personal and psychological qualities necessary for taking the training to participate in team Olympiads;

—assessment of new PPQ values according to the results of following the sets of recommendations for their development.

The *Training* module automates the processing of information on learners PPQd for generating recommendations on improving these PPQd to levels equal to threshold PPQs. Sets of necessary recommendations are automatically generated depending on the chosen type of Olympiad (individual or team contest) and on the results of the psychological testing conducted throughout the entire Olympiad preparation.

The *Information management of learning* module ensures

—registration of learners and teachers in the system;

—creation of individual and team Olympiads (training and contest);

—input of Olympiad tasks (conditions, author solutions, check tests, and expected test results) by the teacher. In this case, the cost of tasks is specified considering their complexity determined using Bloom's taxonomy of learning [29];

—start for executing tasks in such languages as C#, Python, Java, C++, and Pascal;

—generation of system's verdicts by the results of checking task tests; examples of such verdicts are accepted, compilation error, and others;

—visualization of constantly adjusted learning trajectories for individual learners and teams;

—teacher-supervised learning process, for example, visualization of remarks on task solutions;

—maintenance of the rating of single learners and teams.

The mathematical module *Trajectories defining on the basis of swarm intelligence algorithms* contains modified implementations of the fish school search and the firefly algorithms and fulfils the following functions:

—automated determination of swarm intelligence algorithms parameters;

—automated determination of individual education trajectories on the basis of the firefly algorithm, that is, the generation of recommendations for transfers among training courses and lessons in these courses and Olympiad tasks considering the rank and learning trajectories of the most successful participants;

—automated determination of team education trajectories on the basis of calculating the weighted sum of points for the solution of a task by a team according to the fish school search algorithm.

The swarm intelligence algorithm parameters generated in the mathematical module are used to generate recommendations for individual and team education trajectories and passing to the *Information management of learning* module.

The above-specified proposals for and methods of maintaining the intelligent management of preparations for programming Olympiads are implemented in the program for assessing personal traits and psychological qualities of IT specialists [30] and in the program of teaching Olympiad programming on the basis of swarm intelligence algorithms [31].

5. RESULTS OF USING THE PROPOSED METHODS

The proposed methods of the intelligent management of preparations for programming Olympiads were tested in the programming section of a secondary school in Mogilev, Belarus. The preparation of the learners for individual Olympiads was managed on the basis of the modified firefly algorithm. The result of the first year was the first ever diploma awarded for participation in the regional Olympiad in computer science. In the subsequent years the learners followed the preparation trajectories of the most successful participants in Olympiads and fulfilled as required individual sets of recommendations for achieving threshold PPQ levels. As a result, the number of winners in regional Olympiads grew fivefold for five years, which confirms the efficiency of the modified firefly algorithm used in preparations for Olympiads, considering the learners' PPQ. From the third year of training the participants started to form teams for participation in the All-Russian team programming Olympiad for schoolchildren. The modified fish school search algorithm was used to generate team education trajectories considering learners PPQs. As a result, it took the best team only three years to go from the 24th to the sixth place and win a silver medal.

CONCLUSIONS

The intelligent management of preparation for programming Olympiads implements the entire process of preparing the learners for individual and team Olympiads. This preparatory process has been upgraded using the following features:

—The preparation management is based on the system-level method considering the organization system management theory and the IT specialist training management cycle, including the phases of planning, organization, control and motivation, and these phases are implemented in various modules of the developed program suite.

—The analysis of the existing methods of preparation for programming Olympiads held in various software systems has allowed proposing for use swarm intelligence algorithms modified considering the peculiarities of preparation for Olympiads.

—The modified firefly algorithm has been proposed for use in shaping individual education trajectories for single learners.

—The modified fish school search algorithm has been proposed for use in shaping education trajectories for teams of learners.

—It has been proposed to expand the preparation by adaptive education trajectories, constantly modified depending on the training achievements of learners, with the recommendations determined according to the results of psychological tests for developing learners PPQs; the learners must follow these recommendations throughout the entire preparation process until reaching threshold PPQ levels necessary for participation in individual or team Olympiads.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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