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GENETIC ALGORITHM FOR SOLVING THE PROBLEM OF SCALING A CLOUD-ORIENTED OBJECT OF INFORMATIZATION

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ABSTRACT

This article discusses the problem of mathematical modeling performed in the process of choosing server platforms and the required additional amount of RAM for the deployment of additional virtual workstations in the cloud-oriented object of informatization, for example the cloud-oriented learning environment (COLE) of university. At the same time, a number of requirements are imposed on COLE virtual machines (VM). The requirements are primarily related to the required amount of RAM for the server infrastructure of the educational institution's private cloud and the minimization of the modernization overall cost. This paper proposes a modified genetic algorithm (MGA) to solve such a problem. The algorithm can be used to solve problems related to the scaling of the university COLE. As a special case, the problem of analyzing options for scaling virtual workstations of COLE users was considered. Unlike existing solutions, it was proposed to apply a modified coding method. In addition, it was proposed to use an elitist strategy. With use of such an approach, the best individuals are selected for the gene bank. The use of a gene bank made it possible to reduce the number of generations in the search for a solution associated with the selection of the necessary configuration option for the COLE server infrastructure according to the parameters of the required amount of RAM for the servers of the educational institution private cloud and at the same time minimizing the total cost of its modernization.

Keywords: *Cloud-Oriented Learning Environment, Virtual Workstation, Virtual Workplace, Server Equipment, Optimization*

1. INTRODUCTION

Society has entered an important period of its development - the era of informatization [1, 2]. The use of electronic computing machines (ECM) passed into the sphere of direct production.

To solve theoretical and practical problems arising in the course of human activity in various fields of science, technology and production in order to free a person from excessive intellectual load, the use of computer technology gives a great effect, as long as there is sufficient software and its effective use.

Students are increasingly often use smartphones and other gadgets, the main purpose of which for the above-mentioned category of the nowadays population is entertainment and games, although the possibilities for use are much wider. That is why the pedagogical community is faced with the task of providing the educational process with high-quality electronic teaching aids. It applies not only to the familiar personal computers and laptops, but also to other modern devices that could be used in the educational process. Moreover, we should talk about the use of mobile gadgets both in general education and higher educational institutions (school and university, respectively), and in any other place, for example, in places of public gatherings or at home.

As a result, one of the topical issues is the use of Internet resources in the educational process of schools, colleges and universities. Moreover, technologies such as the Internet and cloud computing are helping to change the learning environment and make education more accessible.

The concept of a cloud-based learning environment (COLE) is quite new, so only a few scientists have introduced such a definition. In particular, we agree with the opinion expressed in [3], which by COLE means "an artificially built system consisting of cloud services and providing educational mobility, group cooperation of teachers and students for the effective, safe achievement of didactic goals".

Platform virtualization has become the technological basis of the universities COLE. Such approach lies in the fact that on one physical server, one can simultaneously run tens or hundreds of virtual machines (VM). The next step in transforming the IT infrastructure of universities is to create an infrastructure for virtualized student workstations. At the same time, if the operating system (OS) in which the end user works (for example, a student or scientific and pedagogical worker) is executed on a VM deployed on a server, then visual images are delivered to the end devices of users (PCs, laptops, tablets, smartphones) using special network protocols. The advantages of such an organization of the educational process are [4, 5]:

1) centralized technical support processes. Indeed, with such an organization, it became possible to carry out all technical work on updating and reinstalling the software (software) necessary in the educational process outside of school hours;
2) decreased hardware requirements for users end devices. Nowadays, many students use the university's COLE content via smartphones or tablets;
3) the costs of the university's COLE ownership has been reduced (other words TCO – Total Cost of Ownership);
4) total energy consumption has decreased (Green Computing).
5) and other.

Note, however, that the formation of virtual workplaces within the framework of the university's COLE is a complex problem. During the solution of which, both methods of working with end users and purely technical tasks related to the server infrastructure are affected. After all, it is the server infrastructure that ensures the implementation of specific tasks on the clients VM (students and scientific or pedagogical workers). At the same time, the most significant expenses fall on the purchase of server equipment, which allows the implementation of virtualized workstations in the university's COLE. And, consequently, the development of new models for solving the problem related to the optimization of the server infrastructure of the university's COLE seems to be an urgent task in the context of the overall task of reducing the cost / volume of RAM ratio of the purchased server equipment for creating new virtual machines. It is this optimization problem that is solved within the framework of this article.

2. LITERATURE REVIEW AND ANALYSIS

Over the past ten years, a steady trend has emerged for the development of the educational institutions virtual education environment infrastructure. It is the so-called server virtualization. [6–8]. As shown in [7–9], such an approach makes it possible to efficiently deploy several types of operating systems (OS) on physical servers at the same time. Accordingly, the software products necessary for a particular course are deployed on each virtual server.

In works [10–12] it was argued that virtualization became the basis for the development of many successful educational systems. It was achieved, first of all, by the consolidation of the necessary infrastructure resources in the educational process. It is shown in [13, 14] that the transition to centralized management of workplaces (primarily virtual) has become an additional advantage. All of these virtualization activities have laid a solid foundation for educational services provision. However, it should be noted that only a number of scientific works and publications focus on the optimization problems that arise in the process of deploying virtual workplaces of university's COLE.

In [15], a mathematical model was presented; it was focused on the analytical solution of the optimization problem to minimize the cost of purchasing server equipment. However, the authors do not offer a detailed description of the solution algorithm, which complicates the algorithmization of the solution using computer modeling of different options for solving such optimization problems.

In [16], a modified genetic algorithm was proposed; it was used to solve a similar optimization problem associated with the selection of the required server resources (SR) in the process of forming a reasonable number of virtual workplaces in an organization. However, the

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authors do not consider more complex situations, for example, when, at the first stage of solving such an optimization problem, one should initially determine the feasibility of investing in the expansion of the virtual environment, but migration to an already deployed external cloud structure.

It is in such a situation that it is more justified, for example, through the use of the apparatus of game theory [17], to analyze the general expedient strategy for the deployment of additional workplaces. And if the investment turns out to be expedient, then only in this case should one proceed to the stage of applying the genetic algorithm (GA). The choice of GA as a toolkit for solving such an optimization problem is dictated by its speed, since classical methods work much more slowly.

Note that the research in the field of scaling cloud applications (SCA) for the DSP of the university is quite new. And new difficulties arise as this information technology develops for specific university DSPs. It can be summarized that the disadvantage of many of the analyzed approaches in [11-17] is the lack of a methodological and mathematical apparatus that is quite simple for ordinary university DSP engineers to effectively solve the scaling problem before the university DSP reboot, taking into account possible inaccuracies in the schedule. Thus, these approaches, considered in [11-17], in our opinion, are not efficient enough for the majority of DSPs in universities.

Thus, summing up the above, it can be stated that the search for new models and methods used to optimize the server infrastructure of enterprises and organizations is a relevant task. The solution to this problem is carried out in the context of general tasks to reduce the cost / volume of RAM ratio of purchased server equipment for the creation of new virtual machines in the cloud environment of enterprises and organizations, as a special case for the COLE of the university.

3. MODELS AND METHODS

The purpose of the research is the development of a genetic algorithm used to solve an optimization problem for choosing a configuration of server platforms and the necessary additional amount of RAM required for additional virtual workstations in a cloud-oriented educational environment of the university (COLE).

To achieve the research goal, the following tasks were solved:

1) Development of a genetic algorithm for solving the above mentioned problem;
2) Conducting computational experiments that will confirm the performance of the modified genetic algorithm (MGA).

4. MODELS AND METHODS

4.1. Formulation of the problem.

The deployment of virtual workstations within the framework of the university's COLE infrastructure creation implies the implementation of the computing power transfer from a PC or other client devices (laptops, tablets) to servers. These servers or server will consolidate VMs, see fig. 1. The set of VMs required for efficient operation will operate either on a single server or on a set of servers. If the university does not have redundant computing resources, then the necessary server hardware should be purchased before implementing the VM infrastructure. Moreover, one should note that this equipment will effectively serve a predetermined number of VMs at the operation stage. Therefore, as the VMs quantity increases, it becomes necessary to solve the problem of scaling the VM infrastructure, i.e. essentially solve the optimization problem. In turn, the solution of such an optimization problem presupposes the need to synthesize a new mathematical model. When constructing such a mathematical model, it is necessary to allow in advance the possibility of executing one type of VM with previously specified requirements for the random access memory (RAM) of a server or a set of university's COLE servers.

Each server or set of servers will represent a server platform (hereinafter referred to as the abbreviation SerP), which, in particular, is characterized by the amount of pre-installed random access memory (RAM). However, from a technical point of view, the simplest virtual workspaces (VW) infrastructure scaling can be implemented by adding RAM modules during the formation of the server infrastructure.

However, this raises a dilemma. After all, the ability to add RAM modules to a specific server configuration is limited, due to the number of available RAM slots.

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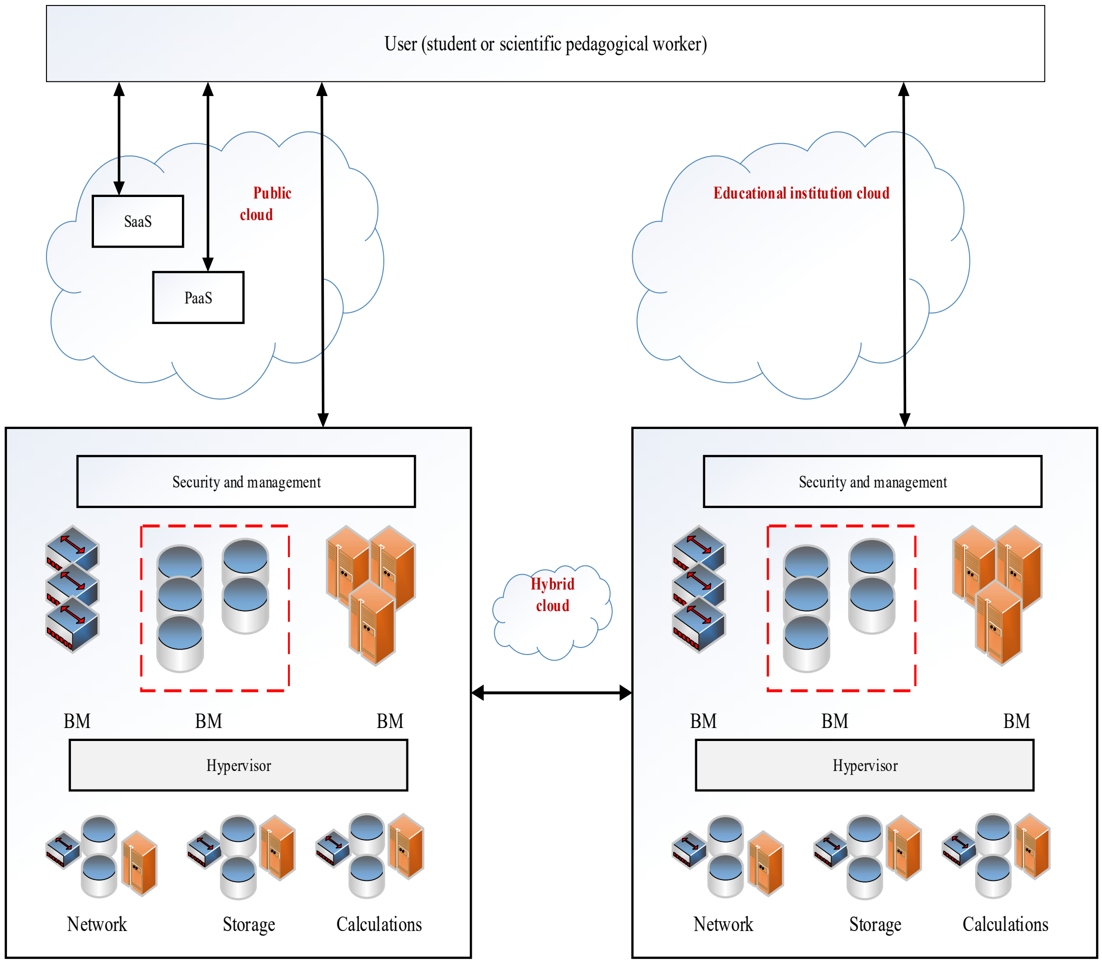

Figure 1. Scheme of Deploying Virtual Desktops in a Cloud-Oriented Learning Environment

4.2. Genetic algorithm for solving the problem of scaling server resources and virtual workplaces in a cloud-oriented educational environment of the university.

In accordance with the work [15], the objective function, which allows solving the problem of optimizing the server infrastructure, is presented as follows:

$$S=\sum_{l=1}^{q}\sum_{i=1}^{m}\left(c_i+\sum_{j=1}^{k}n_{ij}\cdot c_{zj}\right)\cdot cir_{il}, \qquad (1)$$

where c_i – cost i – th SerP; c_{zj} – cost of j – th additional RAM module for server; k – the number of memory types for server RAM (for example, by frequency, generation, etc.); m – SerP quantity of the university's COLE; q – the number of options for filling the RAM blocks of the university's COLE servers; cir_{il} – number of RAM modules of j – th type for i – th SerP of the university's COLE; n_{ij} – number of SerP of the university's COLE.

Wherein

$$q=\sum_{i=1}^{m}q_i=\sum_{i=1}^{m}\frac{(k+d_i)!}{d_i!k!}, \qquad (2)$$

where d_i – number of slots for RAM modules of i – th SerP.

In accordance with [18], in order to determine the value (volumes of investment in the server platform / COLE platforms) c_i in contrast to [15,16], the decision process is based on the game theory which determines the strategies of the interested parties. Such parties can be: 1) administrators of the COLE server infrastructure,

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seeking to maximize the capabilities of the cloud; 2) the administration of the university, striving to minimize financial costs for the COLE development.

The dynamics of changes in the parties resources is described in the form of a system of differential equations given in [19, 21].

Further optimization can be performed for variables c_{zj} and cir_{il}, that are presented in expression (1).

The limitation on the RAM amount for a specific SerP in accordance with [15, 16, 18] can be written as follows:

$$\sum_{j=1}^{k} sram_j \cdot n_{ij} \le m_i, \quad i = 1..cir. \tag{3}$$

Limit on the number of RAM modules that can be added:

$$\sum_{j=1}^{k} n_{ij} \le d_i, \quad i = 1..cir. \tag{4}$$

Limitation on the sufficiency of RAM for SerP, ensuring the functioning of the required number of VMs [16]:

$$\sum_{i=1}^{m} \left(\frac{\sum_{j=1}^{k} sram_j \cdot n_{ij}}{V_{VM}} \right) \ge N_M, \tag{5}$$

where V_{VM} – RAM volume, allocated for one VM;

N_M – the required number of VMs.

Constraint that describes the integer nature of the current task:

$cir_{il}, n_{ij} \ge 0, \quad cir_{il}, n_{ij}$ – integer.

In contrast to works [15, 16], the parameter c_i – cost of the i – th SerP platform was considered as a kind of analogue of investing into the COLE server infrastructure. This infrastructure includes the server / servers itself and the corresponding number of VMs (see Fig. 1) that are deployed on server platforms. One should note that the choice of a rational investment strategy and the size of a reasonable investment can be performed based on the application of game theory. In particular, in [18–21], mathematical models are presented for different formulations of the investing in IT projects problem, including virtualization. Moreover, these models and the main calculations of investors' rational strategies (for example, in cloud infrastructure and virtualization) were carried out on the basis of bilinear differential quality games with several terminal surfaces [20, 21]. Such a combination of different approaches, in our opinion, may be more preferable, since it combines different approaches to solving optimization problems [22-24].

In the considered GA, the population is a set of decisions in the course of choosing server platforms and the required additional amount of random access memory, the need for which increases with the scaling of virtual workstations within COLE. At the same time, a number of requirements are imposed on the COLE VM. These are, in fact, different combinations of RAM sets for servers on which virtualization is performed. Then the individuals in the population will contain one chromosome with the number of genes, which is equal to the number of variants of possible RAM layouts on physical servers, see Fig.2.

In contrast to the classical GA, which uses binary coding, in the course of this study, a coding list was used.

The list item contains the following information regarding the server platform / servers of the university's COLE, according to [15, 16, 20]:

1) SerP;
2) a set of RAM modules in accordance with the chosen strategy for investing in virtualization under existing restrictions;
3) general RAM indicators (frequency, memory size, etc.);
4) the cost of a RAM set for SerP.

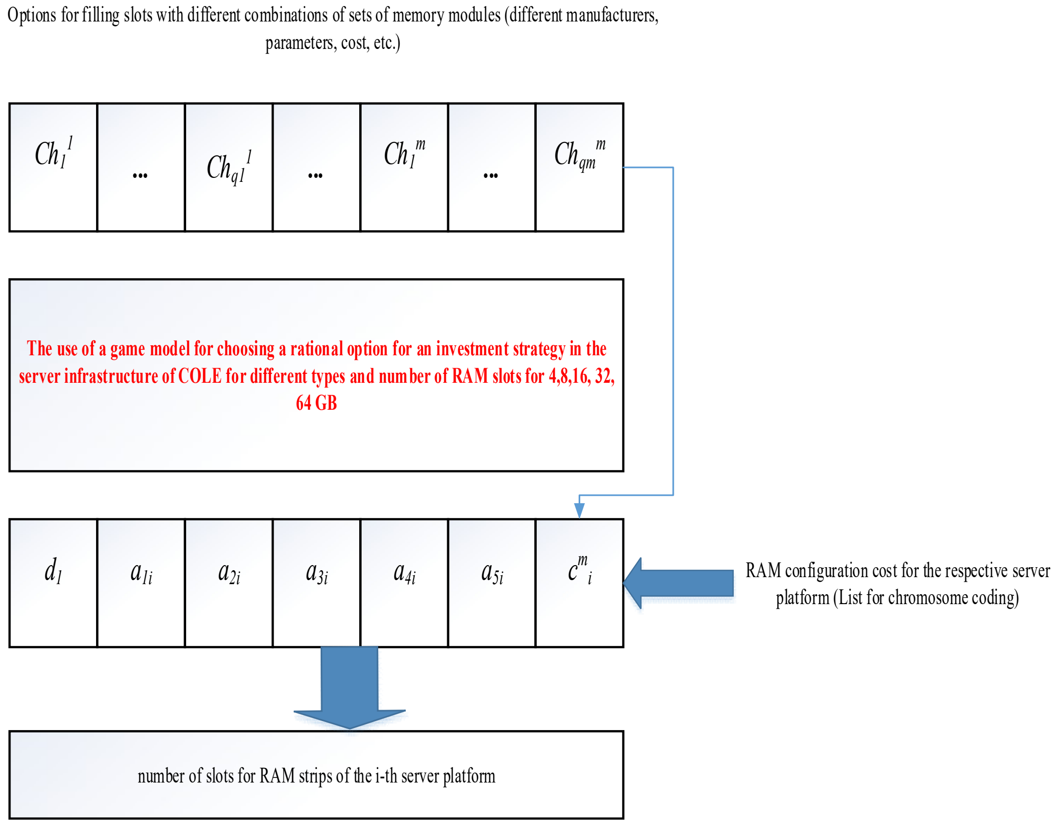

Figure 2. Scheme for Chromosome Coding

The number of genes in a chromosome (ch) was taken equal to the number of elements in the options list for RAM module sets for scalable SerP COLE.

Expression (1) will be used as a fitness function.

Possible combinations of RAM sets for individual SerP will make up a population (pop). At the same time, restrictions were adopted on the number of minimum required server parameters in terms of memory size and the RAM modules total cost.

During the creation of the initial population, the procedure shown in Fig. 3 has been applied.

Randomly select the record number in the list of RAM sets for the server / servers (or SerP) COLE. For example, one can use the roulette method. Next, add 1 to the gene that corresponds to this set.

Then one should check that chromosome (ch) meets constraints (3) and (4).

The procedure shown in fig. 3, we repeat until the required indicators for the required characteristics of the SR are achieved. Enter the numbers (NG) of generations of chromosomes (ch) into the data structure specially generated by the program.

The population size depends on the number of chromosomes. For each chromosome (ch) in the population, a fitness assessment was performed. Such a procedure is performed by calculating the fitness function. The quality of chromosomes will be the higher, the lower the value of the fitness function. At the next step of this modified GA operation (hereinafter referred to as MGA), see Fig. 4, one sort the obtained values. It is the so-called rank selection.

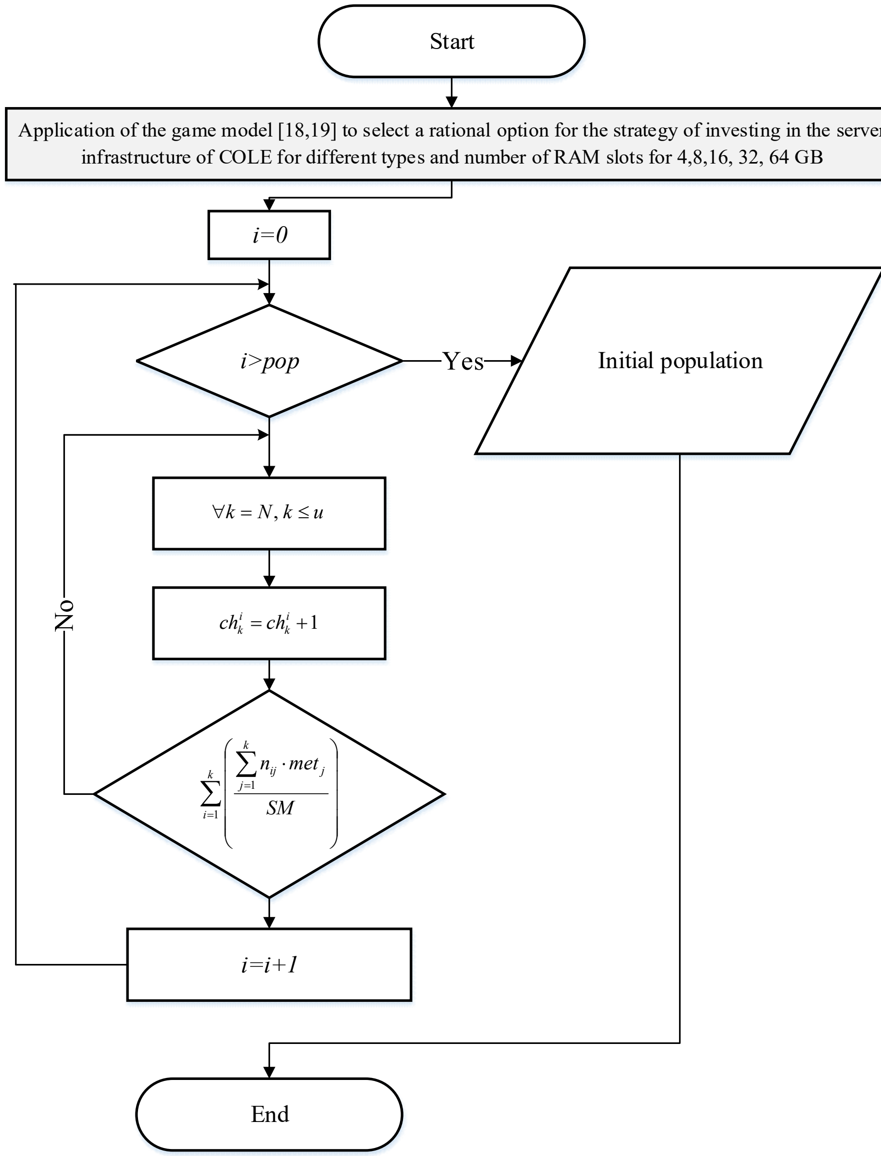

Figure 3. Block diagram of Chromosome Generation for a Combination Variant of a Game Model and a Genetic Algorithm

The general scheme of the MGA is shown in the block diagram, see Fig. 4.

Crossing or crossing over is the exchange of chain fragments between two parental chromosomes. The splitting point of the chromosome is randomly selected. Next, the left side of chromosome #1 in a pair was attached to the right side of chromosome #2. Accordingly, one attach the left side of chromosome #2 to the right side of chromosome #1.

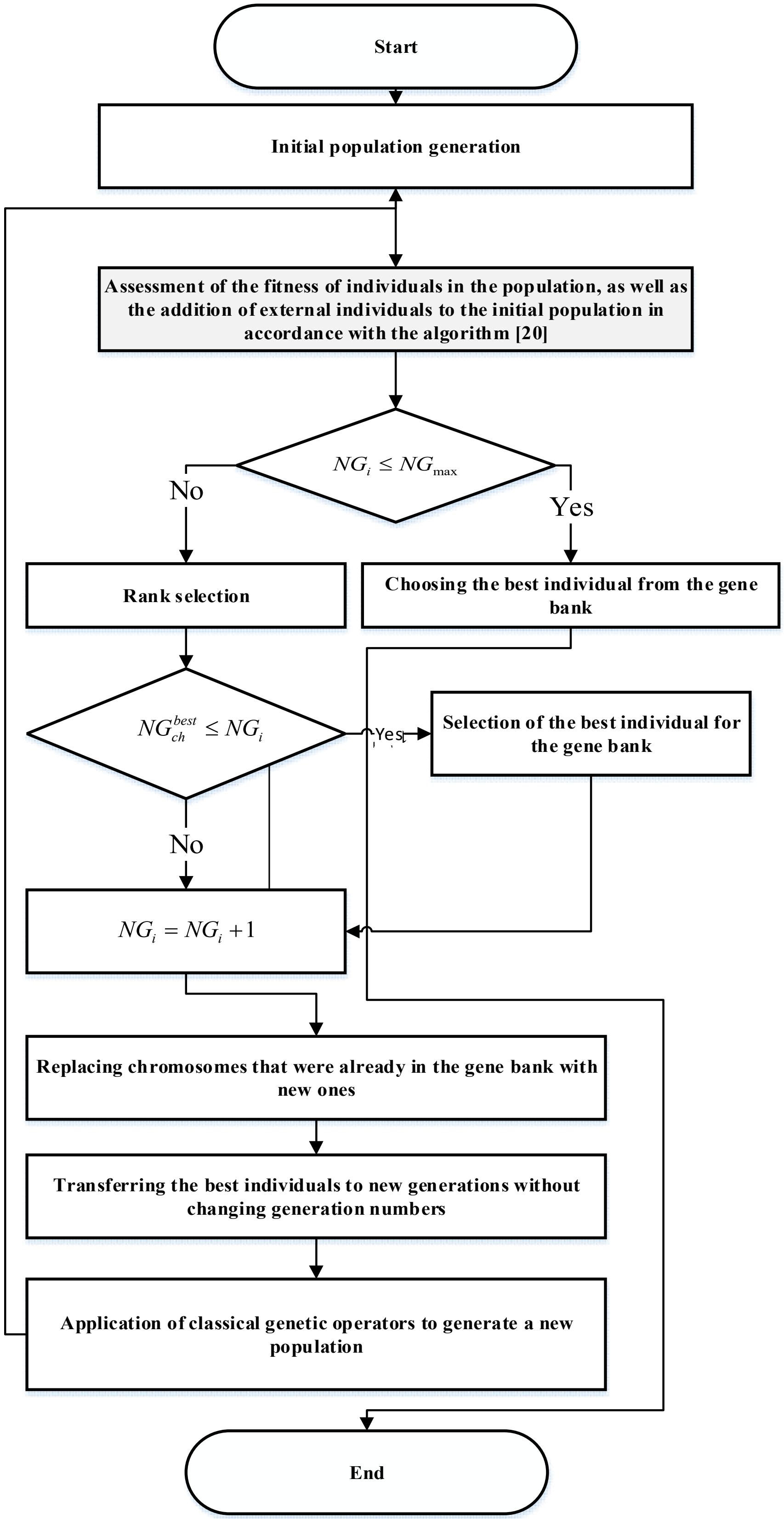

Figure 4. Modified GA for the Selection of Hardware and Software for Information Security

One carry out selection for each generation.

One selects "viable" individuals based on constraints (4). Then the ranking is performed by the value of the fitness function (1).

The best individuals, unchanged, are carried over to the next generations.

The computation ends when the specified number of generations is reached. Computational experiments have shown that the convergence of the algorithm has been achieved for at least fifty generations.

5. COMPUTATIONAL EXPERIMENTS

To check the adequacy of the model described in the work, the corresponding computational experiments were carried out, see Fig. 5.

The initial data for the computational experiment were:

Options for the cost of RAM lines from different manufacturers:

The number of RAM modules added in the process of virtual workspaces scaling on the server;

Population sizes are taken from 2900 to 3000;

The number of generations is 40-50;

The number of directed mutations is 15-20.

Computational experiments were carried out on randomly generated sets of RAM modules designed to expand the number of virtual workspaces in the university's cloud-oriented learning environment. The performance of three algorithms - MGA, the branch-and-bound method, and the greedy algorithm was compared. The results are shown in Fig. 6.

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main.cpp

```cpp
#include <iostream>
using namespace std;
#include <algorithm>
#include <numeric>
int main()
{
    using namespace std;
    srand((unsigned)time(NULL));
    const int N = 1000;
    int a[N];
    //Fill with zeros.
    fill(a, a+N, 0);
    for (;;)
    {
        //Mutation of each element.:
        for (int i = 0; i < N; ++i)
            if (rand()%2 == 1)
                a[i] += 1;
            else
                a[i] -= 1;
        //Selection of the best and sorting in ascending order.
        sort(a, a+N);
                copy(a+N/2, a+N,     a /*куда*/);
                cout << accumulate(a, a+N, 0) / N << endl;
    }
}
```

Figure 5. An Example of a Console Application Fragment (https://www.onlinegdb.com/online_c++_compiler) for Performing Computational Experiments

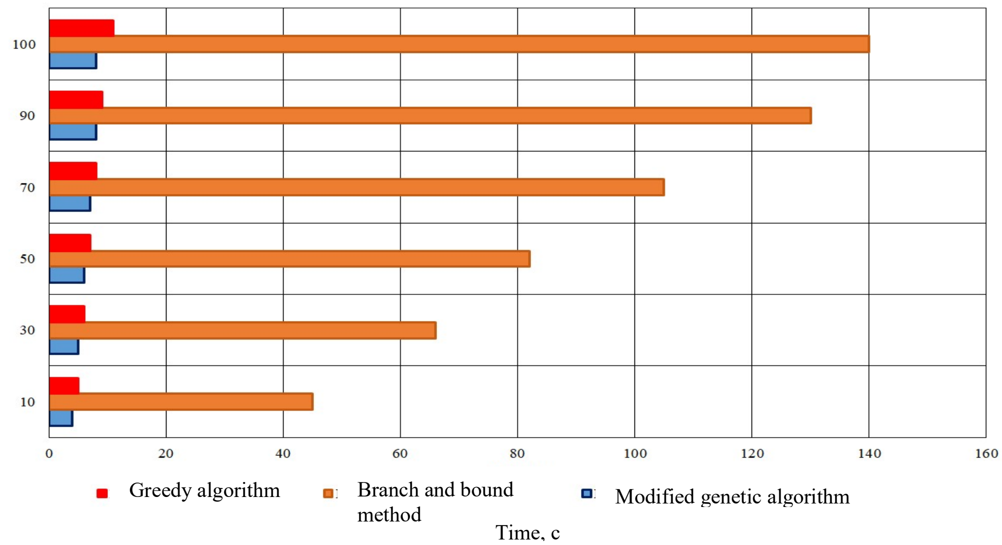

Figure 6. The results of Computational Experiments Comparing the Running Time of Algorithms for a Different Number of Options for Filling the RAM Blocks of Servers in a Cloud-Oriented Educational Environment of the University

In the course of computational experiments, it was found that the modified GA is distinguished by a sufficiently high efficiency and speed. It was found that the time spent on solving the problem using the modified GA described above is approximately 15–20 times less in comparison with the indicators of the branch and bound method. This circumstance allows, in the future, when finalizing the decision support system, to opt for this particular algorithm. Not in all cases it is possible to set a fitness function that is applicable for practical use in a given task. Not all parameter values in it can be determined or measured. The scaling process for cloud DSP applications is often random. it is impossible to predict in advance which of the load cases on the equipment of cloud DSP applications and, above all, the server equipment, will take place. This is a definite disadvantage of the proposed approach.

6. DISCUSSION OF RESEARCH RESULTS

In the course of computational experiments, calculations for selection operators were performed for each generation. That is, it was modeled as a result of the implementation of crossing-over operations, random and directed mutations. Further, each descendant was subjected to analysis. If the analyzed descendant was recognized as a “non-viable” individual in terms of the total memory capacity (ie, the obtained value is less than the specified value), then the value “1” is added to the randomly selected gene locations. This manipulation is done until the individual becomes viable. The final check of the "viability" of the individual is carried out in accordance with the constraint (5). Further, all the obtained individuals were ranked. The ranking is performed in ascending order of the values of the fitness function (1). The best individual was carried over without any changes to the next generations. It was suggested that if the best individuals retain their properties unchanged for 4 consecutive generations, then they were placed in the genetic bank (GenB). Individuals placed in the GenB are replaced with individuals with newly generated random chromosomes. Also, all individuals for which the chromosomes coincided with the chromosomes of those individuals stored in the GenB were replaced with new individuals. This is true for a situation where an individual stored in the GenB has not changed for more than 4 generations. The implementation of such a procedure prevented the cessation of evolution and, accordingly, the degeneration of the population. Further, with a given probability, each of the two new chromosomes underwent random and directed mutations. Random mutations consisted of adding "1" to a randomly selected gene. Directed mutations consisted in the search for the minimum cost / volume RAM ratio among the non-empty loci of the gene. Then "1" was added to this value. Also, "1" is subtracted from the locus value characteristic of the maximum cost / volume of RAM ratio.

After the crossing operation, as well as random and directed mutations, the following parameter of the individuals was analyzed. If the individual is

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"not viable", then one adds "1" to the randomly selected loci until the individual becomes "viable".

The calculations on the simulator ended when the specified population size was reached, i.e. a certain number of generations. As the results of the experiment have shown, the convergence of the algorithm is achieved within at least fifty generations. The best individual from GenB is actually the solution to the optimization problem. The results of the calculations showed good repeatability of the results. In addition, the results of the computational experiment were compared with the results obtained by other authors for the case of using classical algorithms and methods, for example, nonlinear integer programming. For classical methods, the solution is reduced to decomposition in order to obtain two integer linear programming problems [17].

The advantage of the proposed approach to this technical problem is a fairly simple way to automate the solution of everyday tasks of specialists involved in scaling cloud applications for DSP of universities in the face of a shortage of qualified personnel.

7. CONCLUSIONS

The problem of mathematical modeling in the process of choosing server platforms and the required additional amount of random access memory, the need for which increases with the scaling of virtual workplaces in a cloud-oriented object of informatization for example COLE of an educational institution, was considered. At the same time, a number of requirements are imposed on virtual machines (VM) of cloud-oriented learning environment. These requirements are primarily related to the amount of RAM required for the server infrastructure of the educational institution's private cloud and the minimization of the modernization overall cost.

The paper proposes a MGA. This algorithm can be used to solve problems related to scaling the university's COLE. As a special case, the problem of analyzing options for scaling users' virtual workstations is considered. Unlike existing solutions, it is proposed to apply a modified coding method. In addition, it is proposed to use an elitist strategy. With such an approach, the best individuals are selected for the gene bank. The use of a gene bank allows one to reduce the number of generations in the search for a solution associated with the selection of the necessary configuration option for the COLE server infrastructure according to the parameters of the required RAM amount for the servers of the educational institution private cloud and at the same time minimizing the total cost of its modernization.

In the course of the work, a fairly detailed analysis of similar studies on this issue was carried out, including the work in the field of application of evolutionary algorithms for scaling cloud applications. The structure and principles of operation of heuristic optimization algorithms have been studied. The applied result of these studies is the possibility of a relatively simple implementation of a mathematical model for the process of choosing DSP server platforms.

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