The Development of the Informative Line "Modelling" Using Fractals in a Continuous Multi-Level Education System

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Abstract

The relevance of the study is due to the need to develop informational and communicative competence of students using of computer and supercomputer technologies. The problem of the research is to identify the role of fractal geometry in the informative line of computer science "Modeling and Formalization" during the gradual development of professional competence of a person in a multi-level education. Aim: to develop the concept of teaching the informative line of computer science "Modeling and Formalization" using the elements of fractal geometry for the development of informational and communicative competence of students at each level of education. Methods: analysis of methodical literature, observation, pedagogical experiment, mathematical modeling, optimization method, iteration method, linear programming methods. Results: The dynamics of the use of fractal geometry in a continuous education (school, bachelor, master and postgraduate) for the formation and development informational and communicative competence of students of is shown. Emphasis is placed on the features of IT education in the Northern (Arctic) Federal University and how to implement it in the context of the development of supercomputer technologies. Conclusions: the content of education in fractal geometry provides a gradual transition from the student's learning activities to the postgraduate's research by consistently solving modeling problems, linear programming, and performing research projects using computer simulations.

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1 Introduction

The process of informatization of society and the intensive development of programming languages make it possible to take a fresh look at many phenomena of the surrounding world, including those associated with the use of modern information and communication technologies and supercomputer technologies. The increasing productivity of computers gives grounds for solving time-consuming tasks and developing more and more complex mathematical models using new approaches to their implementation. The requirements of employers to specialists in the field of IT education are increasing. One of the ways to solve this problem is the gradual development of professional competencies and creative abilities of future IT specialists from propaedeutics to professionalism in the system of continuous multi-level education.

Modern approaches to the objectives and content of education are based on the idea of continuity of education, which is understood as a connection, coherence and perspective of the goals, objectives, content, methods, means, forms of education at each level of education to ensure continuity in personality development. The basis of the new standards of all levels of education is the competence approach, the essence of which is connected with the formation of the key competences of the individual. This approach is analyzed in the scientific-theoretical and methodological works of E.Alisyltanova, J.Rugelj, A.Kasprzhak, A.Dakhina, I.Zimney, I.Frumin, O. Pankratova, . Konopko, G. Tsukerman, A.Khutorskoy and others [Alis12, Rug16, Pan18].

The concept of multi-level education is designed to highlight the priorities in the content of education at each stage of the age-related personal development for the formation of the competencies necessary to carry out the professional activities of the future IT specialist [Orl03].

The Federal State Educational Standard of Higher Education on major 01.03.02, 01.04.02 "Applied Mathematics and Computer Science" and other technical majors as an object of graduates' professional activity provides for mathematical modeling.

A graduate who has mastered higher education programs in the field of Applied Mathematics and Computer Science in accordance with the federal state educational standard of higher education should have professional competence in the use of mathematical methods of modeling information and simulation models and further improve and use modern mathematical apparatus to solve experimentally - design and applied tasks, scientific works.

The need to apply modeling techniques to form professional competencies of future specialists at any level in the system of continuous multi-level education determines the relevance of the study.

One of the means of formation of professional competencies of IT specialists in the field of mathematical modeling can be one of the directions of modern mathematics - fractal geometry.

Fractal geometry is the most promising and convenient tool for the development of professional competencies in the system of continuing education of an IT specialist, as it has wide potential for developing unusual models and ideas, unsolved problems of modern IT education.

However, the development of a complex of competencies (research, general cultural, professional) necessary for a future specialist should begin in a general education school

A primary school graduate should have universal learning activities that determine the ability of an individual to learn, percive, cooperate in the knowledge and transformation of the world around him. The method of teaching modeling in elementary school is based on taking into account the level of development of the psyche and the cognitive activity of 7-10 years old children and provides for the first acquaintance of students with elements of fractal geometry using the example of self-similar figures and compiling more complex figures from them.

Primary school students aged 11–15 years old are characterized by significant shifts in the development of thinking and activation of cognitive activity. Therefore, in the process of teaching modeling tasks of a problem nature appear, inter-subject relations are used. Elements of fractal geometry can be considered as a tool for working with information models in the lessons of mathematics, computer science, physics, chemistry, biology, technology. Key competencies in adolescence are formed through the content of education, the use of modern learning technologies, the interaction of participants in the educational process. At this stage of education, a large role is assigned to practical activity. One of the effective methods of cognition of the surrounding reality is the method of computer simulation. Therefore, computer models are used during the education. Primary school students have sufficient knowledge and skills in the field of computer science and are able to simulate the simplest processes and phenomena. Computer modeling increases the motivation to learn, the attractiveness of the subject, contributes to the development of independent thinking. A group of students under the guidance of R.F. Mamaluga and E.V. Ablaeva conducted a study of the capabilities of information technology in the study of fractal geometry in school. Students in grades 6-7 learned to see such figures, analyze images from fractal elements on paper using the origami technique. In the environment of "Logo" acquired the ability to build fractal images and experiment with them.

At senior school age (15-17 years old), most students have sustainable cognitive interests, developed abstract thinking, has the ability to analyze, can identify causal relationships, has a sufficient level of knowledge in mathematics and computer science to solve problems of mathematical modeling. The federal state educational standard of secondary education defines modeling as one of the important key lines in the course of computer science in secondary school. The practical nature of training at this age is provided by a wide range of experimental works using computer simulation methods.

A graduate of a secondary school must have basic key competences and solve applied problems in various subject areas, including using computer-aided modeling techniques at the level of graphical, mathematical, and simulation models of social, biological, and technical systems and processes. This will allow him to independently organize his activities and continue his education in professional educational institutions.

Modeling, according to O.M. Gubanova, I.I. Zubko, Y.F. Titova and other scientists [Gub07] is a promising line of research on the use of IT in various fields of human activity. This method integrates intellectual skills, research, independent work. The problem of the formation and development of professional competencies of IT specialists is presented in the studies of Yu.D. Babayeva, A.Ye. Voiskunsky, I. Rozov, O. Zimina, I. Zakharova and others. [Bab03]

Despite the fact that the theory of fractals arose relatively recently at the intersection of mathematics and computer science, at present elements of fractal geometry are widespread in many fields of knowledge and human activity. Fractals have found practical application in computer science, physics, geology, meteorology, biology, geography, metal science, medicine, psychology, philosophy, film industry, linguistics, art, economics, and other fields. In addition, fractal methods of information compression and fractal forms of antennas in the transmission of information are widespread. Special program editors working with fractals are created. The use of fractal geometry in modeling contributes to the development of the creative potential of the individual, the development of aesthetic taste. Many authors dealt with the questions of fractal geometry: B. Mandelbrot, P.M. Kronover, V. Feder, S.V. Bozhokhin, D.A. Parshin, T.À. Shkerina, etc. The works of A.A. Babkin, V.A. Dalinger, V.S. Sekovanov, V.N. Ostashkova, E.S. Smirnova, etc. are dedicated to teaching students of fractal geometry [Smi13, Sek08].

It should be noted that there is practically no special literature on this section. Foreign monographs are designed mainly for senior students and graduate students.

Most modern scientists involved in the study of fractals, believes that fractal geometry is advisable to begin at the university.

For example, V.S. Sekovanov uses the training of fractal geometry of high school students as a means of integrating mathematics and computer science. The scientist believes that the student's mastering of the fractal construction algorithms contributes to the formation of universal methods for creating various mathematical models both in nature and in society, promotes an increase in the level of motivation to study mathematics, computer science, physics, ensures the development of students' worldview, and include them in an independent search on to the solution of non-standard tasks, contributes to the development of their creativity through the formation of a system of aesthetic qualities adequate to the types of creative mathematical activity. [Sek08].

In the work of V.A. Dalinger reveals aspects of the formation of the "Pedagogical education" professional-creative level of informational and communicative competence among bachelors on the example of research tasks of fractal geometry associated with the amazing world in which mathematics, nature and art reign [Dal02]. A.A. Babkin considers the study of elements of fractal geometry as a means of integrating knowledge of mathematics and computer science in the teacher college's learning process [Bab03]. E.S. Smirnova considers the method of teaching elements of fractal geometry as a means for the development of research competencies of students and bachelors.

In Russia, there is little experience in studying fractal geometry in a secondary school in mathematics lessons. However, the use of fractals in the study of the informative line of informatics "Modeling and Formalization" was not found in the scientific and methodological literature, despite the enormous potential for using the construction of self-similar figures and mathematical methods for modeling objects with a fractal structure in various subject areas.

2 Task

The problem of the study is to find the answer to the question: What is the role of fractal geometry in the informative line of informatics "Modeling and Formalization" in the step-by-step formation, development and improvement of informational and communicative competence of students in the system of continuous multi-level education: secondary school (primary, basic, secondary) - university (Bachelor - Master - Postgraduate).

Aim: to develop the concept of learning fractal geometry in the informative line of computer science “Modeling and Formalization” for the formation, development and improvement of informational and communicative competence of students at each stage of continuing education.

Methods: analysis of methodical literature, observation, pedagogical experiment, mathematical modeling, optimization method, iteration method, linear programming methods.

Objectives of the study:

- clarify the existing concept of continuous multi-level education;

- identify the content of education in fractal geometry in the informative line of computer science "Modeling and formalization" at each stage and level of education;

- develop a training concept and information model for the gradual development of professional competencies of future specialists in the field of Applied Mathematics and Computer Science.

It should be noted that there is practically no special literature on this section. Foreign monographs are designed mainly for senior students and graduate students.

3 Development Of Methodology

3.1 Experience Of Teaching Modeling Using Elements Of Fractal Geometry At School

After analyzing the program of primary education, we came to the conclusion that the elements of the fractal geometry of nature can be begun to study in elementary school. To do this, it is necessary to determine the criteria for selecting the content of educational material and tasks using fractals from the standpoint of a person-oriented, activity-based and competence-based approach to all levels of education, and a gradual transition from educational to research activities is ensured.

The propaedeutic stage for elementary school students (grades 1-4) is intended to demonstrate the beauty of innate natural fractals and the simplicity of constructing geometric models of fractals. We propose to begin to introduce the "fractal component" in the content of primary school subjects. In a class, you can disassemble tasks for the visual identification of the main feature of a fractal - self-similarity on a different scale of natural and artificial fractals.

In mathematics, when studying geometrical figures, it is possible to show, for example, how from several triangles (squares, rectangles, etc.), by means of their multiple division, to obtain self-similar figures and collect various models from them by analogy with the Tangram puzzle. This will contribute to the development of mathematical thinking and creativity of younger students.

In computer science lessons, it is possible to give the children themselves one or several Tangram drawings and draw their own drawing in the generator of geometric fractals. At the technology lessons, you can make a model of a fractal snowflake.

It is advisable to introduce younger schoolchildren to fractal structures at the macro and micro levels. At the macro level, you can consider the work of the architect Santiago Calatrava. At the micro level, introduce the technology of filling the internal structure of metamaterials.

Familiarity with natural fractals, for example, with frosty patterns on glass, and flowers can be included in the contents of the program. During the lessons of fine art, we show the method of depicting trees using a fractal structure, using fractals in painting, and accompanying musical lessons with musical works with fractal images. All this will contribute to the development of creativity and aesthetic attitude to the world around us.

By the end of primary school, schoolchildren had universal learning activities and they are motivated to study fractals in grades 5–7.

At the preparatory (cognitive) stage, the content of primary school curricula is supplemented by examples of the use of fractals in nature and human life. Pupils of 5-7 classes are given the opportunity to manage the construction of geometric and algebraic fractals themselves using software tools for constructing fractal structures. For example, geometric fractals are built from elementary repeating elements, which can be specified by a recursive set of rules or directly by a set of segments.

In botany, the examples show the fractal structure of flowers and trees. The student is asked to model his unique tree by modifying a predefined template. It is also possible to explain the golden section and its relationship with the Fibonacci series on the example of the pattern of leaves on the plant stem, revealed by the Swiss biologist Charles Bonn.

In geography, the fractal property of the coastline is demonstrated. It shows how the length of the coastline depends on the scale of the map. It is interesting for children to consider the simplest relief generation schemes, which are widely used in games. Demonstration of graphic scenes from popular games (screenshots) makes it possible to interest children interested in games for the subsequent analysis of methods for generating textures of various surfaces and terrain.

For the development of interest in the study of fractals, and, consequently, to the study of mathematics and computer science, works of fractal painting, fractal music and architecture are demonstrated for schoolchildren of grades 5-7 [Dem14]. As an example of fractals in architecture, it is recommended to continue acquaintance with the works of Spanish architect Santiago Calatrava. In particular, the fractal structure of the pillars of the L'Umbracle Gallery in the City of Arts and Sciences in Valencia is interesting. The interest of children in fractal geometry is reinforced in the classroom "Modeling and programming fractal figures."

The activity stage in the study of fractals for students in grades 8–9 is realized by studying the algorithmic generation of fractals directly by means of program development. At this stage, students are offered a number of mathematical models for generating geometric and algebraic fractals. Acquaintance with the Mandelbrot and Julia fractals must be accompanied by the definition of a complex number and arithmetic operations on a complex plane [Man02].

Pupils of 8-9 classes can use the example of fractals to explain the categories of determinism and stochasticity, that is, to show how the introduction of some random perturbations into the structure of a geometric fractal allows you to get more natural images of trees, relief and textures.

The criteria for selecting the content of teaching elements of fractal geometry are: the integration of knowledge of mathematics and computer science, the creative and research nature of the tasks, the cognitive and aesthetic motives of activity, the choice of means and ways to solve the tasks.

In grades 8-9 students begin to learn programming languages and write programs to build more complex fractal images. The experiment showed that fractal geometry can be studied by schoolchildren and is of great interest due to its unusual nature. To build models of more complex fractals, it is proposed to introduce a pre-major elective course "Basics of Programming". By the end of basic school, students will learn basic concepts, such as algorithm, structured programming, recursive algorithm, raster and vector images, as well as learn the primitives for working with two-dimensional graphics, necessary for continuing IT education in a specialized school.

The educational and research stage of the study of fractal geometry, programming training is implemented in 10-11 grades of school, is carried out at elective courses, elective classes, winter and summer schools or at permanent year-round seminars.

In the major course of informatics, the example of calculating algebraic fractals explains the concept of code refactoring and algorithm optimization. The calculation of the set of Mandelbrot and Julia requires a large amount of computation and the inefficiency of intuitive algorithms adversely affects the time for calculating the fractal. Small changes in the structure of the algorithm can lead to a significant acceleration of the program as a whole, which is what students need to show.

An interesting topic to study is chaos theory and its close connection with fractal structures. In the study of computer science at the core level, you can also show the process of mathematical modeling of chaotic processes using the example of a split chart of a logistic map, the relationship of chaos theory with modeling of evolution in general using the example of cellular automata evolution. As basic models of cellular automata, it is recommended to consider one-dimensional models of Stephen Wolfram and the two-dimensional John Conway "Life" model [Chir14].

A deeper study of fractal models should be accompanied by a wide use of algorithms for modeling temporal processes, modeling evolutionary processes. An introduction to modeling will broaden the picture of the world of students and allow for a higher level of algorithmic skills. By the end of the school, students will have key competencies that are necessary to continue their education at a technical school or university.

Experience with pupils of 9-10th grades of secondary schools showed that they can have the necessary knowledge to master the elements of the theory of fractals. The result of training was the development of visual culture and artistic and creative abilities of children, the formation of the foundations of aesthetic taste.

Thus, the above-described positive experience allows us to judge that the content of the school course of mathematics, computer science and other school disciplines should include such interesting and, at the same time, important sections, like fractal geometry.

3.2 Teaching Modelling In Higher Educational Establishment Using Parallel Programming Technologies

The need for a large amount of computation in the construction of algebraic fractals requires the use of high-performance computing hardware. For example, the calculation of the fractal can be implemented at different levels:a high-level language, which contributes to the acquisition of competences for the development and coding of efficient computational algorithms and data structures; - in assembly language using vector coprocessor commands, such as SSE AVX, which contributes to the study of microprocessor architecture; - in C ++ for the parallel programming technology MPI through significant code parallelization, which contributes to the development of complex disciplines "Introduction to Supercomputer Technologies" (major "Applied Mathematics and Computer Science", 3rd year), "Parallel Programming Technologies" (major "Applied Mathematics and Computer Science, 4th year) [Ger10].

- in C ++ using the OpenMP parallel programming technology in the framework of the discipline "Parallel Methods for Solving Computationally Complex Natural Science Problems" (major "Applied Mathematics and Computer Science", 4th year) [Voe03].

- using libraries of parallel computing on supercomputer architectures, which promotes the study of parallel computing on cluster and multi-core supercomputer architectures [Nem02].

It is interesting to consider the philosophical categories of predictability of the future according to Newton and free will, determinism and chaos, within the framework of a general philosophy course.

The project stage consists in the application of fractals for the implementation of projects of professional activity on 2-4 courses of the university.

In the 2-3 year students of the major "Applied Mathematics and Computer Science" within the disciplines "Introduction to Project Activity" and "Projects" use the methods of mathematical modeling to solve and implement problems of fractal geometry.

In 2 - 4 year students studying major "Applied computer science in design" in the disciplines of "Mathematical foundations of computer graphics" consider fractals from the point of view of chaos theory, they themselves design fractals in the Ultra Fractal program.

The inclusion of the Fractal Geometry module in professional education programs for the training of engineers, physicists, biologists, designers, teachers, psychologists, artists, and other professions can significantly improve the quality of training.

The professional (creative) stage is expedient in the master programs, where abstract systems are studied and designed and the addition of fractality will allow a transition to a synergistic level to study complex artificial, natural and chaotic systems, including ecology, medicine, economics, to analyze the socio-economic processes self-organizing markets. [Glad06].

To use knowledge of fractal geometry, graduate students are offered the solution of optimization problems based on the use of genetic algorithms.

The solution to the problem of figure cutting of strip from material is used in a wide variety of industries. Finding the most optimal solution to the problem will reduce the amount of waste material, which will increase the profit of the enterprise. In practice, the two-dimensional task of cutting sheet material (paper, plastic, plywood, metal, etc.) is often encountered for the workpieces that customers need, which can be quite complex in shape. In the Arkhangelsk region there are woodworking and shipbuilding enterprises, therefore such tasks are relevant for the region. Since, in general, the problem is not solved analytically, and linear programming methods are applicable only for cutting simple forms into forms (for example, into rectangles), this is a good task for developing professional competencies of an IT specialist [Lip02].

The algorithm for solving the cutting problem involves the sequential compaction of figures lying on a plane. Individuals with errors such as the overlapping of the contours on each other or the intersection of the contours with the boundaries of the strip, received a significant increase in the result of the fitness function and, accordingly, provided the first candidates for extinction [Ver00].

Cutting tasks are classified by dimension. The one-dimensional cutting task is encountered when cutting pipes of different lengths from a long blank, when cutting a roll of material into rolls of a given width, sawing boards, etc. These tasks are satisfactorily solved by linear programming methods and do not represent theoretical interest. Two-dimensional cutting tasks arise when processing sheet materials. The application of solving these problems can be found in the clothing, furniture manufacturing, manufacture of sheet metal products, etc.

Three-dimensional cutting tasks are more often encountered in the form of packaging tasks where it is necessary to fill a certain volumetric space with three-dimensional objects. The most popular use of the solution to this problem is to fill the container with boxes.

Tasks of a higher dimension are rather theoretical in nature and concern, first of all, the densest packages of the simplest bodies (for example, balls) and can be offered to graduate students as a dissertation work.

The proposed two-dimensional problem of cutting was solved on a cluster of NArFU on 10 computational nodes with the following settings: 5000 iterations of the algorithm; 100 individuals in the population; 10 individuals obtained from the mutation of each iteration; 10 individuals were obtained from crossing for each iteration. According to the results of the research, a master's thesis on the topic "Development of a genetic parallel algorithm for solving the cutting problem" was defended [Kur09].

The paper gave a general description of the theory of genetic algorithms, made an overview of parallel programming tools for the implementation of genetic algorithms, created a structure of classes for solving various tasks by a parallel genetic algorithm on the NArFU cluster [Gol89]. The solution of the problem of cutting a flat semi-infinite strip is found, a computational experiment and testing of the program are carried out.

The computation time for this configuration was three minutes. During this time, the program performed a total of 50 thousand iterations on all nodes and showed a better solution than the first versions of the algorithm, which students implemented at the undergraduate degree. As a result of this work, parallel computational methods were applied, the MPI standard and the object-oriented programming paradigm were used [Ant12].

The research stage is characteristic of graduate school. In the Northern (Arctic) Federal University there is postgraduate study on major 05.13.18 "Mathematical modeling, numerical methods and program complexes", where students can use their knowledge of fractal geometry to solve complex high-tech problems and scientific research, such as iterations of multivalued mappings and modeling dynamic systems. The last year of postgraduate education is devoted to bringing the final qualifying work of the research to the type of thesis.

At this stage, the main results of the study are being worked out: the purpose and objectives of the research, scientific novelty and scientific statements, the reliability of the scientific statements, the theoretical and practical value of the research are formulated. A computational experiment is carried out on the NArFU cluster using knowledge of fractal geometry and parallel programming technologies obtained at the previous stages of continuous multi-level education, the results of the dissertation research are presented.

The transition to a continuous multi-level education system creates the need to harmonize the requirements of the three standards: standards for bachelor's, master's and graduate students 'training, development of a system of interrelated curricula at all levels. Continuity of educational programs and curricula is carried out by introducing into the curriculum a bachelor of disciplines from the standards of graduate and postgraduate studies, as well as by expanding the fundamental training of bachelors in the professional cycle, introducing disciplines that are common to all profiles within the training area.

4 Discussion

Implemented in the Northern (Arctic) Federal University principle of consistency of the structural and substantive content of the main educational programs and work curricula in the areas of technical training, for example, students of major "Applied Mathematics and Computer Science", makes the learning process continuous in the system of "bachelor program-master program-postgraduate program". Results of successful continuity of educational programs in the continuous education system on major "Applied Mathematics and Computer Science" in NArFU named after M.V. Lomonosov were discussed at the Fifteenth open all-Russian conference "Teaching information technologies in the Russian Federation" [Pol17].

5 Conclusion

The main component of the concept of continuous multi-level IT education is the integration of fundamental and applied research and education in the field of information and supercomputer technologies, interaction with industrial enterprises, which meets the needs of employers.

The article reveals the content of education in fractal geometry in the informative line of computer science "Modeling and Formalization" at each level and level of education as part of the training of future specialists on major "Applied Mathematics and Computer Science".

The implementation of this task is confirmed by the holding for students and schoolchildren of various scientific events - the IT-Arkhangelsk Science Festival and the annual youth scientific and practical school "High-Performance Computing on GRID Systems".

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