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АВТОМАТИЗАЦІЯ СТВОРЕННЯ ЗАДАЧ З МАТЕМАТИЧНОГО АНАЛІЗУ

У цій статті розширено функціональність системи LaTeX для автоматичного створення математичних виразів теорії границь математичного аналізу методами програмування мовою LaTeX. При цьому створено нові команди. Створені нові команди прискорюють створення та оновлення математичних документів і забезпечують гнучкість зміни параметрів. Ці команди можуть бути використані для підготовки наукових публікацій та навчальних матеріалів з математичного аналізу.

Ключові слова: *LaTeX, автоматизація, команди, границі, математичний аналіз.*

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AUTOMATION OF THE CREATION OF PROBLEMS IN MATHEMATICAL ANALYSIS

In order to automatically create mathematical expressions for mathematical analysis, in particular mathematical expressions for the theory of limits, it is advisable to use the LaTeX programming language. In this article, the functionality of the LaTeX system was expanded to automatically create mathematical expressions for the theory of limits of mathematical analysis through programming methods using the LaTeX programming language. New commands were created. The created new commands accelerate the creation and updating of mathematical documents and provide flexibility in changing parameters. The created new commands can be used to prepare scientific publications and educational materials on mathematical analysis.

Keywords: *LaTeX, automation, commands, limits, mathematical analysis.*

Formulation of the problem. The modern stage of the development of mathematics is characterized by a growing need for the automation of data processing, calculations, and document creation. One of the main sections on mathematical analysis is the theory of limits that is used in the sections on mathematical and functional analysis, and other disciplines.

Existing approaches to creating problems in the theory of limits mainly use manual mode. This restricts the variability of parameters and the flexibility of their change and complicates the systematic analysis of the structure of problems.

In order to automatically create mathematical expressions, in particular expressions for the theory of limits of mathematical analysis, it is advisable to use the LaTeX programming language. The LaTeX system supports random number generation, which makes it possible to automate the creation of mathematical expressions.

The relevance of this investigation is the need to create algorithms for automatic generation of mathematical expressions for the theory of limits of different levels of difficulty. This will simplify and accelerate the work of scientists, educators, and students.

The aim of this investigation is to create new commands for the automatic creation of mathematical expressions for the theory of limits in the LaTeX programming language in the LaTeX system.

Analysis of recent research and publications. The LaTeX system is a sophisticated system for creating scientific and educational documents and for performing computations [1-7]. Researchers conduct their research in the LaTeX system creating complex formulas and performing complex formatting in their publications [8-14]. The LaTeX programming language can also be used in learning management systems to improve the quality of education [15-20].

The built-in commands in the system core and the ability to create new commands in the LaTeX system enable to automate the creation of scientific and educational documents of different levels of difficulty and to automate the execution of computations [6], [21-24].

The issues of automating document creation and computations in the LaTeX system are relevant and important [6], [21-26]. Automation in the LaTeX system simplifies and accelerates various computations, the creation and updating of documents, reduces program code, provides a logical document structure and flexibility in changing parameters [6], [27-36].

Main results. In the LaTeX system, we will create new commands for automatic creation of mathematical expressions for the theory of limits of mathematical analysis.

To do this, in the LaTeX document of the article type, we use the amsmath package (this package creates mathematical formulas) and the amssymb package (this package includes additional mathematical symbols). We also use the TikZ package for using `\foreach` loops and for computations using `\pgfmath`.

Let us create a new command `\limitcompare` that takes one argument (the number of problems). This command generates a limit with the expressions that need to be compared. In this command, we organize the number of problems by looping. Using the `\pgfmathparse` command, we compute a mathematical expression by generating a random integer from 2 to 9 with the `random(2,9)` command. We store this result in the `\pgfmathresult` variable. We copy the value of this variable into the variable `\nmbfirst`. Similarly to the previous one, we generate the second random integer from 2 to 8 and store the result in the `\nmbsecond` variable. We generate the third random integer from 1 to 9 and store the result in the `\nmbthird` variable.

We print the problem by creating the `\item` of the enumerated list. The `\item` will be printed inside the enumerate environment that we write in the body of the LaTeX document.

The program code of this command is shown in Fig. 1.

```
\documentclass[a4paper,12pt]{article}
\usepackage{amsmath}
\usepackage{amssymb}
\usepackage{tikz}

\newcommand{\limitcompare}[1]{%
    \foreach \i in {1,...,#1} {
        \pgfmathparse{random(2,9)}
\let\nmbfirst=\pgfmathresult
        \pgfmathparse{random(2,8)}
\let\nmbsecond=\pgfmathresult
        \pgfmathparse{random(1,9)}
\let\nmbthird=\pgfmathresult
         \item Find the limit \(\displaystyle\lim_{n \to
\infty} \frac{\nmbfirst - \nmbfirst\cdot\nmbsecond^{n+1}}
{(\sqrt{\nmbsecond})^n+e^{n+\nmbthird}}\)
    }
}
```

Fig. 1. **The creation of the `\limitcompare` command**

Let us create a new command `\limitirrat` that takes one argument. This command generates a limit with irrationalities. Similar to the previously created command, in the loop, using the `\pgfmathparse` command, we compute the mathematical expression by generating a random integer from 2 to 9 with the `random(2,9)` command. We store this result in the `\pgfmathresult` variable. We copy the value of this variable into the `\nmfirst` variable.

In this problem, we compute the expression `\nmfirst *2` and return the result using the `\numexpr` command, and convert the result of the computing to text using the `\the` command. The `\relax` command completes this computing.

We print the problem by creating the `\item` of the enumerated list.

The program code of the `\limitirrat` command is shown in Fig. 2.

```
\newcommand{\limitirrat}[1]{%
    \foreach \i in {1,...,#1} {
        \pgfmathparse{random(2,9)}
\let\nmfirst=\pgfmathresult
       \item Find the limit \(\displaystyle\lim_{n \to \infty}
\left(\frac{1}{\sqrt{n^2+\nmfirst}}+\frac{1}{\sqrt{n^2+
\the\numexpr\nmfirst* 2\relax}}+\cdots+\frac{1}{\sqrt{n^2+
\nmfirst n}}\right)\)
    }
}
```

Fig. 2. **The creation of the `\limitirrat` command**

Let us create a new command `\limitparam` with one argument. This command generates a limit with a parameter. In a loop using the `\pgfmathparse` command, we compute the mathematical expression by generating a random integer from 2 to 19 with the `random(2,19)` command. We copy the result stored in the `\pgfmathresult` variable into the `\nmrfirst` variable.

Similarly, we print this limit with the `\item` of the enumerated list.

The program code of the `\limitparam` command is shown in Fig. 3.

```
\newcommand{\limitparam}[1]{%
    \foreach \i in {1,...,#1} {
        \pgfmathparse{random(2,19)}
\let\nmrfirst=\pgfmathresult
       \item Find the limit \(\displaystyle\lim_{n \to \infty}
\sqrt[n]{1^{\nmrfirst}+2^{\nmrfirst}+3^{\nmrfirst}+
\cdots+n^{\nmrfirst}+u^{2n}}\)
      }
    }
```

Fig. 3. **The creation of the `\limitparam` command**

Let us create a new command `\limitsmall` with one argument. This command generates a limit with an infinitesimal sequence. Similarly to the previously created commands, in the loop, we compute the mathematical expression by generating a random integer from 2 to 9 and copying the result into the `\nmbrfirst` variable. Similarly, we create and copy the generated random integers from 10 to 15 and from 8 to 16 into the `\nmbrsecond` variable and the `\nmbrthird` variable respectively.

We print this problem with the `\item` of the enumerated list.

The program code of the `\limitsmall` command is shown in Fig. 4.

```
\newcommand{\limitsmall}[1]{%
    \foreach \i in {1,...,#1} {
        \pgfmathparse{random(2,9)}
\let\nmbrfirst=\pgfmathresult
        \pgfmathparse{random(10,15)}
\let\nmbrsecond=\pgfmathresult
        \pgfmathparse{random(8,16)}
\let\nmbrthird=\pgfmathresult
       \item Find the limit \(\displaystyle\lim_{n \to \infty}
\frac{\sin({n^{\nmbrthird} -\nmbrfirst})}{\sqrt{n^{\nmbrfirst}
+n^{\nmbrsecond}}}\)
      }
    }
```

Fig. 4. **The creation of the `\limitsmall` command**

In order to generate different random integers after each compilation of the LaTeX document (at different times), we configure the random number generator in the body of the LaTeX document using the `\pgfmathsetseed` command of the TikZ package.

We invoke the `\limitcompare` command by giving it the parameter `2`. As a result of compilation, this command generates two limits with mathematical expressions that need to be compared.

We invoke the `\limitirrat` command by giving it the parameter `2`. As a result of compilation, this command generates two limits with irrationalities.

We invoke the `\limitparam` command by giving it the parameter `3`. As a result of compilation, this command generates three limits with a parameter.

We invoke the `\limitsmall` command by giving it the parameter `2`. As a result of compilation, this command generates two limits with infinitesimal sequences.

The program code in the body of the LaTeX document with the invocations of the created commands is shown in Fig. 5.

The program codes shown in Figs. 1-5 generate the result shown in Fig. 6.

Conclusions. In this article, the new commands `\limitcompare`, `\limitirrat`, `\limitparam`, and `\limitsmall` that automatically create mathematical expressions for the theory of limits of mathematical analysis were created.

The created new commands accelerate the creation and updating of mathematical documents and provide flexibility in changing parameters.

These commands can be used to prepare scientific publications and educational materials on mathematical analysis.

Thus, in this article, the functionality of the LaTeX system was expanded to automatically create mathematical expressions for the theory of limits of mathematical analysis.

```
\begin{document}

\section*{Problems in Mathematical Analysis}

\pgfmathsetseed{\number\numexpr\year*10000+\month*100+\day+
\time\relax}

\subsection*{Example of using the \texttt{\textbackslash
limitcompare} command}

\begin{enumerate}
\limitcompare{2}
\end{enumerate}

\subsection*{Example of using the \texttt{\textbackslash
limitirrat} command}

\begin{enumerate}
\limitirrat{2}
\end{enumerate}

\subsection*{Example of using the \texttt{\textbackslash
limitparam} command}

\begin{enumerate}
\limitparam{3}
\end{enumerate}

\subsection*{Example of using the \texttt{\textbackslash
limitsmall} command}

\begin{enumerate}
\limitsmall{2}
\end{enumerate}

\end{document}
```

Fig. 5. **The program code in the body of the LaTeX document with the invocations of the created commands**

Problems in Mathematical Analysis

Example of using the \limitcompare command

1. Find the limit $\lim\limits_{n\to\infty} \dfrac{3-3\cdot 5^{n+1}}{(\sqrt{5})^n+e^{n+5}}$
2. Find the limit $\lim\limits_{n\to\infty} \dfrac{2-2\cdot 3^{n+1}}{(\sqrt{3})^n+e^{n+2}}$

Example of using the \limitirrat command

1. Find the limit $\lim\limits_{n\to\infty} \left(\dfrac{1}{\sqrt{n^2+3}}+\dfrac{1}{\sqrt{n^2+6}}+\cdots+\dfrac{1}{\sqrt{n^2+3n}}\right)$
2. Find the limit $\lim\limits_{n\to\infty} \left(\dfrac{1}{\sqrt{n^2+5}}+\dfrac{1}{\sqrt{n^2+10}}+\cdots+\dfrac{1}{\sqrt{n^2+5n}}\right)$

Example of using the \limitparam command

1. Find the limit $\lim\limits_{n\to\infty} \sqrt[n]{1^{18}+2^{18}+3^{18}+\cdots+n^{18}+u^{2n}}$
2. Find the limit $\lim\limits_{n\to\infty} \sqrt[n]{1^{7}+2^{7}+3^{7}+\cdots+n^{7}+u^{2n}}$
3. Find the limit $\lim\limits_{n\to\infty} \sqrt[n]{1^{10}+2^{10}+3^{10}+\cdots+n^{10}+u^{2n}}$

Example of using the \limitsmall command

1. Find the limit $\lim\limits_{n\to\infty} \dfrac{\sin(n^{14}-9)}{\sqrt{n^9+n^{10}}}$
2. Find the limit $\lim\limits_{n\to\infty} \dfrac{\sin(n^{14}-2)}{\sqrt{n^2+n^{12}}}$

Fig. 6. **The generated result**

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