WALIA journal 32(1): 13-18, 2016
Available online at www.Waliaj.com
ISSN 1026-3861

Monitoring software modeling

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Abstract: Today, there are a large number of not only algorithms but also individually designed programs, simulators, whose task is to model such schemes. Many simulators also support special options of modeling that set the required accuracy of the calculation. In this article we consider the principle of the simulation software and algorithmic composition of the example programs run simulations in the time domain.

Key words: *Modeling; SLAE (system of linear algebraic equations) integration*

1. Introduction

The basis for calculating the time-domain simulation of any program on the processes of formation of mathematical models of IS and its solutions. Fig. 1 shows their relationship and the sequence of execution of the algorithm on an example of formation of a mathematical model of nodal analysis and its decision in the analysis in the time domain (Davis, 1991; Inside SPICE, 1994). Under input pattern element in the vector of current sources and an array nodal conduction meant entering a numerical value corresponding to the current flowing through the element or the value of its conductivity at a predetermined settlement time at known potentials at the terminals of the element. In addition to show the effect of the simulation program, it is worth mentioning the previous reading process information about the scheme, including the execution of lexical, syntactic and semantic analysis of the input file with the description of schemes and modeling guidelines, the process of filling the internal data structures. Since the processes of formation and solving mathematical models are the most difficult from a computational point of view, then each of these processes will be discussed in detail.

2. Overview of analytical methods for the formation of a mathematical model of IS

Task analysis is a mathematical model of the formation of the analyzed IS in a system of integral-differential equations and solving the system of equations.

Any circuit condition at any one time is described in a general form a system of nonlinear partial differential equations (1).

$$F\left(\overline{\varphi, t}\right) = \frac{d\,\overline{\varphi}}{dt} \qquad (1)$$

As in step solution of the mathematical model used, as a rule, the methods for solving systems of linear algebraic equations, the system (1.1) is subjected algebraization and linearization. The system of ordinary differential equations of the form (Eq. 1), which describes the dynamic operation of the electronic circuit can be algebraize one of the known methods of numerical integration. The main criterion in determining the choice of the method of integration is a criterion to achieve the required accuracy of numerical integration minimum cost of computer time. The currently used methods of integrating systems of differential equations can be divided into two classes: explicit methods and class implicit methods (Kosarev, 2000; Verzhbitsky, 2002; Mullets and Petrov, 2006; Lin Pen-min, 1980).

Suppose there is a differential equation of the form (Eq. 1), which must be integrated. Analytical solution of this equation will be the integral (Eq. 2).

$$\varphi = \varphi_0 + \int_0^T F(\varphi, t)\,dt \qquad (1.2)$$

Assume that an approximate solution is known in the time required to obtain a solution, and at a time entering step in time equal. When performing timing

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analysis solution begins at t = 0 and a known value. Since the value is known, it is possible to calculate the formula dt (Eq. 1) and obtain an approximate φ_1 value, assuming that t varies from t_0 to $t_1 = t_0 + h$ function $F(\varphi, t)$ remains constant and equal to $F(\varphi_0 t_0)$. Then from (Eq. 2) we find that, $\varphi_1 = \varphi_0 + h \cdot F(\varphi_0, t_0)$ or in the general form

$$\varphi_1 = \varphi_0 + h \cdot F(\varphi_n, t_n). \quad (3)$$

Expression (Eq. 3) is explicit formula of Euler's method. Similarly, making the assumption that t varies from t_0 to $t_1 = t_0 + h$ function $F(\varphi, t)$ remains constant and equal $F(\varphi_1, t_1)$, it is possible to obtain the expression (Eq. 4), which is a formula implicit Euler method.

$$\varphi_{n+1} = \varphi_n + h \cdot F(\varphi_{n+1}, t_{n+1}). \quad (4)$$

Analysis of formation (Fig. 1):

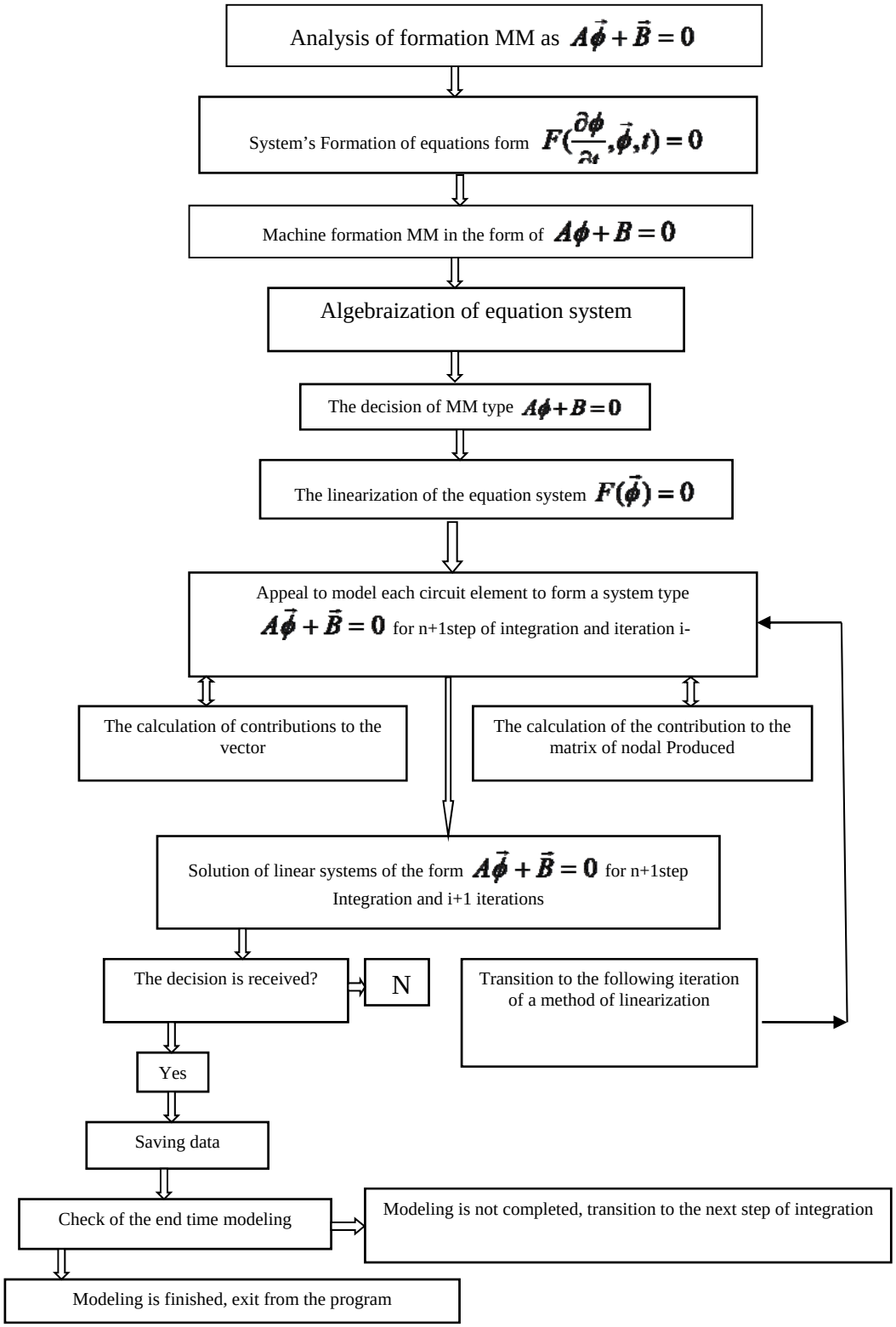

Fig. 1: Block diagram of the algorithm of the simulator

Putting these two formulas, one can obtain the expression (Eq. 5), which is a formula trapezoidal method.

$$\varphi_{n+1} = \varphi_n + \frac{h}{2} \cdot (F(\varphi_n, t_n) + F(\varphi_{n+1}, t_{n+1})) \quad (1.5)$$

For all the obvious methods of major limitation, which leads to considerable machine time is a limit on the time step of integration h, determining the numerical stability of the solution. The value of the integration step for the explicit methods associated with the minimum time constant of the circuit, which is the subject of mathematical modeling, the dependence (Eq. 6)

$$h \le C\tau_{\min} \quad (6)$$

Where C - constant, determined by the procedure used integration formulas; Implicit methods for integration, free from restrictions on the minimum time constant. However, in the case of integration of the system of nonlinear differential equations, implicit methods require solving a system of nonlinear algebraic equations φ_{i+1} at each time step.

The above methods of integration are so-called one-step method. There is also a series of multi-step methods of integration, which is the main difference from the one-step method is the dependence of the calculated values not only of the value of h, prepared for this step of the method of integration, but also the values of h, obtained on several previous steps. In implementing the multi-step methods for the initial set of values of steps h, performed first few steps with the use of one-step methods, during which the values are stored step h, and then begins to work directly with a multi-step integration method. Examples of multistep methods can serve as methods of Gere and Adams (Kosarev, 2000; Verzhbitsky, 2002; Mullets and Petrov, 2006; Lin Pen-min, 1980).

Since the application integration method breaks up the time interval in the intervals required value h, for each time going t_n on the solution of nonlinear algebraic equations of the form (Eq. 7).

$$F(\overline{\varphi}) = 0 \quad (7)$$

For solving systems of the form (Eq. 7), which in general are systems of nonlinear algebraic equations, using different mathematical methods: dichotomy, gold section method, Newton's method? For reasons discussed in detail in (Kosarev, 2000; Verzhbitsky, 2002), in practice for solving problems often uses the Newton method or its modification. Newton's method is based on the expansion of the form (Eq. 7) in a Taylor series. For one-dimensional case the expression for the potential at a point on the (k + 1) - th iteration by Newton's method can be written as

$$\varphi_{k+1} = \varphi_k - \frac{F(\varphi_k)}{F'(\varphi_k)} \quad (8)$$

where φ_{k+1} - the value of the potential in the current iteration, φ_k is the value of the capacity obtained in the previous iteration. In general terms, for a system of equations, the expression (Eq. 8) it will be recorded as:

$$\overline{\varphi}_{k+1} = \overline{\varphi}_k - Y^{-1} F(\overline{\varphi}_k) \quad (9)$$

where Y - the Jacobi matrix, or a matrix of partial derivatives. The calculation of the new values of the unknowns going to iteratively until the norm of the vector of increments of nodal values does not will be less than a predetermined value ε.

$$\left\| \overline{\varphi}_{k+1} - \overline{\varphi}_k \right\| < \varepsilon \quad (10)$$

Y matrix is formed as shown $Y = \frac{\partial \overline{J}}{\partial \overline{\varphi}}$,in expanded form in (Eq. 11).

$$Y = \begin{bmatrix} \frac{\partial J_1}{\partial \varphi_1} & \frac{\partial J_1}{\partial \varphi_2} & \cdots & \frac{\partial J_1}{\partial \varphi_j} \\ \frac{\partial J_2}{\partial \varphi_1} & \frac{\partial J_2}{\partial \varphi_2} & \cdots & \frac{\partial J_2}{\partial \varphi_j} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial J_j}{\partial \varphi_1} & \frac{\partial J_j}{\partial \varphi_2} & \cdots & \frac{\partial J_j}{\partial \varphi_j} \end{bmatrix} \quad (11)$$

Developed by a large number of algorithms to accelerate the search for a solution and to improve convergence of Newton's method (Liniger, 1971; Moursund, 1967; Kuzovkin, 2006). Review of the methods of forming a mathematical model of the machine. The basis of modern methods of topological analysis of electrical circuits laid Kirchhoff, published in 1847, the analysis of the basic laws of electrical circuits. However, the extensive development of topological methods of analysis and synthesis of electric circuits began only after the moment when the calculation of the schemes has started to make with the help of computer technology. Parallel to this, the problem appeared the easiest ways to find programming of such calculations. There are a number of methods of formation of mathematical models of the IS distinct selection of basic variables (Lin Pen-min, 1980). Basic variables called parameters of the schemes, which are selected in a particular method as the unknown and search for values which are respectively conducted. Selecting a significant effect on the basis of three important characteristics of the program associated with the mathematical model of the scheme: 1. simplicity of algorithm of formation of mathematical models; 2. The size of a software representation of a mathematical model, which affects the parameters such as speed and accuracy of the calculation, as well as the maximum size of the simulated circuit; 3. restrictions on permissible in the scheme of the types of dependent sources of supply. By type selected basis, the main methods of forming systems of equations are: method of planimetric currents (MPC), method of nodal potentials (MNP) and method of a variable state (MVS). They represent the analysis algorithms of electronic schemes received by various ways of drawing up and transformation of the equations of Kirchhoff.

The method of planimetric currents is based on the second law of Kirchhoff. Basic variables of this method are currents in scheme contours. In a matrix look the system of the equations formed by MPC can be written down in a look

$$Z \cdot \vec{j} = \vec{E} \quad (12)$$

For the solution of a problem of finding of currents in the scheme, in its allocate independent contours, in each of which value of current is defined. The direction of current in a contour gets out automatically. For each allocated contour the equation under the second law of Krchhoff is worked out, and the direction of round of a contour coincides with the direction of current in a contour. The method of nodal potentials, unlike a method of planimetric currents, is based on the first law of Kirchhoff. Basic variables of this method are potentials in scheme knots. The system of the equations formed according to a method of nodal potentials looks as follows:

$$Y \cdot \vec{\varphi} = \vec{J} \quad (13)$$

Here Y - the square rarefied matrix of nodal provodimost, - a vector column of potentials, - a vector column of sources of current.

Unlike a method of nodal potentials and a method of planimetric currents, the system of the equations describing a condition of the scheme in a method of variables of a state is hybrid, that is as variables both currents, and potentials are used. Transition processes in any electric chain containing the jet L and C elements are described by the differential equations of n-nogo of an order, where n - the number of independent entry conditions equal to number of independent initial stocks of energy in the scheme. As energy stocks up in jet elements of the scheme (to L, C), that the order of the differential equations is equal to the sum of number of capacities With with independent initial charges of Q and number of an induktivnostea with L with independent initial flux linkage ψ. Matrix representation of the system of the equations formed as a result of application of a method of variables of a state is presented in the form (14).

$$\begin{bmatrix} \upsilon_l \\ i_c \end{bmatrix} = \begin{bmatrix} L & 0 \\ 0 & C \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_l \\ i_c \end{bmatrix} \quad (14)$$

In the analysis of difficult electric chains, labor input of calculations is very great. Usually for similar calculations the methods based on use of matrixes are used. However certain shortcomings are inherent in them: on the one hand need of resource-intensive calculations, on the other hand - lack of a direct connection between algorithm of calculation and topology of the scheme. One of examples of attempt to solve these problems can consider approach according to the solution of a problem of calculation of schemes by means of a method of structural numbers which essence is reduced to use of special algebra of structural numbers (Vellert and Wozniacki, 1972). The concept of structural number was for the first time formulated by S. Bellert. The structural number is understood as such system of elements of a look α_{ik} :

$$A = \begin{bmatrix} \alpha_{11} & \cdots & \alpha_{1n} \\ \vdots & \ddots & \vdots \\ \alpha_{mn} & \cdots & \alpha_{mn} \end{bmatrix}$$

which is considered as set of columns, that is A = { α1, α2,..., αn } (thus columns are considered equal if they keep identical elements in any order), and satisfies to the following definitions.

Reduction and simplification of calculations in case of application of a method of structural numbers, in comparison with the calculations used at calculations with the help a method of planimetric currents, a method of nodal potentials and a method of variables of a state is reached, of course, due to some complication of system of axioms in comparison with algebra of matrixes. Advantages of a method of structural numbers in comparison with the standard approaches using the theory of matrixes are as follows:

1. The number of operations at the solution of tasks of the analysis and synthesis of electric chains is considerably reduced, for example, when determining transfer functions or currents and tension in chains;
2. The foundation for creation of the general theory of synthesis and the analysis of electric chains without restrictions concerning structure of a chain or sizes of the used elements is laid;
3. The big economy at record of separate formulas in calculation is observed;
4. The theory of structural numbers represents the logical mathematical apparatus opening ample opportunities of further development and application in other areas except the theory of electric chains. In the analysis of schemes by method of structural numbers it is necessary to calculate determinant functions which actually are the developed determinants of matrixes of full resistance or provodimost of chains. From this the first advantage of the considered method follows: having established the necessary dependences, it is directly possible to receive results without bulky calculations with big matrixes. As the second advantage of a method use of similar structures and counts with general characteristics serves. As a result receiving a formula has universal character that is of especially great importance at synthesis of chains. The third essential advantage of a method of structural numbers - use of the theory of sets. It gives economy in the form of record of separate dependences in the analysis of counts and electric chains. At the heart of a method of structural numbers there are such transformations of chains and counts, to compliance which simple algebraic actions with structural numbers are put. These transformations allow solving many new problems of the theory of counts and the analysis of electric chains whereas at a matrix method of transformation of chains doesn't find broad application.

Despite the specified advantages, this algorithm of formation of the IS mathematical models at the moment difficult we realize on the COMPUTER therefore now it isn't put into practice. For a variety of reasons, considered in (Lin Pen-min, 1980; Kuzovkin, 2006), as the main method of formation of the IS mathematical model the method of nodal potentials or its modification is applied to the subsequent its analysis in the majority of programs simulators. The system of the equations of a look (Eq. 13) is formed of the component and topological equations of the analyzed scheme (Davis, 1991; Inside SPICE, 1994).

The equations describing interrelation of current and tension for each of the components entering the scheme are called as the component equations. The main component equations for the IS elementary elements are presented in Table 1. In case of use of more difficult circuitry elements, for example the semiconductor diode and various type of transistors, for each of elements the so-called equivalent schemes containing simpler elements which imitate behavior of difficult components (Shichman and. Hodges, 1968; Ytterdal et al., 2003) are formed.

Table 1: Component equations of the elementary elements of electronic schemes

Circuit element	Component equation
Resistor	$I_R \Rightarrow \frac{\phi_1 - \phi_2}{R(\phi_1, \phi_2)}$
Condenser	$I_c = C(\phi_1, \phi_2)\frac{d(\phi_1 - \phi_2)}{dt}$
Inductance	$I_l = \frac{1}{L(\phi_1, \phi_2)}\int(\phi_1 - \phi_2)dt$
Ideal diode	$I_D = I_0(e^{\frac{\phi_1 - \phi_2}{m\phi_T}} - 1)$

3. Component equations of the elementary elements of electronic schemes

The topological equations show communication between the component equations and are based on Kirchhoff's laws. For example, on the topological equations, according to the law of currents of Kirchhoff, values of a vector of sources of current in the equation are formed (Eq. 13).

Process of machine formation of system of the equations of a look (Eq. 13), as appears from the scheme in Fig. 1, is reduced to consecutive poll of all program codes of models of elements with entering of information on their numerical contribution to a vector of currents and a matrix of nodal provodimost. Review of methods of the solution of the IS mathematical model. As it is approved in (Valyakh, 1985), about 75% of all settlement mathematical tasks it is the share of the decision of SLAE. That mathematical models of the majority of the phenomena or processes or are under construction at once as linear and algebraic, or as it was shown above is the reason of it, are reduced to that by means of algorithms of an algebraization and linearization. From here importance of a choice of a method of the decision of SLAE, effective from any party, follows. It agrees (Kosarev, 2000; Verzhbitsky, 2002; Mullets and Petrov, 2006), all mathematical methods of the decision of SLAE break into some classes: direct, iterative, probabilistic. Carry such methods of the decision of systems of the equations which lead to the decision for final number of arithmetic operations to direct methods. Theoretically, such operations are realized absolutely precisely, the term "exact methods of the decision" applied to direct methods of the decision follows from here. At the same time it is necessary to remember that from the point of view of machine calculations, direct methods don't yield exact result that is connected with hardware realization of arithmetic operations and word length of an arithmetic grid of computers. As an example of a direct method of the decision we will consider a method of exceptions of Gauss. As it is known (Kosarev, 2000; Verzhbitsky, 2002), the classical method of Gauss consists of consecutive performance of forward and reverse motion. During performance of a forward stroke occurs reduction of SLAE of a look (Eq. 2) to SLAE of a look (Eq. 15):

$$U \cdot \vec{\phi} = \vec{J}' \quad (15)$$

Here the matrix of U is the top triangular matrix which receiving is the main objective of a forward stroke of a method of Gauss. The vector $\vec{J}'$ is also formed as a result of a forward stroke of a method of Gauss.

During reverse motion of a method of Gauss there is a consecutive receiving a vector of decisions of system $\vec{\phi}$ (1.13) through U and a vector $\vec{J}'$ received a matrix. A classic example of iterative methods is the iterative method of Gauss-Sejdel.

The system of the equations of a look (Eq. 13) can be transformed to system of a look (Eq. 16).

$$\vec{\phi} = A\vec{\phi} + \vec{b} \quad \text{(Eq. 16)}$$

Where $\vec{\phi}$ - the same vector of unknown, an A and $\vec{b}$ - some new matrix and a vector respectively. The system (Eq. 16) can be interpreted as a task about $\vec{\phi}^{(k)}$

To $\vec{\phi}^{(*)}$ motionless point and to determine sequence of approximations to a motionless point by a recurrence relation (Eq. 17).

$$\vec{\phi}^{(k+1)} = A\vec{\phi}^{(k)} + \vec{b} \quad (17)$$

The iterative process described by a ratio (Eq. 17), beginning with some vector $\vec{\phi}_0$ is called as method of simple iterations.

Gauss-Sejdel's method is understood as such modification of a method of simple iterations (Eq. 17) at which for calculation of i-that components (k+1) - ro approximations to $\vec{\phi}^*$ a required vector are used already found on it, (k+1) a step, new values of previous (i-1) a component. It means that for the system of a look (Eq. 13) consisting of n of the

equations reduced somehow to system (Eq. 16), are defined by system of equalities (Eq. 18).

$$\begin{cases} \phi_1^{(k+1)} = a_{11}\phi_1^{(k)} + a_{12}\phi_2^{(k)} + \ldots + a_{1n}\phi_n^{(k)} + c_1 \\ \phi_2^{(k+1)} = a_{21}\phi_1^{(k+1)} + a_{22}\phi_2^{(k)} + \ldots + a_{2n}\phi_n^{(k)} + c_2 \\ \phi_n^{(k+1)} = a_{n1}\phi_1^{(k+1)} + a_{n2}\phi_2^{(k+1)} + \ldots + a_{nn}\phi_n^{(k)} + c_n \end{cases} \quad (1.18)$$

In practice iterative methods are used rather seldom as possess a number of essential shortcomings. It is possible to carry the increase in an error of calculations connected with need to add to a methodical mistake and an error of rounding the maximum admissible error of calculations, and also need of a choice of initial approach for sufficient proximity from the exact decision for ensuring high speed of convergence of iterative process to the main of them. In some situations, at a bad choice of initial approach or in the absence of diagonal prevalence of the main diagonal of a matrix, iterative methods don't meet to the decision (Moursund, 1967; Beyer, 1964; Kuzovkin, 2006; Vellert and Wozniacki, 1972) at all. The specified shortcomings force to use when developing simulators as methods of the decision of SLAE direct methods.

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