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DEVELOPMENT OF A MATHEMATICAL MODEL AND SOFTWARE PACKAGE TO OPTIMIZE INFORMATION PROCESSING IN INFORMATION SYSTEMS

Alisher Shamuradovich Fazilov
Associate professor, Head of the Department of Informatics and Information Technologies at Tashkent Institute of Architecture and Civil Engineering, Tashkent, Uzbekistan

Maruf Kuchimovich Kuchimov
Senior Lecturer at Tashkent Institute of Architecture and Civil Engineering, Tashkent, Uzbekistan

ABSTRACT
The research paper discusses the development of a mathematical model and information processing algorithms in information systems. Based on simulation and a mathematical model, a complete set of probability-time characteristics is determined.

KEYWORDS. ***Information system, modeling, queuing system, simulation model.***

INTRODUCTION

Information systems (IS) are one of the effective means of information processing in shared systems and are widely used in office automated control systems (ACS), computer-aided design systems (CAD), etc. The widespread use of IP is primarily due to their high economic efficiency.

However, in many respects the success of the development of information computing systems is determined by their accessibility to the mass user, on the one hand, and the socio-economic consequences that they bring to flexible automated systems in various spheres of human activity, on the other hand. Therefore, the selection and optimization of access modes is an important part of the problem of optimizing information processing in IS.

The performance and bandwidth of the IS is determined by a complex of systemically interrelated factors:

- Characteristics of technical means (choice of computers and workstations, communication equipment, operating systems of workstations, servers and their configurations, etc.),
- The nature of the distribution and storage of information resources,
- Modes of access to the system,
- Organization of distributed information processing,
- Distribution of database files among system servers,
- Organization of a distributed computing process,
- Protection, maintenance and restoration of operability in situations of failures and failures.

METHODS OF RESEARCH

Thus, when designing, it is very important to determine the areas of effective use of the IC with its given parameters. The solution to such a problem is possible on the basis of a systematic analysis of these factors, which characterize the degree of efficiency of composite subsystems and IS components. One of the important factors that determine the overall efficiency of the IS functioning are the characteristics of the access subsystem. In turn, the study of the characteristics of various access modes and the selection of the most optimal for specific operating modes of the IS and, accordingly, the optimization of information processing modes when solving a given class of problems, possibly by developing mathematical models of these processes and organizing simulation modeling using computational experiment tools.

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The creation of a mathematical model of the IS for the analysis of VVH was carried out in two phases.

At the first phase, on the basis of a given system configuration, characteristics of request sources and their processing, as well as flow distribution algorithms, a mathematical model was built to determine the load factors for all traffic routes in the IS. At the same time, the most general assumptions are allowed regarding the nature of the flow distribution laws and their processing on the system elements, i.e. flows of applications and their processing can have arbitrary laws of probability distribution.

In the second phase of the development of a mathematical model, using the obtained values of the load factors for all fragments of the IS, an equivalent in terms of the average model of the exponential queuing system is formed, on the basis of which the IHC are calculated for all the necessary routes of information movement in the IS.

On the basis of the IS functional diagram, it is necessary to move to its representation in terms of queuing systems, as a result, a queuing model is obtained, which reflects the work of the corresponding subscribers. The peculiarity of the functioning of the IS under consideration lies in the fact that each of the subscribers can contact any other with the same probability.

The use of an exponential queuing system as an IS model is justified by the general assumptions of convergence of processes depending on a large number of equally weighted random factors to Poisson ones, which is shown in the works of Grigelionis B.I. and Pogozheva I.B. This approach to the development of a model is justified especially at the design stages of fundamentally new systems, since this model makes it possible to evaluate the operation of the system under the most unfavorable conditions, which is especially important in conditions of incomplete statistical information on the designed object.

To construct a mathematical model, let us single out a fragment that determines the interaction of any two subscribers "subscriber A_i and subscriber A_j, $i \neq j$," (Fig. 1).

For each phase, proceeding from the exponentiality conditions of the entire system, the following VVH can be obtained: the density of the probability distribution of the residence time of the request, its mathematical expectation and variance; the probability distribution density of the waiting time of the application, its mathematical expectation and variance; the distribution of probabilities of the number of claims being serviced and waiting in the servicing queue, their mathematical expectations and variances; the probability that the delivery time of the package will exceed the value of $T_{additional}$; equipment load factors for each phase.

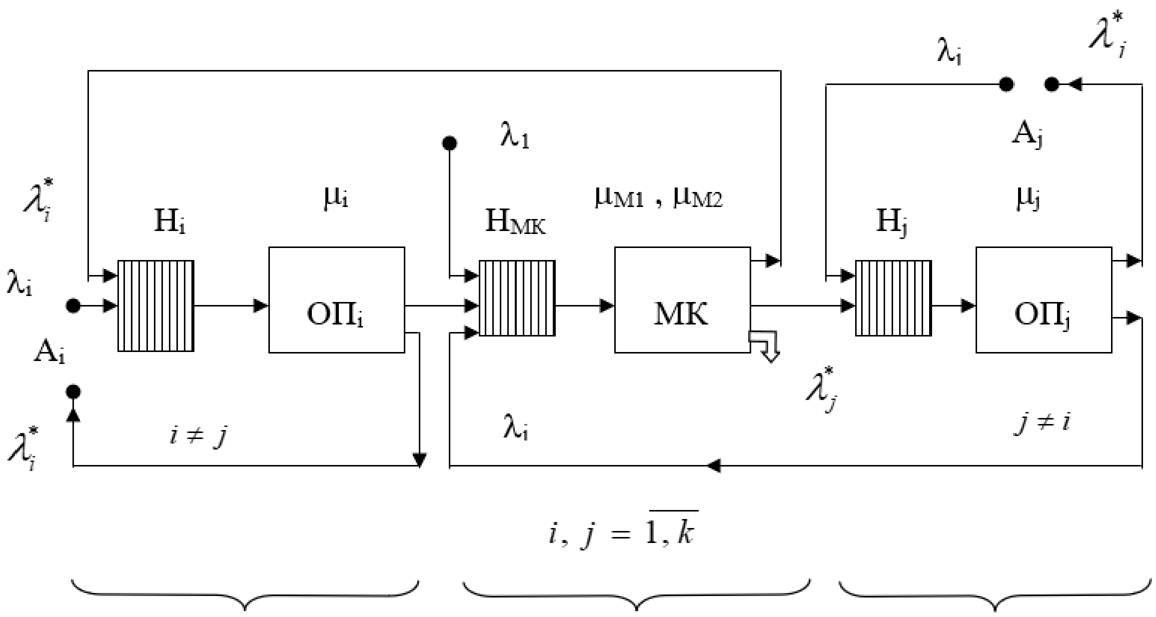

Fig.1. Mathematical model, let us single out a fragment that determines the interaction of any two subscribers "subscriber A_i and subscriber A_j, $i \neq j$"

The conditions for the occurrence of a conflict are determined dynamically and depend on the number of claims waiting for service in the mono-channel (SMO_{mc}).

The probability of the onset of a conflict is determined as follows:

$$P_{nk} = P(h \geq 3) - H, \quad (1)$$

where, $P(h\geq3)$ – probability of finding in SMO_m three or more applications from all subscribers,

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H – the probability of conflict-free situations, provided that there are three or more applications in the system.

The probability P (h≥3) is determined on the basis of the SMO_m M / M / 1 model, taking into account the fact that at the input we have a total flow from all subscribers, i.e.

$$P(h > 3) = \rho^3 ,$$

where $\rho = \sum_{i=1}^{k} \rho_i$, a $\rho_i = \frac{\lambda_i}{\mu_i}$.

As a result of the analysis of IS with a different number of subscribers = 3.

Due to the independence of the input flows of applications, the probability that there are exactly n1, n2, n3 applications from 1, 2, 3 subscribers in the QS can be represented as products of separate components, i.e.

$$P(n_1, n_2, n_3)=P(n_1)P(n_2)P(n_3).$$

The general expression H is represented as follows:

$$H=\sum_{i=2}^{\infty} P_1(i)\cdot P_2(1)\cdot P_3(0) + P_1(1)\cdot\sum_{j=2}^{\infty} P_2(j)\cdot P_3(0) + P_1(0)\cdot P_2(1)\cdot\sum_{k=2}^{\infty} P_3(k) +$$

$$+P_1(0)\cdot\sum_{j=2}^{\infty} P_2(j)\cdot P_3(1) + P_1(1)\cdot P_2(0)\cdot\sum_{k=2}^{\infty} P_3(k) + \sum_{i=2}^{\infty} P_1(i)\cdot P_2(0)\cdot P_3(1) +$$

$$+\sum_{i=3}^{\infty} P_1(i)\cdot P_2(0)\cdot P_3(0) + P_1(0)\cdot\sum_{j=3}^{\infty} P_2(j)\cdot P_3(0) + P_1(0)\cdot P_2(0)\cdot\sum_{k=3}^{\infty} P_3(k)$$

Because of, $P_i(0)=1-\rho_I$, $i=\overline{1,3}$

$P_i(1)=(1-\rho_I)\rho_I$, $i=\overline{1,3}$

$$\sum_{j=R}^{\infty} P_i(j) = \rho_i^R , \quad i=\overline{1,3}$$

for CMO M/M/1, then

$$H = \rho_i^2(1-\rho_2)\rho_2(1-\rho_3) + (1-\rho_1)\rho_1\rho_2^2(1-\rho_3) + (1-\rho_1)(1-\rho_2)\rho_2\rho_3^2 +$$
$$(1-\rho_1)\rho_2^2(1-\rho_3)\rho_3 + (1-\rho_1)\rho_2(1-\rho_2)\rho_3^2 + \rho_1^2(1-\rho_2)(1-\rho_3)\rho_3 +$$
$$\rho_1^3(1-\rho_2)(1-\rho_3) + (1-\rho_1)\rho_2^3(1-\rho_3) + (1-\rho_1)(1-\rho_2)\rho_3^3$$

Then the component of the load factor for a mono channel from each "i" -th subscriber can be determined as follows:

$$\rho_i = \lambda_i(1/\mu_{M1} + P_{VR} + P_{MK}\cdot\mu_{M2}), i=\overline{1,k}$$

Thus, the model of the considered IS is fully defined and it is possible to carry out a comprehensive analysis of the computing system with various initial data.

Further, a mathematical model of an IS with an arbitrary number of subscribers is considered.

Analysis of the behavior of the probability of conflict-free situations with an increase in the number of subscribers "k" showed that the value of H decreases and for k> 4 the value of H can be neglected, and then

$P_{nk} = P(h\geq3)= \rho^3$ (2)

When using (2.2), the share of the load factor in the mono channel from the i-th subscriber is determined as follows:

$\rho_i = \lambda_i (1/M_{M1} + P_{HK}/M_{M2})$, i = 1,k

or $\rho_i = \lambda_i/M_{M1} + (\Lambda/M_{M1})^3 /M_{M2}$, i = 1,k , (3)

where, $\Lambda = \sum_{i=1}^{k} \lambda_i$ - total summary intensity of streams arriving at the input of the mono channel;

k – the total number of incoming streams to the mono channel;

M_{M1} – the intensity of processing requests of all subscribers in the mono channel;

M_{M2} - the intensity of processing requests in the mono-channel in the event of a conflict

Summing over all elements ρ_i, i=1,k ρмк = $\sum_{i=1}^{k} \rho_i^{MK} = \frac{1}{M_{M1}} \sum_{i=1}^{k} \lambda_i + \frac{1}{M_{M2}} \left(\frac{\Lambda}{M_{M1}} \right)^3 \sum_{i=1}^{k} \lambda_i$ или

ρмк = $\frac{\Lambda}{M_{M1}} + \frac{\Lambda}{M_{M2}} \left(\frac{\Lambda}{M_{M1}} \right)^3$, (4)

In expression (2.4) it is necessary to determine M_{M2}.

The probability that the conflict for a given message occurred "n" times is determined by the exponential distribution:

$P_n = (1- \Omega)\Omega^{n+2}$.

Based on the definition of the mathematical expectation for discrete random numbers, the average backoff time is determined:

$T_{отср}$ (n) = $\frac{1}{2} \sum_{n=0}^{9} \left[(2^n - 1) P_n \right] + \frac{2^{10} - 1}{2} \sum_{n=10}^{15} P_n$;

or

T_{middle} (n) = $\frac{1-\Omega}{2} \sum_{n=2}^{9} \left[(2^n - 1)\Omega^{n+2} \right] + 511.5 \sum_{n=10}^{15} (\Omega^{11} - \Omega^{16})$;

где Ω = $\left(\sum_{i \subset вх.моноканал} \lambda_i \right) / M_{M1}$

then M_{M2} = 1/ $T_{отср}$ (5)

Each of these characteristics will be denoted by $П_m^{n_ф}$, where m=$\overline{1, s}$ = is the index number, and $n_ф$ = $\overline{1,3}$ is the phase number. The VVHs for the first and third phases can be determined based on the well-studied M / M / 1 queuing model. It should be borne in mind that the input of each subscriber unit receives a stream with an intensity, which is processed in a subscriber station with an intensity $\mu_i, i = \overline{1, k},$

where $\lambda_i^{вх} = \lambda_i + \lambda_i^*$, where $\lambda_i^* = (\sum_{r=1}^{k} \lambda_r)/(k-1)$, $i = \overline{1,k}$ (6)

Due to the exponentially of the system, the VVH of the first phase is determined as follows:

$g_i^{1ф}(t)$ - probability distribution density of the time spent by the “i” -th subscriber in the first processing phase.

$g_i^{1ф}(t)$ $g_i^{1ф}(t)$ =(μ_I - $\lambda_i^{вх}$) exp[(μ_I - $\lambda_i^{вх}$) t], (7)

$\overline{u}_i^{1ф}$ - average time spent by the application "i" -th subscriber in the first phase,

$\overline{u}_i^{1ф}$ $\overline{u}_i^{1ф}$ = [μ_I (1- $\lambda_i^{вх}$) / μ_I]$^{-1}$. (8)

$D_{g_i}^{1ф}$ - variance of the time spent by the application "i" -th user in the first phase,

$D_{g_i}^{1ф}$ = [μ_I - $\lambda_i^{вх}$)]$^{-2}$. (9)

$f_i^{1ф}(t)$ - probability distribution density of order waiting time

$f_i^{1ф}(t)$ «i» - 1st subscriber in the first phase,

$f_i^{1ф}(t)$ =($\lambda_i^{вх}$ /μ_I)(μ_I - $\lambda_i^{вх}$) exp [-(μ_I - $\lambda_i^{вх}$) t]. (10)

$\overline{w}_i^{1ф}$ - average waiting time for a request in the first phase,

$\overline{w}_i^{1\phi}$ $\overline{w}_i^{1\phi} = \frac{1}{\mu_i} \cdot \frac{\lambda_i^{вх} / \mu_i}{1 - \lambda_i^{вх} / \mu_i}$ (11)

$D_f^{1\phi}$ - the variance of the waiting time for the request of the "i" -th subscriber in the first phase

$D_f^{1\phi}$ = $(\lambda_i^{вх}/\mu_I)^2(\mu_I - \lambda_i^{вх})^{-2}$. (12)

$P_i^{1\phi}(n)$ - probability distribution of the number of customers being serviced in the first phase,

$P_i^{1\phi}(n)$ =$(1-\lambda_i^{вх}/\mu_I)(\lambda_i^{вх}/\mu_I)^n$. (13)

$\overline{n}_i^{1\phi}$ - average number of applications in the first phase,

$\overline{n}_i^{1\phi}$ $\overline{n}_i^{1\phi}$ =$(\lambda_i^{вх}/\mu_I)(1-\lambda_i^{вх}/\mu_I)$. (14)

$D_{n_i}^{1\phi}$ - variance of the number of claims in the first phase of the system,

$D_{n_i}^{1\phi}$ = $(\lambda_i^{вх}/\mu_I)/(1-\lambda_i^{вх}/\mu_I)^2$. (15)

$P_i^{*1\phi}(n)$ - probability distribution of the number of customers waiting for the next service,

$P_i^{*1\phi}(0)$ = $1-\lambda_i^{вх}/\mu_I$.

$P_i^{*1\phi}(n)$ = $[1-(\lambda_i^{вх}/\mu_I)](\lambda_i^{вх}/\mu_I)^{n+1}$, at $n \geq 1$. (16)

$\overline{U}_i^{1\phi}$ - average queue length in the first phase,

$\overline{U}_i^{1\phi}$ $\overline{U}_i^{1\phi}$ = $(\lambda_i^{вх}/\mu_I)^2/(1-\lambda_i^{вх}/\mu_I)$. (17)

$D_{D_i}^{1\phi}$ - variance of the queue length of applications in the first phase,

$D_{D_i}^{1\phi}$ = $(1-\lambda_i^{вх}/\mu_I)\sum_{k=1}^{\infty} k^2 /(\lambda_i^{вх}/\mu_I)^{k+1} - (\lambda_i^{вх}/\mu_I)^2/(1-\lambda_i^{вх}/\mu_I)$. (18)

VVH of the second processing phase is determined on the basis of the M/M/1 queuing model, where the input stream is represented by the sum of all "k" subscribers Λ circulating in the IS. The input flow rate of the second phase is determined as follows:

$$\Lambda = \sum_{i=1}^{k} (\lambda_i + \lambda_i^*) + \Lambda_{вовне} + \Lambda_{извне} \quad (19)$$

The average processing time of a message packet in a mono channel is as follows:

$$\tau_{экв}^{MK} = \frac{1}{\mu_{экв}^{MK}} = \frac{\rho_{MK}}{\Lambda} \text{ , } \Lambda = \sum_{i=1}^{k} \lambda_i \quad (20)$$

Having as initial parameters for the second phase of processing the obtained values «Λ» and « $\mu_{MK}^{экв}$ »and, using the same queuing model (M/M/1) for the definition as for the first phase, we obtain for the second phase a similar set of VVH: $g^{2\phi}(t), \overline{U}^{2\phi}, \overline{D}_{g_i}^{2\phi}, f^{2\phi}(t), \overline{w}^{2\phi}, D_{g_i}^{2\phi}, P^{2\phi}(n), \overline{n}^{2\phi}, D_{n_i}^{2\phi}$, where in all expressions of the VVH of the first phase μ_I changes to $\mu_{MK}^{экв}$, and λ_I is replaced by Λ.

For the third phase of processing, VVH are determined based on the same queuing model M/M/1. The initial parameters here will be

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$$\Lambda = \sum_{i=1}^{k}(\lambda_i + \lambda_i^*) + \Lambda_{вовне} \text{ и } \mu^* .$$

By analogy with the VVH obtained at the first and second processing phases, we obtain the following set of indicators:

$$g^{3\phi}(t), \overline{U}^{3\phi}, \overline{D}_{g_i}^{3\phi}, f^{3\phi}(t), \overline{w}^{3\phi}, D_{g_i}^{3\phi}, P^{3\phi}(n), \overline{n}^{3\phi}, D_{n_i}^{3\phi} .$$

It should be noted that both for a mono channel (second phase) and for a server (third phase), the input stream is the sum of all streams circulating in the IS. Obviously, the load will be maximum for the server and mono channel.

Having a complete set of VVHs for each of the three processing phases, integral characteristics can be obtained.

Since the IS model is an exponential system, the integral VVH for the three phases of the route "subscriber A_i – subscriber A_i» are determined by the following relations:

$$\overline{\Pi}_m^{\Sigma}(i,j) = \overline{\Pi}_m^{1\phi}(i) + \overline{\Pi}_m^{2\phi} + \overline{\Pi}_m^{3\phi}(j) \qquad (21)$$

- for VVH, which determine the means and variances, where $\overline{\Pi}_m^{\Sigma}(i,j)$ - integral indicator, m – indicator number;
- $\overline{\Pi}_m^{n\phi}(i)$ - m – th indicator n – th processing phase.

$$\overline{\Pi}_m^{\Sigma}(i,j) = \overline{\Pi}_m^{1\phi}(i) * \overline{\Pi}_m^{2\phi} * \overline{\Pi}_m^{3\phi}(j) \qquad (22)$$

integral indicator for VVH, which determine the probability distribution density and the probability distribution of discrete states, where * is the sign of the composition.

Let's define the integral indicators for all three phases of processing.

Density of the probability distribution of the time spent by the request in the system:

$$g_i(t) = g_i^{1\phi}(t) * g_i^{2\phi}(t) * g_i^{3\phi}(t) \qquad (23)$$

Average time spent by a request in the system:

$$\overline{u}_i = u_i^{1\phi} + u_i^{2\phi} + \overline{u}_i^{3\phi} \qquad (24)$$

Dispersion of the residence time of a request in the system:

$$Dg_i = Dg_i^{1\phi}(t) + Dg_i^{2\phi} + Dg_i^{3\phi} \qquad (25)$$

The density of the probability distribution of the waiting time of the order in the system:

$$f_i(t) = f_i^{1\phi}(t) * f_i^{2\phi}(t) * f_i^{3\phi}(t) \qquad (26)$$

Average waiting time for service of a request in the system:

$$\overline{w}_i = \overline{w}_i^{1\phi} + w_i^{2\phi} + w_i^{3\phi} \qquad (27)$$

The variance of the waiting time for servicing a claim in the system:

$$Df_i = Df_i^{1\phi} + Df_i^{2\phi} + Df_i^{3\phi} \qquad (28)$$

Distribution of probabilities of the number of customers in service:

$$P_i(n) = P_i^{1\phi}(n) * P_i^{2\phi}(n) * P_i^{3\phi}(n) \qquad (29)$$

Average number of requests in the system:

$$\overline{n}_i = \overline{n}_i^{1\phi} + \overline{n}_i^{2\phi} + \overline{n}_i^{3\phi} \qquad (30)$$

Dispersion of the number of orders in the system:

$$Dn_i = g_i^{1\phi} + g_i^{2\phi} + g_i^{3\phi} \qquad (31)$$

Average queue length:

$$\overline{D}_i = \overline{D}_i^{1\phi} + \overline{D}_i^{2\phi} + D_i^{3\phi} \qquad (32)$$

$$D_{D_i} = D_{D_i}^{1\phi} + D_{D_i}^{2\phi} + D_{D_i}^{3\phi} \qquad (33)$$

Performing the composition operation for (23) and (26), we obtain the following analytical expressions:

$$g_i(t) = k_1 \exp[-(\mu_I - \lambda_i^{вх})\, t] + k_2 \exp[-(\mu_{M1} - \Lambda)\, t] + \exp[-(\mu_{M2} - \Lambda)\, t] , \qquad (34)$$

where,

$$k_1 = \frac{(\mu_i - \lambda_i)(\mu_{M1} - \Lambda)(\mu_{M2} - \Lambda)}{[(\mu_{M1} - \Lambda) - (\mu_i - \lambda_i)][(\mu_{M2} - \lambda_i)]};$$

$$k_2 = \frac{(\mu_i - \lambda_i)(\mu_{M1} - \Lambda)(\mu_{M2} - \Lambda)}{[(\mu_i - \lambda_i) - (\mu_{M1} - \Lambda)][(\mu_{M2} - \Lambda) - (\mu_{M1} - \Lambda)]};$$

$$k_3 = \frac{(\mu_i - \lambda_i)(\mu_{M1} - \Lambda)(\mu_{M2} - \Lambda)}{[(\mu_i - \lambda_i) - (\mu_{M2} - \Lambda)][(\mu_{M1} - \Lambda) - (\mu_{M2} - \Lambda)]}.$$

$$f_i\ (t) = \frac{\lambda_i}{\mu_i} \cdot \frac{\Lambda}{\mu_{M1}} \cdot \frac{\Lambda}{\mu_{M2}} \cdot g_i(t) \qquad (35)$$

To express (29):

$$P_i\ (n) = \sum_{j=0}^{k} P_i^{1\phi}(j) \cdot P^{2\phi}(k-j) \cdot P^{3\phi}(n-k) \qquad (36)$$

The rest of the integral VVH are fully defined by the corresponding expressions (24), (25), (27) – (33).

To obtain the probability that the delivery time of information from the subscriber "i" to the server will exceed the value Tadd, it is determined as follows: $P_i[t > T_{\partial on}] = 1 - \int_0^{T_{\partial on}} g_i(t)dt$

(37)

CONCLUSION

Consequently, we got the opportunity to calculate the VVH, both for individual processing phases and for typical routes of information movement. These VVH allow to carry out a complete analysis of the functioning of the IS and to solve the set problem of optimizing information processing in the IS.

The described analytical model is implemented as an integral part of the IS analysis software system.

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