**Introduction**

Connection pool in servlet is a cache of database connections maintained in memory so that the connections can be reused when future requests to the database are required. Separate database connection is fairly expensive operation; here are the sequences of steps involved into a typical database connection life cycle:

1. Opening a connection to the database using the database driver.
2. Opening a TCP socket for data manipulating (reading/writing).
3. Data manipulating (reading/writing) over the socket.
4. Closing the connection.
5. Closing the socket.

Instead of performing this list of operations every time when client sends a request, it is better to implement a database connection pool, which allows to reuse a number of existing connections, the cost of performing a huge number of expensive database trips can be effectively saved, boosting the overall performance of implemented database-driven application.

Connection pools can be tuned to maximize performance, while keeping resource utilization below the point where application will start to fail rather than just run slower. It is very good concept for those web application...
where number of users operate at the same time, where many connections are required at the same time, this process of creating new connection every time makes server too busy so that performance decreases, although connection pooling method manages all the connection required by users [1].

The aim of the study

Construction of a mathematical model of non-stationary flow of user requests to the database based on the obtained statistical information about the intensity of queries and time of their execution.

Statement of the main material

Literature review. Database connection as a key resource to interact with the database is particularly important in the applications especially, in web application of multi-user. Database connection pool technology is proposed to solve the problem of frequently creating and releasing database connection that reduces the system performance in software system. An important problem in database connection pool technology is how to configure the parameters of the connection pool in order to make the software system at the optimal performance [2].

The purpose of connection pools is to enhance the performance of executing queries on database, but connection pool requires extra memory size for every extra connection kept long time in memory. In this way arises the task to find out the optimal number of opened connections in connection pool. This task can be solved, for example, using queuing theory [3] under the assumption that the intensity of the incoming and outgoing query flows [4] are known. The intensity of queries can be estimated using statistics from server but their intensities very in day time and in days of the week [5-6]. So, the task of the paper is to develop the mathematical model of query flows intensity depending on a time.

In [7] is given a quantitative data about the improvement of the performance of the database access based on the connection pool through performance contrast tests under three different kinds of database access modes. In [8] was proposed the optimal allocation method of database connection pool based on the log file records. In [9] was given the configuration method in detail for database connection pool parameter configuration based on XML under J2EE frame study. In [10 -14] was made a study and have obtained some significant results from database connection pool technology.

The performance analysis methods of database connection pool technology can be divided into three categories: Experimental data analysis [15], simulation study method [16] and mathematical model analysis methods [17]. In this study [18], the mathematical model analysis method is used for the database connection pool technology to establish a discrete-time multi-server queuing model. The analysis of classical discrete-time queuing model is shown in [19].

Connection pools include a set of properties that are used to control the size of the pool [20]. The properties allow the number of connections in the pool to increase and decrease as demand increases and decreases. This dynamic behavior helps conserve system resources that are otherwise lost [21] on maintaining unnecessary connections [22].

Model developing. The actual incoming request flows from the client to the servlet are non-stationary. A direct analysis of the observations of the calls reveals the presence of weekly and daily fluctuations in the intensity of calls. Let’s divide the entire observation interval into a set of subintervals of length Δ (for example, Δ = 1 hour). Let’s calculate the number of calls received within each sub-interval.

Let’s process the aggregate random requests number which arrive at the same time-point of day and on the same day of the week (for example, all time intervals from 10:00 till 11:00 every Monday). Let’s calculate the average value and variance of the number of requests that arrive during each of the sub-intervals. In this case, we obtain the totality of the average values $m_1, m_2, ..., m_n$ of the number of requests and their variances $\sigma_1^2, \sigma_2^2, ..., \sigma_n^2$, $n = 24 \cdot 7 = 168$.

Let’s input $b_0$ - the average number of requests to the server during the day, $b_1$ - the amplitude of the daily fluctuations of the number of requests, $b_2$ - the amplitude of the weekly fluctuations of the number of requests. Then, the model which describes the dependence of the average intensity of incoming requests on time is represented by relation (1).

\[
\lambda(t) = \left( b_0 + b_1 \sin \frac{2\pi}{24} t \right) \left( 1 + b_2 \sin \frac{2\pi}{168} t \right) = b_0 + b_1 \sin \frac{2\pi}{24} t + b_2 \sin \frac{2\pi}{168} t + b_1 b_2 \sin \frac{2\pi}{24} t \sin \frac{2\pi}{168} t = a_0 + a_1 \sin \frac{2\pi}{24} t + a_2 \sin \frac{2\pi}{168} t + a_3 \sin \frac{2\pi}{24} t \sin \frac{2\pi}{168} t
\]

Model (1) parameters $a_0, a_1, a_2$ are calculated using data from real observations by least squares method.

Let’s input the functional

\[
J = \sum_{k=1}^{n} \left[ m_k - \lambda(t_k) \right]^2
\]

(2)
Model parameters calculating. Let’s rewrite the functional (2) in matrix form. Let’s input the matrix $H$ and vectors $A, M$:

$$H = \begin{pmatrix}
    1 \sin \frac{2\pi}{24} t_1 & \sin \frac{2\pi}{168} t_1 \\
    1 \sin \frac{2\pi}{24} t_2 & \sin \frac{2\pi}{168} t_2 \\
    \vdots & \vdots \\
    1 \sin \frac{2\pi}{24} t_n & \sin \frac{2\pi}{168} t_n
\end{pmatrix},$$

$$A = \begin{pmatrix}
    a_0 \\
    a_1 \\
    a_2 \\
    a_3
\end{pmatrix},

$$M = \begin{pmatrix}
    m_1 \\
    m_2 \\
    \vdots \\
    m_n
\end{pmatrix}.$$  

Then

$$J = (HA - M)^T(HA - M).$$  

Minimizing (3) over the vector $A$, the desired vector of regression equation estimates is obtained

$$A = (H^T H)^{-1} H^T M.$$  

Moreover, so as
Then

\[
A = \begin{pmatrix} \eta_{11} & \eta_{22} & 0 \\ 0 & \eta_{33} & \eta_{44} \end{pmatrix} \times \begin{pmatrix} 1 & 0 & \ldots & 0 \\ \sin \frac{2\pi}{24} t_1 & \sin \frac{2\pi}{24} t_2 & \ldots & \sin \frac{2\pi}{24} t_n \\ \sin \frac{2\pi}{168} t_1 & \sin \frac{2\pi}{168} t_2 & \ldots & \sin \frac{2\pi}{168} t_n \\ \sin \frac{2\pi}{24} t_1 \sin \frac{2\pi}{168} t_1 & \sin \frac{2\pi}{24} t_2 \sin \frac{2\pi}{168} t_1 & \ldots & \sin \frac{2\pi}{24} t_n \sin \frac{2\pi}{168} t_n \end{pmatrix} \begin{pmatrix} m_1 \\ m_2 \\ \ldots \\ m_4 \end{pmatrix}
\]

\[
= \begin{pmatrix} \eta_{11} & 0 \\ 0 & \eta_{44} \end{pmatrix} \times \begin{pmatrix} \sum_{k=1}^{n} m_k \\ \sum_{k=1}^{n} m_k \sin \frac{2\pi}{24} t_n \\ \sum_{k=1}^{n} m_k \sin \frac{2\pi}{168} t_n \\ \sum_{k=1}^{n} m_k \sin \frac{2\pi}{24} t_n \sin \frac{2\pi}{168} t_n \end{pmatrix}
\]

As a result of calculations according to formula (5), taking into account real values of \(m_k, k = 1,2,\ldots,n\), we obtain

\[
A = \begin{pmatrix} 3.16 \cdot 10^5 \\ 1.28 \cdot 10^5 \\ 0.46 \cdot 10^5 \\ 0.21 \cdot 10^5 \end{pmatrix}
\]

Let us make a statistical analysis of the observations processing results. This procedure contains several steps.

The discussion of the results

Dispersions homogeneity checking. As at each point in the factor space of the variable \(t_k, k = 1,2,\ldots,m\) possible values a series of observations was carried out containing 6 repeated experiments, the experiments results have the form:

\[
X = \begin{pmatrix} x_{11} & x_{12} & \ldots & x_{1m} \\ x_{21} & x_{22} & \ldots & x_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ x_{61} & x_{62} & \ldots & x_{6m} \end{pmatrix}
\]

Here we have:

\[
x_{ik} \text{- random value of the observed variable at the } k \text{-th point of the experiment, obtained at the } i \text{-th week, } i = 1,2,\ldots,6, k = 1,2,\ldots,m.
\]

For each column of the matrix \(X\), lets average the results of repeated experiments for the observed variable and calculate the variances of these results

\[
m_k = \frac{1}{q} \sum_{i=1}^{q} x_{ik}, \quad \sigma_k^2 = \frac{1}{q-1} \sum_{i=1}^{q} (x_{ik} - M_k)^2,
\]

\[
k = 1,2,\ldots,m, q = 6.
\]

The dispersions homogeneity is checked by the Fisher criterion. For this let’s find out
\[ \sigma_{\text{max}}^2 = \max_k(\sigma_k^2), \quad \sigma_{\text{min}}^2 = \min_k(\sigma_k^2) \]

and calculate \( F_p = \frac{\sigma_{\text{max}}^2}{\sigma_{\text{min}}^2} \).

The obtained value of the \( F_p \) criterion let's compare with the critical in the Fisher distribution table for a given significance level \( \alpha = 0.05 \) and the number of degrees of freedom \( \nu_1 \) and \( \nu_2 \) of the numerator and denominator, which is equal to the number of repeated experiments minus the number of estimated parameters (in this case we have \( \nu_1 = \nu_2 = q - 1 \)).

Moreover, if \( F_p < F_{\alpha, \nu_1, \nu_2} \), then the hypothesis of homogeneity is accepted, otherwise it should be rejected and steps for homogeneity improvement should be done (for example, to make additional experiments at a point with maximum dispersion) [24].

In the considering problem eliminating of the dispersions heterogeneity by providing additional experiments is impossible. Moreover, to evaluate the parameters of the regression equations in the case of dispersion heterogeneity, the usage of least square method is impossible. Moreover, to evaluate the dispersions heterogeneity by providing additional steps for homogeneity improvement should be done (for example, to make additional experiments at a point with maximum dispersion) [24].

Using it the functional on least squares (3) transforms to

\[ J = (HA - M)^T D^{-1} (HA - M). \]

This functional minimization on model parameters vector \( A \) leads to equation

\[ \hat{A} = (H^T D^{-1} H)^{-1} H^T D^{-1} M. \]  

(6)

If the homogeneity hypothesis is accepted, then the variance of the experiments is averaged by the formula

\[ s_0^2 = \frac{1}{n} \sum_{k=1}^{n} \sigma_k^2 \]  

(7)

and thus, a dispersion of reproducibility of the experiment is obtained. Moreover, here \( f_0 = n(q - 1) \) - is the number of degrees of freedom.

So, if during the calculation of the variance reproducibility of the experiment, the homogeneity of the variances at different points of the factor space was established, then using the relations (4), the coefficients of the regression equation (1) are calculated. If the heterogeneity of dispersions is revealed, then for evaluating the components of the vector \( A \) is necessary to use formula (6).

In current task we have \( \sigma_{\text{max}}^2 = \sigma_{\text{min}}^2 \) and \( F_p = 1,516 \). According to the table of critical points of Student distribution for the significance level \( \alpha = 0.05 \) and the number of degrees of freedom \( q - 1 = 5 \), we obtain \( F_{\alpha, q - 1} = 2.57 \). So, as \( F_p < F_{\alpha, q - 1} \) the experiment is homogeneous. After averaging the variances, we obtain the reproducibility dispersion \( s_0^2 = 3.74 \cdot 10^5 \).

After calculating the coefficients of the regression equation, let's proceed directly to the statistical analysis of the results, which is carried out in two stages:

1. Assessment of the coefficients significance of the regression equation.
2. Assessment of the model adequacy.

Let's run into their consideration.

Assessment of the coefficients significance of the regression equation. Firstly, let's calculate the accuracy variance of the regression coefficient estimates. For this let's calculate the covariance matrix of calculating errors of the regression equation parameters by the formula:

\[ \Psi = s_0^2 H^T H^{-1} = s_0^2 \begin{pmatrix} \sigma_{a_0}^2 & \text{cov}(a_0, a_1) & \ldots & \text{cov}(a_0, a_m) \\ \text{cov}(a_1, a_0) & \sigma_{a_1}^2 & \ldots & \text{cov}(a_1, a_m) \\ \vdots & \vdots & \ddots & \vdots \\ \text{cov}(a_m, a_0) & \text{cov}(a_m, a_1) & \ldots & \sigma_{a_m}^2 \end{pmatrix}. \]

In current task

\[ (H^T H)^{-1} = \begin{pmatrix} \eta_{11} & 0 \\ 0 & \eta_{22} \end{pmatrix}. \]

So

\[ \Psi = \begin{pmatrix} s_0^2 \eta_{11} & 0 \\ 0 & s_0^2 \eta_{22} \end{pmatrix}. \]

Lets \( a_i \) is the real value of the \( i \)-th coefficient of the regression equation,

\( \hat{a}_i \) - assessment of this value according to the experiment results.

Then the random variable

\[ T_i = \frac{\hat{a}_i - a_i}{\sigma_{a_i}}. \]

(8)

is distributed according to Student’s law with \( n \) degrees of freedom. Let’s create the confidence interval for \( a_i \). Let \( \varepsilon_{a_i} \) - will be a half of this interval. Let's take \( \varepsilon_{a_i} \) so that \( P(\hat{a}_i - a_i < \varepsilon_{a_i}) = \gamma \), where \( \gamma \) is the confidence probability. Let’s consider the left part of this equation to a random variable \( T_i \):

\[ P \left( \frac{\hat{a}_i - a_i}{\sigma_{a_i}} < \frac{\varepsilon_{a_i}}{\sigma_{a_i}} \right) = \gamma \]

or

\[ P \left( T_i < \frac{\varepsilon_{a_i}}{\sigma_{a_i}} \right) = \gamma. \]
Using tables of $T_i$-distribution, let’s find $t_a$. So, that

$$P(T_i < t_a) = \gamma.$$  

Then

$$t_{ai} = \frac{\varepsilon_{ai}}{\sigma_{ai}};$$

Wherein $\varepsilon_{ai} = \sigma_{ai}t_{ai}$ and $|\hat{a}_i - a_i| < \sigma_{ai}t_{ai}$ or

$$\hat{a}_i - \sigma_{ai}t_{ai} < a_i < \hat{a}_i + \sigma_{ai}t_{ai}. \quad (9)$$

Thus, a confidence interval is found $[\hat{a}_i - \sigma_{ai}t_{ai}, \hat{a}_i + \sigma_{ai}t_{ai}]$, which cover the real value of coefficient $a_i$ with probability not less then $\gamma$.

Further, it is believed that $a_i$ coefficient is significant with reliability $\gamma$ if the corresponding confidence interval does not cover zero. Otherwise, this coefficient should be considered as insignificant and equal to zero. The corresponding factor should be excluded from the regression equation.

In current task we have

$$\begin{pmatrix}
6.9 \cdot 10^{-3} \\
2.1 \cdot 10^{-3} \\
1.4 \cdot 10^{-3} \\
0 \\
6.9 \cdot 10^{-3}
\end{pmatrix}^{-1} = \begin{pmatrix}
0 \\
2.1 \cdot 10^{-3} \\
0.72 \cdot 10^{-3} \\
1.4 \cdot 10^{-3} \\
0
\end{pmatrix}$$

Then

$$\Psi = \begin{pmatrix}
2.59 \cdot 10^3 \\
7.88 \cdot 10^2 \\
5.25 \cdot 10^2 \\
0 \\
2.59 \cdot 10^3
\end{pmatrix}$$

So, as critical value $t_a = 1.98$ (with confidence probability $\gamma = 0.95$), then

$$\varepsilon_{a_0} = \sigma_{a_0} \cdot t_a = 100.8,$$

$$\varepsilon_{a_1} = \sigma_{a_1} \cdot t_a = 55.59,$$

$$\varepsilon_{a_2} = \sigma_{a_2} \cdot t_a = 45.37,$$

$$\varepsilon_{a_3} = \sigma_{a_3} \cdot t_a = 32.05.$$  

Moreover, in all cases, the confidence interval does not cover zero and, therefore, all the coefficients of the regression equation (1) are significant.

**Checking the adequacy of the regression equation.**

To check the adequacy of the regression equation obtained after discarding insignificant factors, it is necessary, in addition to reproducibility variance, to calculate the adequacy variance which characterizes the degree of deviation of the regression line from the value of the response function at the points of the factor space corresponding to the performed experiments. The adequacy variance is calculated by the formula

$${\sum}_{i=0}^{(r-1)} \sum_{j=1}^{n} (\hat{y}_j - y_j)^2 = \frac{1}{n-r} \sum_{j=1}^{n} (m_k - \lambda(t_k))^2. \quad (10)$$

For the $s^2_{ad}$ calculation, let’s use the response function values averaged over the results of repeated experiments $y_j$, $j = 1, \ldots, n$. Therefore, the variance of the adequacy does not depend on the variance of the measurement errors. In relation (10) $\ell$ - is the number of terms in the regression equation remaining after the signification assessment. Thus, the adequacy variance characterizes the residual sum of squares of the results deflection of real experiments from the created regression equation per one free experiment (i.e., one degree of freedom). Now, the adequacy of the obtained regression equation is checked according to the Fisher test, comparing the equation

$$F_p = \frac{s^2_{ad}}{S^2_0}$$

with critical value

$$F_p < F_{exp}. \quad (11)$$

For the number of degrees of freedom $f_\text{ad} = n - \ell$ and $f_0 = \sum_{j=1}^{n} (q_j - 1)$ set value of significance $\alpha$.

Adopting the hypothesis of adequacy is equivalent to accepting the hypothesis of equality of variances of adequacy and reproducibility. The adequacy of the regression equation shows that the scattering of experimental data relative to the regression equation is of the same order as the scattering associated with experimental accuracy. Moreover, the deviation of the experimental points relative to the constructed regression equation is explained precisely by these errors, and not by the erroneous hypothesis about the structure of the model. In the considered problem a direct calculation of the variance of adequacy by formula (10) gave the following result $s^2_{ad} = 4.17 \cdot 10^5$. In this case, the calculated value of the Fisher test

$$F_p = \frac{4.17 \cdot 10^5}{3.75 \cdot 10^5} = 1.083.$$

So, as a critical value of Fisher’s criterion for $\alpha = 0.05$ equals to $F_{exp} = 2.38$, and $F_p < F_{exp}$, consequently current model is adequate.

**The residuals autocorrelation analyses.**

The residuals autocorrelation in the trend deflections could be detected using the Darbin-Watson statistic, which can be calculated by the formula

$$d = \frac{\sum_{j=1}^{n} (\xi_j + \xi_{j-1} - 2\xi_{j-1})^2}{\sum_{j=1}^{n} \xi_{j-1}^2}. \quad (12)$$

Where $\xi_j$ - deflection from trend in $j$ -th observation.

The values distribution of the Darbin-Watson statistic is given in the table.

Let’s compare the calculated value of the criterion $d$ with the tabular $d_1, d_2$. The following cases are possible:

- if $d < d_1$, the hypothesis of the autocorrelation absence is rejected (positive correlation is present);
Reliability (12) directly follows from the relation used to detect the random process autocorrelation presence $\xi(t)$. This equation has the form

$$r(t) = \frac{M[(\xi(t) - m(t))(\xi(t + 1) - m(t + 1))] - 2M[(\xi(t) - m(t))(\xi(t + 1) - m(t + 1))] + M[(\xi(t) - m(t))^2] + M[(\xi(t + 1) - m(t + 1))^2]}{D(t + 1) + D(t) - 2K(t, t + 1)}.$$

Let’s rewrite (13) as a follow

$$r(t) = \frac{M[(\xi(t) - m(t))^2]}{M[(\xi(t) - m(t))^2]}.$$

Here $D(t)$, $D(t + 1)$ - process variation at time points $t$ and $t + 1$; $K(t, t + 1)$ - covariance between random values of process at time points $t$ and $t + 1$.

If the process is stationary, then $D(t) \equiv D(t + 1)$ and (14) can be approximately changed as follows:

$$r(t) = 2 - 2k(t, t + 1),$$

where $k(t, t + 1)$ - correlation coefficient between random process values at time points $t$ and $t + 1$.

Concerning to this fact, it is clear that if the correlation between these random values is absent (or small), then the value of $r(t)$ is approximately equals to 2.

If the correlation coefficient increases, the value of $r(t)$ decreases, approaching to zero (for a positive correlation), or four (for a negative correlation).

It is clear that (12) is a special case of (13) when the process is observed at discrete time instants $j = 1, 2, \ldots, n$ and obtained residues autocorrelation after trend exclusion is analyzed.

In considered problem $d_1 = 1, 41, d_2 = 1, 72$, and the value of the Darbin-Watson statistic $d = 1, 87$. Therefore, it should be considered that there is no autocorrelation of residues, confirming the conclusion about the adequacy of the model.

Conclusions

The obtained mathematical model describes fluctuations in the intensity of clients’ requests to the servlet during the week. The mathematical model can be used to predict the load on the server or to build a simulation model of the query service system. The adequacy of the model is checked, the homogeneity of variances is checked, the significance of the coefficients of the regression equation is estimated, the adequacy of the regression equation is checked, the analysis of the autocorrelation of the residues is carried out.

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АННОТАЦІЯ Робота посвячена построєнню математичної моделі нестационарного потоку запитів клієнтів до бази даних з використанням моделювання показателей якості обслуговування. Математична модель колибрання інтенсивності запитів до бази даних має вигідне високу інтенсивність, що або грунтується на інтенсивності потоку запитів клієнтів до сервера. Ключові слова: модельне підключення, колебання інтенсивності запитів; розміри підключень; статистичний аналіз

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