Model and method for optimizing heterogeneous systems

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Abstract. Methodology of distributed computing performance boost by reduction of delays number is proposed. Concept of n-dimentional requirements triangle is introduced. Dynamic mathematical model of resource use in distributed computing systems is described.

Keywords: optimization, resource use, decision support system, distributed computer system.

Introduction. Most modern process automation solutions rely on distributed computer systems (DCS) [1]. These systems consist of thousands of high-performance servers, hundreds of databases and often hundreds of thousands workstations and different communication channels for information exchange both inside the perimeter of network and outside of it with external data sources. Gigabytes of data are being captured and processed by these systems [2]. In most cases information (first of all for monitoring and forecasting) is distributed in global scale, stored and processed in regional data centers of in federal level data centers. Results of data processing are used directly by decision makers [3, 4]. Despite constantly growing processing power of computer systems and networks capacity resources of individual nodes are often insufficient for processing of necessary volume of information. It results in delays in delivery of necessary information that increases time required for decision making and thus decrease the quality of decisions [5].

Model. We will solve the problem of redistribution of load in real time for instant reacting on changing conditions such as increase or decrease of input information flow, servers' breakdown, physical database overload [6].

Variation of provisioning-transfer parameters may be used as one of the variants of redistribution. At the moment when a certain computational node is overloaded decision is made to transfer "raw" data on higher level node. The counter process is possible – when communication channels are overloaded distributed computer systems run necessary computational jobs in place and transfer processed data that has much lower volume.

We further consider dynamic model of network resource distribution for decision support information system that support this task.

Let us denote PBC as N={P,C}, where P is a set of nodes of this network – processing power, data warehouses and communication channels, C – a set of networks edges described by unified transition coefficient that depends on parameters of nodes that are the parts of these edges.

Set of all nodes P may be divided by functionality into three disjoint subsets: P_1 - processing resources (processors), P_2 - data warehouses, P_3 - communication channels.

Is element p_i^1 of P_1 is characterized by the following parameters:

q^i_t- free processing power of p_i node in time point t,

m^i_t- free storage capacity provided for data storage in p_i node in time point t,

w^i_t- p_i node reliability measure in time point t calculated as the possibility of p_i node breakdown.

Data warehouse p_i^2 of P_2 has the following parameters:

f^i_t- disc space allocated for new data,

a^i- database type.

Channels p_i^3 of P_3, are characterized by the following:

v_i- bandwidth of channel p_i^3,

z_i^t- workload of p_i^3 in time point t,

b_i^t-cost of information unit transfer by p_i^3 in time point t,

s^i_t- forecasted delay in p_i^3 in time point t.

To simplify application of optimization algorithms these sets may be joined provided that all parameters of subset elements that relate to other subset are zero. For example for P_2 all parameters except f^i_t and a^i are zero.

Considering the above the function that defines each edge may by written as

$W_{ji}^t\ (q^i_t, m^i_t, w^i_t, f^i_t, a^i, v_i, z_i^t, b_i^t, s^i_t)$, that defines transfer from node j to node in time point t. Function W_{ji}^t is multi-criterion and defines free capacity of edge from i to j in time point t – o_{ji}^t.

As mentioned earlier input data for distributed computer systems are generated mainly by automated data capture systems that capture information from different systems of information gathering. Let us call them sources in terms of network modeling. The main task of distributed computing is to process raw data coming from sources as required (applying predetermined models and methods) and transfer them to destinations for use in decision support systems on workplaces of decision makers [7]. To describe processes applied to data on its way from source to destination we represent it as a flow:

Let us denote q_{ji}^k € Q(set of all flows in the system), k^{th} flow with the source in node p_i, and destination in p_j.

This flow is characterized by the following:

V_{input}^k- input information volume,

V_{output}^k- out put information volume,

c^k- amount of work (number of calculation) to transfer input information into output,

Parametr — requirements to data transfer route: cost of transfer in Rubles, time frame for package transfer, reliability.

If necessary q^k may be divided into N stages for serial or parallel processing, so:

$c^k = \sum c_n^k$,

where c_n^k is the volume of n^{th} stage q^k. Time required for processing and transfer of k^{th} flow is:

$\tau^k = \sum \tau_n^k$

where τ_n^k expected processing time on n^{th} stage q^k.

One may easily see that all the flow of input and output data may be divided into separate parts if calculations are divided like this. To denote them we introduce the following:

$V_{input}{}^k{}_n$ input data volume for stage n,

$V_{output}{}^k{}_n$ expected output data volume of stage n.

More generally this task may be represented in the following way: minimizing transfer time of all flows existing in time point t from source in nodes P_i to destinations in p_j for limited resources defined for each edge as c_{ji}^t As in each following time point t+1 function may have the other extreme the task has dynamic character.

Formal representation of this statement is like follows:

$\sum \tau^k_t$->min

where $\tau^k{}_t$ is expected time for processing of k^{th} flow existing in time point t.

Under limitations:

$\sum c_n{}^k{}_{ij}{}^t \leq o_{ji}{}^t$,

where $\sum c_n{}^k{}_{ij}{}^t$ total of all jobs for running on edge from I to j in time point t.

One of the most important tasks for calculation of this model is calculation of limitations $o_{ji}{}^t$ because they originate not only from internal factors. To calculate $o_{ji}{}^t$ we use parameter $s^i{}_t$ (forecasted delay $p_i{}^3$ in time point t) that depends on external unaccounted effects. In most cases, companies use external communication channels for information transfer with unreliable effectiveness and bandwidth.

The best instrument for forecasting in this case is neuron networks. Statistical methods and time series method may be also useful but configuration of global network is constantly changing and these methods in most cases do not solve the problem [8]. Unlike these methods neural networks are capable not only to run predetermined operations sequence but also analyze inputting information on the fly find patterns in it and make forecasting. Neuron networks are constantly learning basing on previous values.

Method. There are two methods to solve this problem:

1. Static – scaling capacity of computer network and in the first place in bottlenecks or problem nodes.

This approach is not universal for given level of complexity because it does not allow solving problem in real time. It is also ineffective for constantly changing volumes and data flow directions and it is also costly [9].

2. Dynamic – taking off the load from overloaded nodes by idle ones in real time (resources allocation optimization).

This approach allows balancing the load between the nodes of computer system making it more uniform, increase performance and reliability of information processing and decrease total cost of ownership of resource.

The rule of n-dimentional requirement triangle may be used to define optimal set of criteria for equation.

Criteria are being divided into interrelated discrepant triplets. Values of all criteria should be normalized. We assume 1 as the best value of criterion and 0 for the least value. Distance between actual value of K^{th} criterion and its least value we denote as Δk (segment AO, BO, CO, see Fig. 1). The least requirement value is in point O and the best value - in points A_{max}, B_{max}, C_{max} respectively. In geometrical interpretation it means that in triangle segments from medians intersection (points O) to vertexes of internal triangle are values of analyzed requirements and optimal values of these requirements are in the vertexes of external triangle.

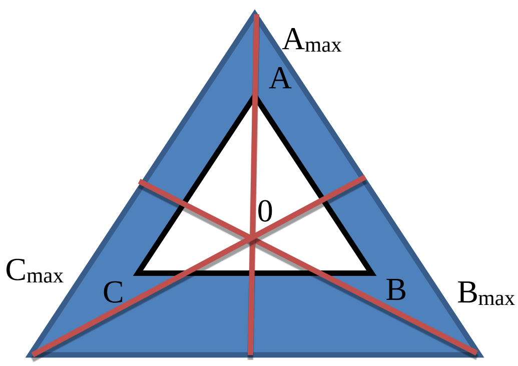

Fig. 1. Triangle of requirements' discrepancy.

Basing on discrepancy and interconnection of requirements let us consider each third requirement to be discrepant with two others. It may be interpreted as the system of equations:

$$\begin{cases} AB = \sqrt{AO^2 + BO^2 - 2\,AO\,BO\,\cos\alpha} \\ BC = \sqrt{BO^2 + CO^2 - 2\,BO\,CO\,\cos\beta} \\ AC = \sqrt{AO^2 + CO^2 - 2\,AO\,CO\,\cos\gamma} \\ \alpha + \beta + \gamma = 360^{\circ} \end{cases}$$

Where [α], [β], [γ] are angles between AOOB, BOOC, AOOC respectively. Segments AB, BC, AC in this case define not only interconnection but also discrepancy.

Let us introduce requirements' balancing function. For 3 requirements it is equal

$$F(x) = \frac{1}{\sqrt{\left(\frac{1}{\Delta_k^1} + \frac{1}{\Delta_k^2} + \frac{1}{\Delta_k^3}\right)\left(\frac{1}{\Delta_k^1} + \frac{1}{\Delta_k^2} - \frac{1}{\Delta_k^3}\right)\left(\frac{1}{\Delta_k^1} + \frac{1}{\Delta_k^3} - \frac{1}{\Delta_k^2}\right)\left(\frac{1}{\Delta_k^3} + \frac{1}{\Delta_k^2} - \frac{1}{\Delta_k^1}\right)}}.$$

Geometric sense of this function is area of ABC triangle.

Equilateral triangle has maximal area. In analyzed case equality of legs is achieved in case of equality or balance of all requirements.

Number of requirements in most real world jobs is much greater that three. To apply the rule of N-dimentional triangle it is necessary to draw triangle in every plane defined by triples of requirements. To simplify task areas of drawn triangles may be multiplied together to go to maximum.

Resume. Proposed methodology allows formalizing the process of distributed computer system resources allocation by dynamic mathematical model. Software implementation of proposed technology experimentally proved the possibility of successful application of theoretical results of proposed research.

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