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MODELING PROCESSES OCCURRING IN DISTRIBUTED DATABASES

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Abstract

Distributed databases allow for the efficient management of data from various sources. This article examines the main approaches to modeling processes in such databases. It analyzes data synchronization, improving process efficiency, and technical issues. The approaches aim to ensure system reliability and fast data exchange in a multi-user environment.

Keywords: Distributed database, modeling, synchronization, efficiency, technical challenges, reliability, multi-user environment, data exchange, data integration, algorithmic approaches, data management.

INTRODUCTION

The exchange of information (voice, video, articles, images, infographics, etc.) between users on the servers of institutions under the Committee on Religious Affairs, studying, processing, and analyzing various materials, facilitates work processes by up to 95%. These servers provide users with important information. Replicating databases, in general, is not an easy task in developing distributed systems. Currently, the digitization of many daily life and work processes of users, the emergence of various social networking platforms, blogs, the placement of devices collecting information about their surrounding environments in different regions, on various devices and mechanisms, as well as the high growth rate in the use of handheld digital

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devices, wearable devices, and the internet, is resulting in the generation of massive data streams. As a result, large data streams are formed, unprecedented in size and difficult to process using both traditional and modern methods on large and small computing systems, as well as on personal devices [1; p. 563-564, 2; p. 7-10]. Issues of reliable and timely data delivery on the servers of organizational institutions are based on several key concepts.

METHOD

In the study of the research topic, methods such as scientific description, comparative analysis, and component analysis were used.

MAIN PART

A modern distributed database, integrated with the telecommunications subsystem, can be represented as a set of N servers and groups of workstations connected to the servers through an access subsystem. In this structure, each group of workstations is capable of connecting directly to only one DDB server.

The telecommunications subsystem, which performs the functions of switching nodes and is connected to data transmission channels in the networks, is designed to establish logical channels between the logical connection points of DDB servers. The access subsystem, on the other hand, consists of communication equipment and data transmission channels that ensure data exchange between DDB servers and workstations [3; p. 419].

Although there are various approaches to modeling processes in distributed databases, each has certain drawbacks in its application. In D. A. Apanasevich's research, the mathematical apparatus of finite automata theory is used to construct mathematical models of information processes [3; p. 120].

In this case, the model of the information exchange process is represented by a finite state machine, which at any given time t is in a specific state $S(t) = \{s_1, s_2, s_3\}$, where:

s_1 -the state when data is being sent;

s_2 -the state when data is being received;

s_3 -the state when the system is waiting for a communication session.

When certain events occur (e.g., a data update request), the state of the DDB changes. The characteristics of the information process are determined by the system depending on the state of the finite automaton:

$$P(s) = \begin{cases} D, if \ \ S(t) = s_1 \\ R, if \ \ S(t) = s_2, \\ O, if \ \ S(t) = s_3 \end{cases} \quad (1)$$

Here, D represents the sender machine, R represents the receiver automaton, and O refers to an automaton that is neither a sender nor a receiver.

The main advantage of the model is its simplicity of description; however, it does not allow for consideration of the probabilistic-time characteristics of the processes occurring in the DDB.

Another approach to the mathematical description of DDB operations is proposed in the work of T. Connolly, which is based on probability theory and queueing theory. The DDB is presented as a collection of independent files, which can be viewed as a set of requests for updating and retrieving specified data. At the same time, the volumes of data generated in the telecommunications subsystem depend on the source nodes. In each unit of time, a certain amount of data is transmitted through the telecommunications subsystem, which is associated with distributing copies of these files across the DDB.

$$V = \frac{1}{\lambda}\sum_{i=1}^{m}\sum_{j=1}^{n}\lambda_{ij}V_{ij}, \qquad (2)$$

Here,

n - the number of DDB nodes,

m -the number of DDB files,

λ_{ij} —the request intensity for the i -file at the j -node,

V_{ij} —the volume of data sent when requesting the i -file at the j-node,

λ — the total request intensity for all nodes and files in the DDB.

This model describes the transactional characteristics of requests but does not account for the properties of the telecommunications subsystem or the effects of data replication parameters. The process of handling requests in the DDB has been most comprehensively studied in the work of A. Yu. Ivanov [41; p. 277]. In the DDB, the request processing is depicted within the framework of servicing requests in a stochastic queueing network (SeMO), as shown in Figure-1.

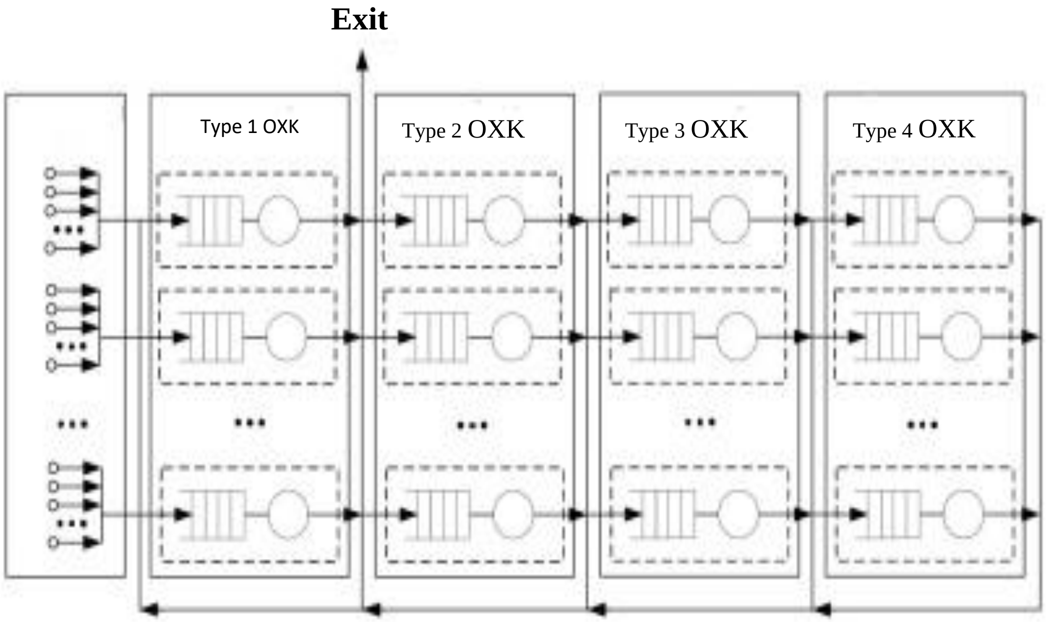

Figure 1 - Generalized structure of the DDB request processing model

In this case, the queueing systems (TKS) and components (SeMO) are explained by the standard elements of the DDB:

Type 1 TKS	**Access to network segments (the part of the queueing system that manages access across the network) is responsible for controlling and coordinating how requests are distributed and handled throughout the network, ensuring efficient communication between different nodes and managing potential bottlenecks.**
Type 2 TKS	DDB servers (these servers are the core part of the queueing system, receiving requests and responding to them) handle the processing of incoming queries, managing data retrieval, updates, and the transmission of responses back to the requesting workstations or nodes.
Type 3 TKS	Data transmission channels (these channels manage the flow of data and ensure the exchange of information between networks) facilitate the efficient transfer of data across the network, enabling communication between different nodes, servers, and subsystems within the DDB.
Type 4 TKS	Communication equipment (this equipment supports the network infrastructure and ensures connectivity) is responsible for maintaining stable and reliable links between various components of the DDB, enabling data transmission and coordination across the system.

Search queries executed on local servers are considered as the sources of requests. These queries are transmitted and processed through various elements of the system.

This model of processing requests in the DDB is characterized by the following functionality:

$$t = F(V\ x, T, S, L), \tag{3}$$

Here:

- t — the time to execute a request in the DDB;

- $V\ x$ -the volumetric characteristics of the DDB, which include: request sizes, response sizes, the number of data replicas, sizes of data replicas, the capacity of data transmission channels, buffer sizes in communication equipment, available memory on servers, and other resources.
- T- time-related factors such as the capacity of data transmission channels and their utilization;
- S - characteristics of the DDB structure, which include: network topology, the number of DDB servers, the distribution of requests between DDB servers, and other technical specifications;
- L - characteristics of information flows in the network, including: the intensity of receiving search queries and update requests, as well as the impact of other relevant flow parameters.

This equation represents the factors used to calculate the request execution time in the DDB. The factors affecting time include the size of the DDB, the technical characteristics of the network, the specific features of the network structure, and various aspects of information flows.

Each type of detailed queueing system (TKS) can be represented by a Petri net, a specific type of graph composed of two types of vertices: places and transitions, which are connected by directed arcs. Each arc can only link vertices of different types. Place vertices are depicted as circles, and transition vertices are shown as rectangles [5; p. 288].

Thus, the Petri net describing one of the stages of request processing in the DDB is presented in Figure 2 [6; p. 264].

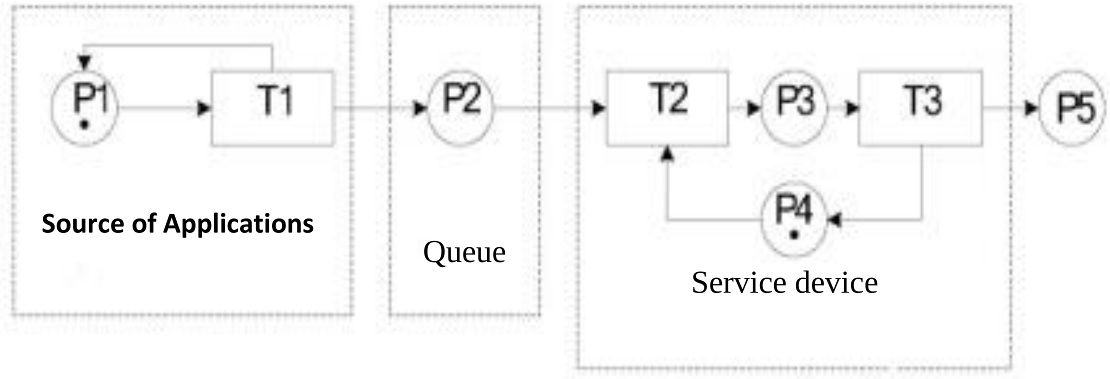

Figure 2 - Petri net providing a detailed description of a request processing stage in the DDB.

The following can serve as sources of requests in relation to the DDB: the flow of requests for updates and searches, and the flow of requests for transmitting remote queries and updates.

The queue may be associated with waiting for service on the primary and backup servers, as well as waiting for the release of communication subsystem (TKS) segments during transmission between different DDB nodes.

The service device can describe the operation of both the primary and backup servers, as well as the performance of the communication equipment.

The marker in position P1 corresponds to the readiness of the source to issue requests. Feedback is required after the transition from T1 to position P1 to generate subsequent requests. Position P2 models the queue of service requests. The marker in position P4 represents the idle state of the service device, while position P3 models the busy state of the service device. In this case, transitions T2 and T3 determine the allocation of applications between positions P3 and P4.

A significant drawback of this model is its failure to account for the replication parameters of the DDB.

The study conducted by J. M. Johanson, J. D. Naumann, and S. T. Mart explores an approach to determining the data update time in the DDB. In general, the calculation of update time is described by the expression [7; p. 677–706]:

$$T_u = 3 \cdot \left[MAX_{j=1}^{n}\left[\left(\sum_{i=1}^{j} S_i\right) + R_j\right]\right] + \sum_{i=1}^{n} S_i, \qquad (4)$$

Here, S_i – the time to transfer the request from the transaction source to the i -node, R_j - the time to transmit the response from the j -node, n - the number of nodes containing data fragments.

Another option that combines the advantages of the described models is the mathematical description of the DDB's response process to requests during replication, presented in the work of L. I. Meikshan [8; p. 56-60].

Thus, the processes of servicing different types of requests are determined by the following quantities:

- the average processing time of a search request τ_q (on a remote server) and τ'_q (on a local server);
- the average processing time of an update request τ_u (on a remote server) and τ'_q (on a local server);
- the average time required to send a single message to update a data fragment on a remote server from the local server τ_r.

During replication, the average response time of the DDB to requests is determined based on the following expression:

$$R = h\left[W_w + \tau'_q\right] + (1 - h)\left[2\tau_r + W_c + \tau_q\right] \qquad (5)$$

Here, W_w and W_c are the average waiting times in the queue for processing a request on the local and remote servers, respectively. The coefficient h determines the proportion of requests processed by the local server. The message delivery time between the remote and local servers is considered a constant value, τ_r.

The main drawback of this model is the assumption that the value of τ_r, the message delivery time, is constant across all sections of the communication subsystem (TKS) and for all types of requests. In reality, under conditions of limited resources, the value of τ_r is variable and significantly dependent on many factors: the length of the network segment, the number and characteristics of the communication tools involved in transmission, the bandwidth resources of the network, transmission technologies, data ownership schemes, replication type, and more. Additionally, selecting the coefficient h, which characterizes the proportion of replicated data, as a control parameter immediately limits the model's flexibility in terms of selecting data fragments for replication.

Let's construct an example based on the described equation and calculate the average response time for requests during replication in the DDB.

Equation: $R = h(Ww + \tau q') + (1 - h)(2\tau r + Wc + \tau q)$

The given expression is used to determine the average response time of the Distributed Database (DDB) during replication. Here:

R - the average response time of the DDB.

h - the proportion of write requests (the ratio of write requests to the total number of requests).

W_w - The processing time of a write request.

τ'_q - The queue waiting time for a write request.

$2\tau_r$ - The processing time for two consecutive read requests.

W_c - The input time for a read request.

τ_q - The queue waiting time for a read request.

The expression's right-hand side consists of two parts, each determined by the respective share of the requests:

The average response time for a write request.:

Multiplied by the proportion of write requests, h .
The average response time for a write request $W_w + \tau_q'$.
As a result, this part will be in the form h× ($W_w + \tau_q'$), where:
The average response time for a read request:
Multiplied by the proportion of read requests, 1-h.
The average response time for a read request $2\tau_r + W_c + \tau_q$
As a result, this part will be in the form (1−h)×($2\tau_r + W_c + \tau_q$), where:
The sum of these two parts gives the overall average response time of the DDB during replication: $R = h\times(W_w+\tau_q^{'})+(1-h)\times(2\tau_r+W_c+\tau_q)$
Proof::
Let's take an example with the following parameters::
h=0.6 (i.e., 60% of the requests are write requests),
W_w =5 ms, τ_q'=3 ms, τ_r =2 ms, W_c =4 ms, τ_q =6 ms,
Now let's calculate the average response time:
For write requests: $h\times(Ww+\tau q')=0.6\times(5+3)=0.6\times8=4.8\text{ms}$
For read requests:
$(1-h)\times(2\tau_r+W_c+\tau_q)=0.4\times(2\times2+4+6)=0.4\times(4+4+6)=0.4\times14=5.6\text{ms}$
Now let's find the total average response time:
R=4.8+5.6=10.4 ms
This example demonstrated the application of the given expression to determine the average response time of the DDB during replication.
In this regard, in the present dissertation research, the model presented in the work of L. I. Meikshan [8; p. 56-60] has been improved to remove the constraints on control parameters and to provide a more detailed description of the waiting time and data transmission through the communication subsystem (TKS).

CONCLUSION

In conclusion, the modeling of processes in distributed databases aims to enhance the overall system performance. Elements such as synchronization, replication, and reliability play a crucial role in ensuring system stability. By utilizing modern modeling methods, these processes are analyzed to develop optimal solutions, which are essential for environments that deal with multiple users and large volumes of data. The models presented in this article provide a theoretical foundation for the optimal allocation of system resources and the efficient execution of processes, which is of significant importance for the future development of distributed databases.

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