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Big Data Processing in Complex Hierarchical Network Systems II: Computer Environments and Parallelization

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This article covers the problem of processing of Big Data that describe process of complex networks and network systems operation. Approaches are proposed for creation of efficient computing environments, distributed computations organization and information processing methods parallelization at different levels of system hierarchy. Methods for preprocessing of large data sets and procedures for parallelization of primary data processing and formation of aggregated conclusions are described.

Introduction

Network technologies have been rapidly developing during recent 20 years [1, 2]. At the same time, network bandwidth continuously increases and the computer interaction latency decreases. Communication characteristics of many local (LAN) and wide area (WAN) networks have already exceeded the corresponding parameters of the first cluster computing systems. However, the process of network development continues. Due to the number of positive properties, they have become the basis for a new generation of computer systems – distributed computing environments (CE) [3, 4].

In each complex large scale technological system (CLSTS), a distributed CE that can be called a kind of hierarchical network grid usually has been already created and it is developing. Structure of this hierarchical network computing environment (HNCE) in general reflects the structure of the system itself. Usually it is closed (in contrast to classical understanding of Grid [5]) information network where data exchange is regulated by quite strict rules. The hierarchy of the control system of CLSTS determines the hierarchy of user access rights to the system internal information. This can be explained by clear requirements of internal and external security, since the leakage or distortion of certain data can lead to unpredictable negative consequences [6, 7]. Indeed, it is hard to imagine situation where any user can change the schedule of trains on the railway. For many government agencies or large transnational corporations the scope of such HNCEs can significantly exceed the volume of traditional voluntary, scientific or commercial Grids. The structure and capacity of such CE must first of all provide the opportunity to work with Big Data, i.e. to store all the necessary information, provide high speed data access, support efficient algorithms for information processing, analysis and system behavior forecasting, ensure information security and protection from unauthorized access. Creating of HNCE is the first stage of the distribution and parallelization of Big Data processing in CLSTS.

Hierarchical Network Computing Environments

Computer environments of almost all CLSTS has parallel architecture and uses distributed memory, which makes it similar to computing clusters. However, the real essence of this environment is determined by the following main features:

- *distributedness*: the distance between computing nodes of this environment may be up to tens, hundreds or thousands kilometers, which leads to significant latency during their interaction;
- *heterogeneity*: nodes of environment may have different architecture and performance levels;
- *agility*: the architecture of the environment is able to change, new computing resources can be quickly added to it;
- *reliability*: any node can be extracted from the environment at any moment but this should not lead to delay or shutdown of the computing process;
- *large scope*: total number of processors (cores), general memory volume, number of users working simultaneously and applications running can be very large.

It is obvious that the distributedness of environment can lead to significant delays during remote nodes interaction. The only way to increase the efficiency of data processing in this case consists in maximum loading of nodes with computing tasks and minimizing the number of exchange operations between them.

Potential heterogenity of CE is predetermined by the fact that each node can process and store different volume of data and implement special algorithms of their processing. This means that computing node performance actually depends on the amount of data being processed, and its architecture – on the characteristics of highly parallel processing algorithms. Usually this is the cluster with required number of processors (or computing cores) and sufficient memory volume, including data warehouses. Clusters are known to be an affordable analogue of MPP (Massively Parallel Processing) systems and incorporate multiple SMP (Symmetric Multi-Processing) systems. Therefore, they can effectively implement highly parallel algorithms oriented at computers with common and distributed memory. In this case, we can use OpenMP (Open Multi-Processing) and MPI (Message Passing Interface) services of parallel programming to create parallel programs. If it is necessary to effectively carry out parallel algorithms that implement SIMD (Single Instruction Multiple Data) mode [8] or optimal performance parallel pipeline algorithms, the node of CE can have hybrid architecture. In this case, new computing units of graphics or quasisystolic processors can be connected to the cluster [9, 10].

It should be noted that the nodes have maximum commitment to CE, i.e. delegate it all their resources and work solely for it. Obviously, the structure of relations between nodes in environment is agile and can change in case separate nodes fail or new nodes are connected.

Reliability of CE means that in case one node fails or leaves the environment the whole computing operation of this node is assigned to another node of the same hierarchy level. The node that received additional tasks will probably require involving additional computing resources.

The scope of CE allows to integrate large number of independently operating computers, which means that it has powerful parallelism (and, therefore, productivity) resource. This is why such environment may be referred to as high performance CE.

In general, the structure of computing operation arrangement in such environment is based on independent processes. In this case, there is no common memory, common variables and other objects, and the interaction between the processes is carried out indirectly through message transfer. Thus, the CE described can be considered as an effective tool for the metacomputer computations [11] with the aim to solve complex preprocessing problems and further analysis of large data sets in CLSTS. In contrast to modern expensive supercomputers, it is not unique single device and its computing resources are used in an optimum manner.

Preprocessing of Large Data Sets

When working with large amounts of information we may encounter several important problems such as:

- providing high data transmission speed;
- creation of data warehouses and arrangement of high speed access to the data contained in them;
- real time processing;
- providing proper visualization of data processing results.

Solution of the problems above is impossible without the involvement of modern parallel computing systems. Such systems must be installed in every local processing center. It should be noted that first two problems can be solved by technology means. As to the fourth problem, approach to its solution can be based on the development of new principles of study outcomes visualization, which was partially performed in [12, 13].

Let us describe the approaches to solution of the third problem more detailed. First, we shall pay attention to data preprocessing. Information that comes from the elements of CLSTSs to local processing centers in the form of numerical data arrays may contain inaccurate or significantly distorted components. Therefore, before such arrays may be used for further analysis, they need to be preprocessed. We use for this methods and algorithms of digital filtering. In most cases, preprocessing must be carried out in real time. We suggest using quasisystolic method of computations arrangement for this purpose [14]. This method has become a basis for developing parallel pipeline algorithms of digital filtering in different dimensions with optimum performance and memory usage [15]. In this case, optimality was proved in the class of algorithms that are equivalent according to information graph within the accuracy of associativity and commutativity ratios performance. Proposed quasisystolic method has been extended to problems of cascade digital filtering in different dimensions [16] and problems of filtering that use adaptive smoothing procedure [17]. Optimum parallel pipeline filtering algorithms that were developed are oriented at implementation via special computer tools i.e. quasisystolic structures. These structures differ from systolic structures because they allow to perform data transmission from a single output point to multiple input points. Such quasisystolic structures can be considered as separate accelerating units in multipurpose parallel computing systems used for solving filtering problems [18].

We have proposed and studied algorithms with limited parallelism [19] for solving digital filtering problems on systems with common or distributed memory, as well as on the systems with structural and procedural organization of computations. Note that in some cases, digital filtering problems in different dimensions may be solved with the help of neural network methods and algorithms [20] oriented on implementation on modern and prospective parallel computing systems.

Parallelization of Primary Data Processing Procedures

Filtered data sets can be used to analyze the state and operation of system elements. While performing such analysis, the number of element characteristics, operation modes and evaluation criteria and parameters should be taken into account [21]. This leads to a substantial increase of computational expenditures. Therefore, to speed up the calculations it is necessary to develop approaches to their parallelization.

The procedure for local CLSTS element characteristic behavior evaluation was described in detail and analyzed in [22]. We have proposed parallel and sequentional approach for carrying out this procedure in modern CE that use common memory. According to this approach, parallelization of some fragments is performed in the form of several autonomous branches, and the mode of parallelization of the other ones is close to full binary tree. To implement proposed approach we have developed algorithmic constructions, that take into account actual capabilities of available computing resources (the number of processors, computational cores, RAM volume etc.). We have also obtained results of parallel computing acceleration evaluation which confirm the efficiency of constructions developed.

Parallel Organization of Formation of Aggregated Conclusions

Aggregation allows to make generalised conclusions regarding the state and operation quality of both elements and separate sybsystems of a system on the basis of processed local data. To provide clarity and understanding of the aggregated behavior evaluation process for separate elements and CLSTS in general we have constructed corresponding analysis trees [23]. According to these trees we proposed and studied four types of algorithmic constructions for organization of parallel calculations. They represent two stages of parallelization. On the first stage, two constructions are described, as follows:

- parallel and sequential construction that consists of two consecutive fragments: the first one (the main, it assigns carrying out large amount of computations) is a set of certain number of parallel independent branches, the results of their carrying out is then used in the second fragment (with small amount of computations);
- parallel construction that is a set of some number of independent parallel branches performing approximately equal amount of calculations.

In the second stage of parallelization, more efficient algorithmic constructions are proposed. They are obtained from the two constructions described above in the following way: calculations in main fragment of each branch are carried out in the form of some number of independent parallel branches. These algorithmic constructions are oriented to implementation on parallel computing systems with common and distributed memory, in particular, on clusters. Cluster computing systems are affordable analogues of massively parallel systems as they are assembled from serial production components. This is why parallel algorithms for aggregated conclusions formation may be implemented with the help of properly configured clusters.

Future Research

We have used described in this article methods and approaches to optimize the structure and functioning of CE for such system as the regional railroad of the country. This CE is a prime example of HNCE. Now the work is done in two directions. The first direction is to extend the experience of optimization of regional railways CE to the HNCE of the railroad of the country as a whole. The second direction is to improve the interaction between regional rail and road cargo transport association, as the components of the transport conglomerate of region. Here the focus is on the synchronization of information flows between them, optimizing logistics operations and reduce delays in the movement and processing of local and transit cargo. ■

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