High-performance GRID Database Manager for Scientific Data*

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Abstract

The GRID initiative provides an infrastructure for distributed computations among widely distributed high-performance computers. This will allow for exchanging and processing very large amounts of data. The LOFAR project (www.nfra.nl/lofar) is an international initiative to build a versatile, geographically distributed, multi-point radio facility for astrophysics, space physics, atmospheric physics, and radio research, utilizing very high performance GRID computing. LOIS is a proposed Swedish outrigger to LOFAR providing a software radar. As the volume of data processed by LOFAR/LOIS is very large and dynamic there will be need for very high performing data management systems. For this a high-performance stream-oriented distributed data manager and query processor is being developed that allows very efficient execution of database queries to streamed data involving numerical and other data. Very high performance is attained by utilizing many object-relational main-memory database engines running on

PCs and connected through the GRID. The project leverages upon a high-performance, extensible, and object-oriented database engine, the Amos II kernel, developed in the Uppsala Database Laboratory. A very high performing stream-oriented DBMS is being developed for representing and querying non-relational data representations extracted from the data flows used in space and environmental physics applications. Of particular interest is the development of new distributed data population and query processing techniques for this kind of applications and thereby utilizing distributed and scalable data structures for high-performance stream data processing.

Keywords

Parallel and Distributed Databases, Stream-Oriented Databases, Extensible Databases, GRID Computing, Space Data Management

1   Introduction

We are developing a new kind of database manager utilizing the evolving GRID infrastructure for distributed computations [3], called the *GRID Data Manager (GDM)*. GDM will have very high performance and support for customizable representation of streamed data in distributed data and computation servers. The target application area is space physics, in particular the LOFAR/LOIS project described below, whose purpose is to develop a distributed software space telescope and radar utilizing the GRID. LOFAR/LOIS will produce extremely large amounts of distributed data streams by sensors receiving signals from space. Various numerical selection and transformation algorithms are applied on these streams before the data to be delivered to the client workstations for visualization and other processing. This is a new environment very different from the conventional server-oriented database environments. A research challenge is to make GDM able to handle very large amounts of dynamically produced distributed data. The application requires orders of magnitude better data processing performance than conventional DBMSs and support for queries involving customized computations. We will achieve this by utilizing cheap and large main-memories (on PCs) connected through the GRID to form clusters of main-memory based object-relational databases. Each node in such a system is a main-memory database managed by a fast main-memory object-relational DBMS engine. Sections of the streams are materialized in the node databases and numerical algorithms are run on the nodes to filter, combine, and transform the data. GRID-based clusters of main memory database nodes combined with extensibility through user-defined data representations provide very high performance. The databases are scalable by dynamically incorporating new GRID nodes as the database grows.

The environment will require the integration of both data and computations. Research is needed on how to effectively combine high-performance distributed stream databases with distributed computation techniques. A framework will be

developed for general extensibility of the parallel GDM through user-defined data representations and query optimization algorithms distributed over many nodes. Efficient customized data representations and query optimization algorithms can thus be distributed to each node in the cluster.

It will be impossible to store all data in the distributed nodes, but rather only moving windows of the streams are stored in the nodes and the queries are executed over these windows. Managing the very high data flow though the nodes requires support for very high insert and delete frequencies. It will be virtually impossible to manually configure subtasks in this dynamic environment. New tools and algorithms will be needed for automatically configure and adapt data and computations servers based on the resources available.

We are developing a prototype illustrating the new database architecture and how to utilize such an architecture for the very demanding LOFAR/LOIS application. Through it we will evaluate the benefits from using GDM for such a kind of demanding applications.

The prototype will combine high performance through main-memory data representations, extensibility through object-orientation and plug-in of external code, and scalability through the use of scalable and distributed data structures [16] for storing of distributed node data.

2   LOFAR/LOIS

Public concern about natural and anthropogenic effects on Earth and its space habitat, Man's existential questions about the origin and fate of Universe, and the quest for better and more resource conserving information processing, are challenges that society puts on the Earth and Space Science communities. These communities accept these challenges and also formulate their own.

In response to these challenges, novel scientific methodologies and innovative research facilities are continually being developed. Generally speaking, the research facilities are of two kinds: space-borne and ground-based. While instruments on-board satellites can detect and monitor processes and phenomena which cannot be observed from Earth, the rapid motion of the spacecraft—of the order of 5-10 km/s—precludes long-term observations of given, fixed regions in Earth-space. For such observations, of utmost importance for the discovery of long-term trends, observatories on the ground are ideally suited. Therefore, the space-borne and ground-based instruments complement each other in an almost ideal manner.

An example of the former is the upcoming ENVISAT (envisat.esa.int) advanced polar-orbiting Earth observation satellite which will provide measurements of the atmosphere, ocean, land, and ice over a five year period, and the ongoing space physics mission Cluster (sci.esa.int/cluster) and atmospheric physics and astrophysics mission Odin (www.snsb.se/Odin/Odin.html), in which Swedish science and technology play prominent role.

An example of the latter is the radio observatory LOFAR (www.nfra.nl/lofar), an international initiative to build, during the 2002-2006 time-frame, in northern Europe and Scandinavia, a versatile, geographically distributed, multi-point radio facility for astrophysics, space physics, atmospheric physics, and radio research which in a unique way addresses the above challenges and more.

For a giant radio and radar research project such as LOFAR, Swedish physics, technology and industry has a very interesting profile. Therefore, LOFAR proper, primarily designed for radio astronomy, will be augmented by a Swedish "outrigger" called LOIS (www.wavegroup.irfu.se/LOIS) which will add atmospheric, ionospheric, solar and planetary space physics capabilities by providing a radar sub-facility, including an absolute top-notch infrastructure, in the region surrounding Växjö in southern Sweden.

LOFAR/LOIS will be at least a hundred times more sensitive than any comparable facility anywhere and is best viewed as a huge, geographically distributed network of electromagnetic sensors and emitters, fully digitized and operated entirely in software. The data from Earth's space environment and Universe will be broadcast in real time over the World Wide Grid. This will be the first facility of this kind where public outreach issues, including immediate, direct access to scientific data as they are being produced, will be considered primary design criteria.

At full operation in the 2006 time-frame and beyond, LOFAR/LOIS will consist of 31,000 antennas with sensors and emitters, organized in hundreds of clusters distributed within a circular geographical region of about 350 km diameter. The total data rate will be circa 25 Tbits/s. This means that LOFAR/LOIS will utilize technology at or even beyond the current leading edge and, hence, will advance antenna, radio, detector, and data handling technologies far beyond their current limits and therefore be an ideal Swedish DataGRID test-bed.

3   Related Work

The area of stream data management has gained increased attraction recently [1, 6, 7, 17, 31, 33] and results from that area are expected to be very important for this project. A good recent overview of the area can be found in [2].

Another modern development in the database area is to use large main memories to represent the database [8]. The main memory of modern computers can be cheap and large enough to entirely store many databases. Furthermore, many applications can be simplified by embedding a lightweight DBMS that manages its data. DBMS vendors are therefore developing lightweight main memory relational databases [13, 24, 32] that often interoperate with their regular relational server DBMSs. The Amos II DBMS engine [27] is also such an embeddable main-memory DBMS. However, different from commercial embedded databases, it has a complete and extensible query optimizer for object-oriented queries, i.e. it is

an object-relational main memory DBMS. Amos II supports extensibility of both the storage manager and the query processor, but the engine itself is limited to a single main-memory. It has been used for integrating high performance query capabilities in engineering analysis systems [4, 23, 25].

The performance and scalability of main memory databases can be substantially further enhanced by relying not only on one main memory in one computer but also on clusters of main-memory databases. Examples of relational DBMSs using such architectures are ClustRa [9] and NDB [28, 29]. Those systems are very high performing systems, e.g., for telecom applications. They also have the additional property of very high reliability by automatic data replication, which is required for their applications.

The development of very high performance and scalable distributed data structures, SDDSs [16] provides distributed dynamic data structures that scale well by utilizing large main memories on distributed computers connected through fast communication networks. Some important properties of SDDSs are that they do not rely on a central server node and gracefully scale to use more nodes as the database grows. There are many variants of SDDSs depending on their indexing capabilities, high availability, etc. [14, 15, 18, 20]. The Amos II kernel has successfully been coupled to a manager of SDDSs developed at Dauphine University (Paris) [22] indicating very good performance and scalability. In the GDM project we will investigate how SDDSs can be utilized for high-performance query processing of stream data.

Object-Relational DBMSs [30] allow definition of abstract data types whose instances are stored in relational tables and user defined functions that are executed in the database server. Cost hints can be defined to guide the query optimizer how to place calls to the UDFs in the optimized query execution plans. Modern relational DBMSs have object-relational extensions and extensibility is now part of the SQL standard through the SQL-MED standard [21]. However, commercial object-relational databases are still disk based, and computationally intensive applications still require customized main-memory based data representations.

The difference between GDM and previous approaches is the development of a DBMS that supports advanced queries over both regular data and data streams and is extensible while at the same time having very high performance. This is achieved by developing a distributed, main-memory, stream-oriented, object-relational DBMS. We are extending an existing main-memory object-relational DBMS engine with capabilities to utilize large distributed main memories. Main-memory, distribution, and query processing will provide high performance, while object-relational functionality will provide extensibility capabilities.

4   Project Status

The GDM project has just started. Based on studies of the problem area we are developing the system architecture based on Amos II and modern research on scalable data structures, stream oriented data management, extensible data managers, etc. A first prototype on a PC cluster will be developed during 2002. LOFAR/LOIS subsystems, mainly for interactive selection and visualization of the space data, are being developed in parallel. These applications will be used as benchmarks for evaluation and evolution of GDM.

GDM is expected to have significant practical impact on LOFAR/LOIS as well as on other applications requiring high performance data processing, while at the same time providing basis for state-of-the-art database research.

An interesting possible further development is to combine GDM with our previous work on integration of heterogeneous data sources [5, 10, 11, 12, 19]. This would provide a high-performance extensible database engine that also could query data from many different external data sources, e.g. on the Internet and in relational databases.

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