GRID COMPUTING (18KP2CSELCS2:A)

UNIT – I : Introduction – Grid Activities data – Computation , Computational and Data Grids – current Grid Activities – Overview of Grid Business Areas : Life Sciences, Financial Analysis and Services – Research Collaboration – Engineering and Design – Collaborative Games – Government – Grid Applications: Schedule – Resource Brokers – Load Balancing – Grid Portals – Integrated solutions – Grid Infrastructure.

UNIT – II: Grid Computing Organizations and their roles : Organizations Developing Grid standards and best practice guidelines: Global Grid forum – Organizations developing Grid Computing Toolkits and the Framework – Organizations Building and using Grid Based solutions to solve computing , Data and Network Requirements – Commercial organizations building and using Grid-based solutions.

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Grid Computing

Chapter I - introduction

Introduction to Grid Computing

In today's pervasive world of needing information anytime and anywhere, the explosive Grid Computing environments have now proven to be so significant that they are often referred to as being the world's single and most powerful computer solutions. It has been realized that with the many benefits of Grid Computing, we have consequently introduced both a complicated and complex global environment, which leverages a multitude of open standards and technologies in a wide variety of implementation schemes. As a matter of fact the complexity and dynamic nature of industrial problems in today's world are much more intensive to satisfy by the more traditional, single computational platform approaches.

Grid Computing equates to the world's largest computer ...

The Grid Computing discipline involves the actual networking services and connections of a potentially unlimited number of ubiquitous computing devices within a "grid." This new innovative approach to computing can be most simply thought of as a massively large power "utility" grid, such as what provides power to our homes and businesses each and every day. This delivery of utility-based power has become second nature to many of us, worldwide. We know that by simply walking into a room and turning on the lights, the power will be directed to the proper devices of our choice for that moment in time. In this same utility fashion, Grid Computing openly seeks and is capable of adding an infinite number of computing devices into any grid environment, adding to the computing capability and problem resolution tasks within the operational grid environment.

The incredible problem resolution capabilities of Grid Computing remain yet unknown, as we continue to forge ahead and enter this new era of massively powerful grid-based problem-solving solutions.

This "Introduction" section of the book will begin to present many of the Grid Computing topics, which are discussed throughout this book. These discussions in Chapter 1 are intended only to provide a rather high-level examination of Grid Computing. Later sections of the book provide a full treatment of the topics addressed by many worldwide communities utilizing and continuing to develop Grid Computing.

The worldwide business demand requiring intense problem-solving capabilities for incredibly complex problems has driven in all global industry segments the need for dynamic collaboration of many ubiquitous computing resources to be able to work together. These difficult computational problem-solving needs have now fostered many complexities in virtually all computing technologies, while driving up costs and operational aspects of the technology environments. However, this advanced computing collaboration capability is indeed required in almost all areas of industrial and business problem solving, ranging from scientific studies to commercial solutions to academic endeavors. It is a difficult challenge across all the technical communities to achieve this level of resource collaboration needed for solving these complex and dynamic problems, within the bounds of the necessary quality requirements of the end user.

To further illustrate this environment and oftentimes very complex set of technology challenges, let us consider some common *use case* scenarios one might have already encountered, which will begin to examine the many values of a Grid Computing solution environment. These simple use cases, for purposes of introduction to the concepts of Grid Computing, are as follows:

- A financial organization processing wealth management application collaborates with the different departments for more computational power and software modeling applications. It pools a number of computing resources, which can thereby perform faster with real-time executions of the tasks and immediate access to complex pools of data storage, all while managing complicated data transfer tasks. This ultimately results in increased customer satisfaction with a faster turnaround time.

- A group of scientists studying the atmospheric ozone layer will collect huge amounts of experimental data, each and every day. These scientists need efficient and complex data storage capabilities across wide and geographically dispersed storage facilities, and they need to access this data in an efficient manner based on the processing needs. This ultimately results in a more effective and efficient means of performing important scientific research.

- Massive online multiplayer game scenarios for a wide community of international gaming participants are occurring that require a large number of gaming computer servers instead of a dedicated game server. This allows international game players to interact among themselves as a group in a real-time manner. This involves the need for on-demand allocation and provisioning of computer resources, provisioning and self-management of complex networks, and complicated data storage resources. This on-demand need is very dynamic, from moment-to-moment, and it is always based upon the workload in the system at any given moment in time. This ultimately results in larger gaming communities, requiring more complex infrastructures to sustain the traffic loads, delivering more profits to the bottom lines of gaming corporations, and higher degrees of customer satisfaction to the gaming participants.

- A government organization studying a natural disaster such as a chemical spill may need to immediately collaborate with different departments in order to plan for and best manage the disaster. These organizations may need to simulate many computational models related to the spill in order to calculate the spread of the spill, effect of the weather on the spill, or to determine the impact on human health factors. This ultimately results in protection and safety matters being provided for public safety issues, wildlife management and protection issues, and ecosystem protection matters: Needles to say all of which are very key concerns.

Today, Grid Computing offers many solutions that already address and resolve the above problems. Grid Computing solutions are constructed using a variety of technologies and open standards. Grid Computing, in turn, provides highly scalable, highly secure, and extremely high-performance mechanisms for discovering and negotiating access to remote computing resources in a seamless manner. This makes it possible for the sharing of computing resources, on an unprecedented scale, among an infinite number of geographically distributed groups. This serves as a significant transformation agent for individual and corporate implementations surrounding computing practices, toward a general-purpose utility approach very similar in concept to providing electricity or water. These electrical and water types of utilities, much like Grid Computing utilities, are available "on demand," and will always be capable of providing an always-available facility negotiated for individual or corporate utilization.

In this new and intriguing book, we will begin our discussion on the core concepts of the Grid Computing system with an early definition of grid. Back in 1998, it was defined, "A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities" (Foster & Kesselman, 1998).

The preceding definition is more centered on the computational aspects of Grid Computing while later iterations broaden this definition with more focus on coordinated resource sharing and problem solving in multi-institutional virtual organizations (Foster & Kesselman, 1998). In addition to these qualifications of coordinated resource sharing and the formation of dynamic virtual organizations, open standards become a key underpinning. It is important that there are open standards throughout the grid implementation, which also accommodate a variety of other open standards-based protocols and frameworks, in order to provide interoperable and extensible infrastructure environments.

Grid Computing environments must be constructed upon the following foundations:

- *Coordinated resources*. We should avoid building grid systems with a centralized control; instead, we must provide the necessary infrastructure for coordination among the resources, based on respective policies and service-level agreements.

- *Open standard protocols and frameworks*. The use of open standards provides interoperability and integration facilities. These standards must be applied for resource discovery, resource access, and resource coordination.

Another basic requirement of a Grid Computing system is the ability to provide the quality of service (QoS) requirements necessary for the end-user community. These QoS validations must be a basic feature in any Grid system, and must be done in congruence with the available resource matrices. These QoS features can be (for example) response time measures, aggregated performance, security fulfillment, resource scalability, availability, autonomic features such as event correlation and configuration management, and partial fail over mechanisms.

There have been a number of activities addressing the above definitions of Grid Computing and the requirements for a grid system. The most notable effort is in the standardization of the interfaces and protocols for the Grid Computing infrastructure implementations. We will cover the details later in this book. Let us now explore some early and current Grid Computing systems and their differences in terms of benefits.

Early Grid Activities

Over the past several years, there has been a lot of interest in computational Grid Computing worldwide. We also note a number of derivatives of Grid Computing, including compute grids, data grids, science grids, access grids, knowledge grids, cluster grids, terra grids, and commodity grids. As we explore careful examination of these grids, we can see that they all share some form of resources; however, these grids may have differing architectures.

One key value of a grid, whether it is a commodity utility grid or a computational grid, is often evaluated based on its business merits and the respective user satisfaction. User satisfaction is measured based on the QoS provided by the grid, such as the availability, performance, simplicity of access, management aspects, business values, and flexibility in pricing. The business merits most often relate to and indicate the problem being solved by the grid. For instance, it can be job executions, management aspects, simulation workflows, and other key technology-based foundations.

Earlier Grid Computing efforts were aligned with the overlapping functional areas of data, computation, and their respective access mechanisms. Let us further explore the details of these areas to better understand their utilization and functional requirements.

Data

The data aspects of any Grid Computing environment must be able to effectively manage all aspects of data, including data location, data transfer, data access, and critical aspects of security. The core functional data requirements for Grid Computing applications are:

- The ability to integrate multiple distributed, heterogeneous, and independently managed data sources.
- The ability to provide efficient data transfer mechanisms and to provide data where the computation will take place for better scalability and efficiency.
- The ability to provide data caching and/or replication mechanisms to minimize network traffic.
- The ability to provide necessary data discovery mechanisms, which allow the user to find data based on characteristics of the data.
- The capability to implement data encryption and integrity checks to ensure that data is transported across the network in a secure fashion.
- The ability to provide the backup/restore mechanisms and policies necessary to prevent data loss and minimize unplanned downtime across the grid.

Computation

The core functional computational requirements for grid applications are:

- The ability to allow for independent management of computing resources
- The ability to provide mechanisms that can intelligently and transparently select computing resources capable of running a user's job
- The understanding of the current and predicted loads on grid resources, resource availability, dynamic resource configuration, and provisioning
- Failure detection and failover mechanisms

- Ensure appropriate security mechanisms for secure resource management, access, and integrity

Let us further explore some details on the computational and data grids as they exist today.

Computational and Data Grids

In today's complex world of high speed computing, computers have become extremely powerful as to that of (let's say) five years ago. Even the home-based PCs available on the commercial markets are powerful enough for accomplishing complex computations that we could not have imagined a decade prior to today.

The quality and quantity requirements for some business-related advanced computing applications are also becoming more and more complex. The industry is now realizing that we have a need, and are conducting numerous complex scientific experiments, advanced modeling scenarios, genome matching, astronomical research, a wide variety of simulations, complex scientific/business modeling scenarios, and real-time personal portfolio management. These requirements can actually exceed the demands and availability of installed computational power within an organization. Sometimes, we find that no single organization alone satisfies some of these aforementioned computational requirements.

This advanced computing power applications need is indeed analogous to the electric power need in the early 1900s, such that to provide for the availability of electrical power, each user has to build and be prepared to operate an electrical generator. Thus, when the electric power grid became a reality, this changed the entire concept of the providing for, and utilization of, electrical power. This, in turn, paved the way for an evolution related to the utilization of electricity. In a similar fashion, the computational grids change the perception on the utility and availability of the computer power. Thus the computational Grid Computing environment became a reality, which provides a demand-driven, reliable, powerful, and yet inexpensive computational power for its customers.

As we noted earlier in this discussion, a computational Grid Computing environment consists of one or more hardware- and software-enabled environments that provide dependable, consistent, pervasive and inexpensive access to high-end computational capabilities (Foster & Kesselman, 1998).

Later in this book, in the "Grid Anatomy" section, we will see that this definition has evolved to give more emphasis on the seamless resource sharing aspects in a collaborative virtual organizational world. But the concept still holds for a computational grid where the sharable resource remains a computing power. As of now, the majority of the computational grids are centered on major scientific experiments and collaborative environments.

The requirement for key data forms a core underpinning of any Grid Computing environment. For example, in data-intensive grids, the focus is on the management of data, which is being held in a variety of data storage facilities in geographically dispersed locations. These data sources can be databases, file systems, and storage devices. The grid systems must also be capable of providing data virtualization services to provide transparency for data access, integration, and processing. In addition to the above requirements, security and privacy requirements of all respective data in a grid system is quite complex.

We can summarize the data requirements in the early grid solutions as follows:

- The ability to discover data
- The access to databases, utilizing meta-data and other attributes of the data
- The provisioning of computing facilities for high-speed data movement
- The capability to support flexible data access and data filtering capabilities

As one begins to realize the importance of extreme high performance-related issues in a Grid Computing environment, it is recommended to store (or cache) data near to the computation, and to provide a common interface for data access and management.

It is interesting to note that upon careful examination of existing Grid Computing systems, readers will learn that many Grid Computing systems are being applied in several important scientific research and collaboration projects; however, this does not preclude the importance of Grid Computing in business-, academic-, and industry-related fields. The commercialization of Grid Computing invites and addresses a key architectural alignment with several existing commercial frameworks for improved interoperability and integration.

As we will describe in this book, many current trends in Grid Computing are toward service-based architectures for grid environments. This "architecture" is built for interoperability and is (again) based upon open standard protocols. We will provide a full treatment including many of the details toward this architecture throughout subsequent sections in this book.

Current Grid Activities

As described earlier, initially, the focused Grid Computing activities were in the areas of computing power, data access, and storage resources.

The definition of Grid Computing resource sharing has since changed, based upon experiences, with more focus now being applied to a sophisticated form of coordinated resource sharing distributed throughout the participants in a virtual organization. This application concept of coordinated resource sharing includes any resources available within a virtual organization, including computing power, data, hardware, software and applications, networking services, and any other forms of computing resource attainment. This concept of coordinated resource sharing is depicted in Figure 1.1.

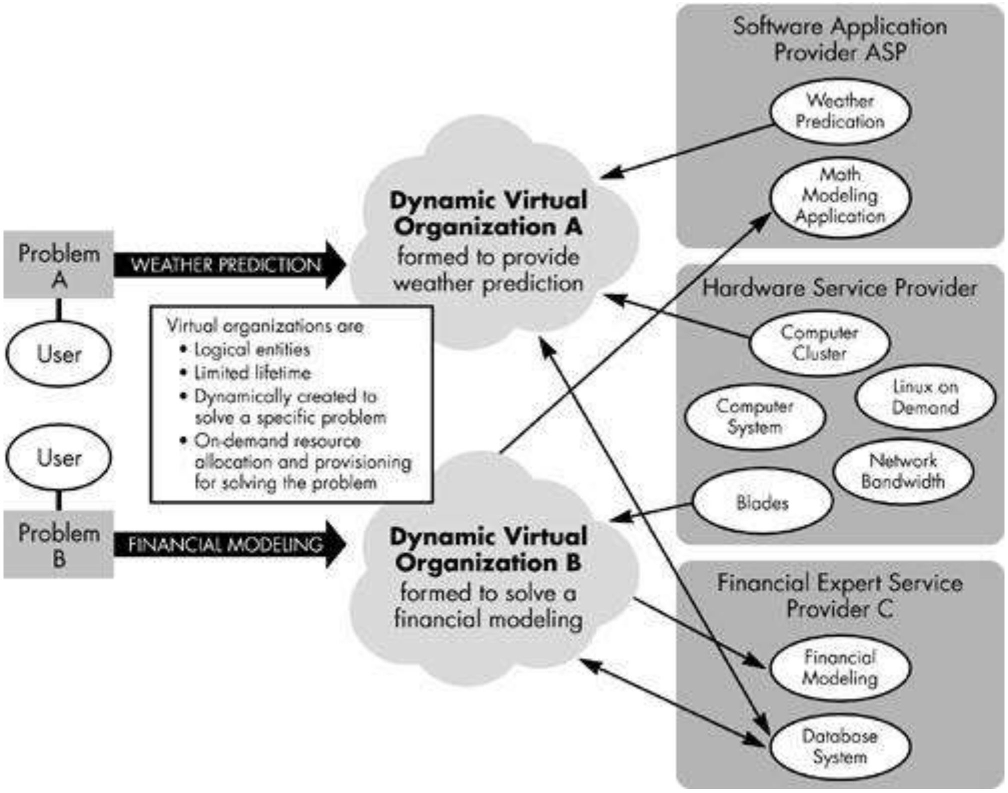


Figure 1.1. Dynamic benefits of coordinated resource sharing in a virtual organization.

As depicted in the previous illustration, there are a number of sharable resources, hardware and software applications, firmware implementations, and networking services, all available within an enterprise or service provider environment. Rather than keeping these resources isolated within an atomic organization, the users can acquire these resources on a "demand" basis. Through implementing this type of Grid Computing environment, these resources are immediately available to the authenticated users for resolving specific problems. These problems may be a software capability problem (e.g., modeling, simulation, word processing, etc.) or hardware availability and/or computing capacity shortage problems (e.g., processor computing resources, data storage/access needs, etc.). While on another level, these problems may be related to a networking bandwidth availability problem, the need for immediate circuit provisioning of a network, a security event or other event correlation issue, and many more types of critical environmental needs.

Based upon the specific problem dimension, any given problem may have one or more resolution issues to address. For example, in the above case there is two sets of users, each with a need to solve two different types of problems. You will note that one has to resolve the weather prediction problem, while the other has to provide a financial modeling case. Based upon these problem domains noted by each of the user groups, their requirements imply two types of virtual organizations. These distinct virtual organizations are formulated, sustained, and managed from a computing resource viewpoint according to the ability to access the available resources. Let us further explore this concept of "*virtualization*" by describing in more detail the usage patterns found within each of the virtual organizations.

- *A virtual organization for weather prediction*. For example, this virtual organization requires resources such as weather prediction software applications to perform the mandatory environmental simulations associated with predicting weather. Likewise, they will require very specific hardware resources to run the respective software, as well as high-speed data storage facilities to maintain the data generated from performing the simulations.

- *A virtual organization for financial modeling*. For example, this virtual organization requires resources such as software modeling tools for performing a multitude of financial analytics, virtualized blades[1] to run the above software, and access to data storage facilities for storing and accessing data.

These virtual organizations manage their resources and typically will provision additional resources on an "as-needed" basis. This on-demand approach provides tremendous values toward scalability, in addition to aspects of enhanced reusability. This approach is typically found in any "on-demand" environment. This capability is based upon a *utility* infrastructure, where resources are allocated as, and when, they are required. Likewise, their utility pricing scenarios are always based upon the capturing of usage metrics.

The following discussion introduces a number of requirements needed for such Grid Computing architectures utilized by virtual organizations. We shall classify these architecture requirements into three categories. These resources categories must be capable of providing facilities for the following scenarios:

- The need for dynamic discovery of computing resources, based on their capabilities and functions.
- The immediate allocation and provisioning of these resources, based on their availability and the user demands or requirements.
- The management of these resources to meet the required service level agreements (SLAs).
- The provisioning of multiple autonomic features for the resources, such as self-diagnosis, self-healing, self-configuring, and self-management.
- The provisioning of secure access methods to the resources, and bindings with the local security mechanisms based upon the autonomic control policies.

Virtual organization must be capable of providing facilities for:

- The formation of virtual task forces, or groups, to solve specific problems associated with the virtual organization.
- The dynamic collection of resources from heterogeneous providers based upon users' needs and the sophistication levels of the problems.
- The dynamic identification and automatic problem resolution of a wide variety of troubles, with automation of event correlation, linking the specific problems to the required resource and/or service providers.
- The dynamic provisioning and management capabilities of the resources required meeting the SLAs.
- The formation of a secured federation (or governance model) and common management model for all of the resources respective to the virtual organization.
- The secure delegation of user credentials and identity mapping to the local domain(s).

- The management of resources, including utilization and allocation, to meet a budget and other economic criteria.

Users/applications typically found in Grid Computing environments must be able to perform the following characteristics:

- The clear and unambiguous identification of the problem(s) needing to be solved
- The identification and mapping of the resources required solve the problem
- The ability to sustain the required levels of QoS, while adhering to the anticipated and necessary SLAs
- The capability to collect feedback regarding resource status, including updates for the environment's respective applications

The above discussion helps us now to better understand the common requirements for grid systems. In the subsequent chapters in this section, and moreover throughout this book, we discuss the many specific details on the Grid Computing architecture models and emerging Grid Computing software systems that have proven valuable in supporting the above requirements.

The following section will provide treatment toward some of the more common Grid Computing business areas that exist today, and those areas that will typically benefit from the above concepts of Grid Computing. It is worthy to mention that these business areas are most often broadly classified, and based upon the industry sector where they reside.

An Overview of Grid Business Areas

One of the most valuable aspects of all Grid Computing systems are that they attract the business they are intended to address. In an "on-demand" scenario, these Grid Computing environments are the result of autonomic provisioning of a multitude of resources and capabilities, typically demonstrating increased computing resource utilization, access to specialized computer systems, cost sharing, and improved management capabilities.

IBM Business On Demand Initiative

Business On Demand (in the rest of the book we will refer to this as On Demand) is not just about utility computing as it has a much broader set of ideas about the transformation of business practices, process transformation, and technology implementations. Companies striving to achieve the Business On Demand operational models will have the capacity to sense and respond to fluctuating market conditions in real-time, while providing products and services to customers in a Business On Demand operational model. The essential characteristics of on-demand businesses are responsiveness to the dynamics of business, adapting to variable cost structures, focusing on core business competency, and resiliency for consistent availability. This is achieved through seamless integration of customers and partners, virtualization of resources, autonomic/dependable resources, and open standards.

There have been a significant number of commercialization efforts, which support Grid Computing in every sector of the marketplace. In general terms, the utilization of Grid Computing in business environments provides a rich and extensible set of business benefits. These business benefits include (but are not limited to):

- Acceleration of implementation time frames in order to intersect with the anticipated business end results.
- Improved productivity and collaboration of virtual organizations and respective computing and data resources.
- Allowing widely dispersed departments and businesses to create virtual organizations to share data and resources.
- Robust and infinitely flexible and resilient operational infrastructures.
- Providing instantaneous access to massive computing and data resources.
- Leveraging existing capital expenditures investments, and operational expenditure investments, which in turn help to ensure optimal utilization and costs of computing capabilities.
- Avoiding common pitfalls of overprovisioning and incurring excess costs.

Many organizations have started identifying the major business areas for Grid Computing business applications. Some examples of major business areas include (but are not limited to):

- Life sciences, for analyzing and decoding strings of biological and chemical information
- Financial services, for running long, complex financial models and arriving at more accurate decisions
- Higher education for enabling advanced, data- and computation-intensive research

- Engineering services, including automotive and aerospace, for collaborative design and data-intensive testing
- Government, for enabling seamless collaboration and agility in both civil and military departments and other agencies
- Collaborative games for replacing the existing single-server online games with more highly parallel, massively multiplayer online games

Let us now introduce and explore the analytics of each of these industry sectors by identifying some of the high-level business-area requirements for Grid Computing systems. In doing so, we will look at the facilities necessary for grid systems in order to meet these requirements.

Life Sciences

This industry sector has noted many dramatic advances in the life sciences sector, which have in turn provided rapid changes in the way that drug treatment and drug discovery efforts are now being conducted. The analytics and system efforts' surrounding genomic, proteomics, and molecular biology efforts provides the basis for many of these Grid Computing advancements in this sector. These advances have now presented a number of technical challenges to the information technology sector, and especially the Grid Computing disciplines.

Grid Computing efforts have realized that these challenges include huge amounts of data analysis, data movement, data caching, and data mining. In addition to the complexity of processing data, there needs to be additional requirements surrounding data security, secure data access, secure storage, privacy, and highly flexible integration. Another area that requires attention is the querying of nonstandard data formats and accessing data assets across complex global networks.

The above requirements presented by life sciences require a Grid Computing infrastructure to properly manage data storage, providing access to the data, and all while performing complex analysis respective to the data. The Grid Computing systems can provide a common infrastructure for data access, and at the same time, provide secure data access mechanisms while processing the data. Today, life sciences utilizes the Grid Computing systems to execute sequence comparison algorithms and enable molecular modeling using the above-collected secured data. This now provides the Life Sciences sector the ability to afford world-class information analysis respective to this discussion, while at the same time providing faster response times and far more accurate results.

Financial Analysis and Services

This industry sector has noted many dramatic advances in the financial analysis and services industry sector. The technological and business advances are most noted in the information technology areas, the emergence of a competitive market force customer satisfaction, and reduction of risk as the most competitive areas financial communities continually strive to achieve. The requirements related to sophistication, accuracy, and faster execution are among the more salient objectives across financial communities. These objectives are now achieved by real-time access to the current and historical market data, complex financial modeling based on the respective data, and faster response times to user queries.

Grid Computing provides the financial analysis and services industry sector with advanced systems delivering all the competitive solutions in Grid Computing. These solutions exemplify the infrastructure and business agility necessary to meet and exceed the uniqueness that the financial analysis and services industry sector requires. This particular value statement is accomplished by the fact that many of these solutions in this industry are dependent upon providing increased access to massive amounts of data, real-time modeling, and faster execution by using the grid job scheduling and data access features. For this to be most successful, these financial institutions tend to form virtual organizations with participation from several different departments and other external organizations. In addition to the use of existing resources, a grid system can provide more efficiency by easily adapting to the rapidly changing algorithms pertaining to the financial analytics.

Research Collaboration

Research-oriented organizations and universities practicing in advanced research collaboration areas require the analysis of tremendous amounts of data. Some examples of such projects are subatomic particle and high energy physics experiments, remote sensing sources for earth simulation and modeling, and analysis of the human genome sequence.

These virtual organizations engaged in research collaboration activities generate petabytes[2] of data and require tremendous amounts of storage space and thousands of computing processors. Researchers in these fields must share data, computational processors, and hardware instrumentation such as telescopes and advanced testing equipment. Most of these resources are pertaining to data-intensive processing, and are widely dispersed over a large geographical area.

The Grid Computing discipline provides mechanisms for resource sharing by forming one or more virtual organizations providing specific sharing capabilities. Such virtual organizations are constituted to resolve specific research problems with a wide range of participants from different regions of the world. This formation of dynamic virtual organizations provides capabilities to dynamically add and delete virtual organization participants, manage the "on-demand" sharing of resources, plus provisioning of a common and integrated secure framework for data interchange and access.

Engineering and Design

The enormous competitive pressure in the business and industry sectors today afford most engineering and design far less turnaround time. They need mechanisms to capture data, speed up the analysis on the data, and provide faster responses to market needs. As we already know, these engineering activities and design solutions are inherently complex across several dimensions, and the processing requirements are much more intense than that of traditional solutions of the past.

These complexities fall into several areas of solutions in Grid Computing that span across industry sectors all over the world. These complexities are described (but are not limited to) the following areas:

- The analysis of real-time data to find a specific pattern within a problem
- The parametric studies to verify different aspects of the systems
- The modeling experiments to create new designs
- The simulation activities to verify the existing models for accuracy

Grid Computing systems provide a wide range of capabilities that address the above kinds of analysis and modeling activities. These advanced types of solutions also provide complex job schedulers and resource managers to deal with computing power requirements. This enables automobile manufacturers (as an example) to shorten analysis and design times, all while minimizing both capital expenditures and operational expenditures.

Collaborative Games

There are collaborative types of Grid Computing disciplines that are involving emerging technologies to support online games, while utilizing on-demand provisioning of computation-intensive resources, such as computers and storage networks. These resources are selected based on the requirements, often involving aspects such as volume of traffic and number of players, rather than centralized servers and other fixed resources.

These on-demand-driven games provide a flexible approach with a reduced up-front cost on hardware and software resources. We can imagine that these games use an increasing number of computing resources with an increase in the number of concurrent players and a decrease in resource usage with a lesser number of players. Grid Computing gaming environments are capable of supporting such virtualized environments for enabling collaborative gaming.

Government

The Grid Computing environments in government focus on providing coordinated access to massive amounts of data held across various agencies in a government. This provides faster access to solve critical problems, such as emergency situations, and other normal activities. These key environments provide more efficient decision making with less turnaround time.

Grid Computing enables the creation of virtual organizations, including many participants from various governmental agencies (e.g., state and federal, local or country, etc.). This is necessary in order to provide the data needed for government functions, in a real-time manner, while performing the analysis on the data to detect the solution aspects of the specific problems being addressed. The formation of virtual organizations, and the respective elements of security, is most challenging due to the high levels of security in government and the very complex requirements.

Grid Applications

Based on our earlier discussion, we can align Grid Computing applications to have common needs, such as what is described in (but not limited to) the following items:

- Application partitioning that involves breaking the problem into discrete pieces
- Discovery and scheduling of tasks and workflow
- Data communications distributing the problem data where and when it is required
- Provisioning and distributing application codes to specific system nodes
- Results management assisting in the decision processes of the environment
- Autonomic features such as self-configuration, self-optimization, self-recovery, and self-management

Let us now explore some of these Grid applications and their usage patterns. We start with schedulers, which form the core component in most of the computational grids.

Schedulers

Schedulers are types of applications responsible for the management of jobs, such as allocating resources needed for any specific job, partitioning of jobs to schedule parallel execution of tasks, data management, event correlation, and service-level management capabilities. These schedulers then form a hierarchical structure, with meta-schedulers that form the root and other lower level schedulers, while providing specific scheduling capabilities that form the leaves. These schedulers may be constructed with a local scheduler implementation approach for specific job execution, or another meta-scheduler or a cluster scheduler for parallel executions. Figure 1.2 shows this concept.

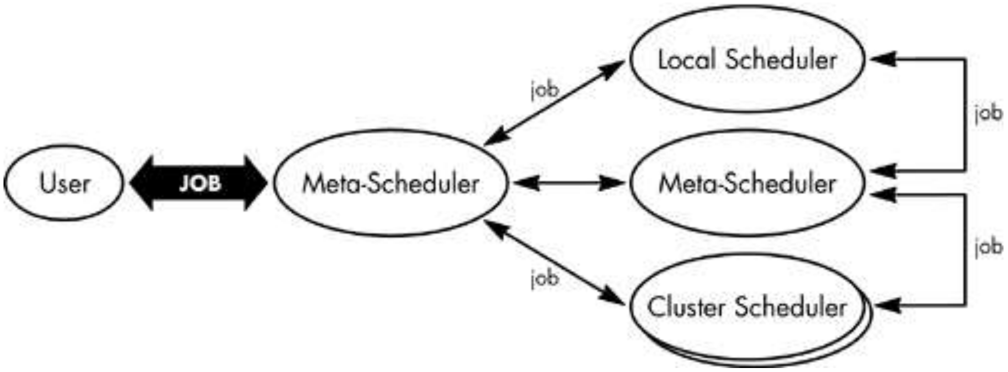


Figure 1.2. The scheduler hierarchy embodies local, meta-level, and cluster schedulers.

The jobs submitted to Grid Computing schedulers are evaluated based on their service-level requirements, and then allocated to the respective resources for execution. This will involve complex workflow management and data movement activities to occur on a regular basis. There are schedulers that must provide capabilities for areas such as (but not limited to):

- Advanced resource reservation
- Service-level agreement validation and enforcement
- Job and resource policy management and enforcement for best turnaround times within the allowable budget constraints
- Monitoring job executions and status

- Rescheduling and corrective actions of partial failover situations

Later in this book, full treatment is provided for many of the most notable scheduler and meta-scheduler implementations.

Resource Broker

The resource broker provides *pairing* services between the service requester and the service provider. This pairing enables the selection of best available resources from the service provider for the execution of a specific task. These resource brokers collect information (e.g., resource availability, usage models, capabilities, and pricing information) from the respective resources, and use this information source in the pairing process.

Figure 1.3 illustrates the use of a resource broker for purposes of this discussion. This particular resource broker provides feedback to the users on the available resources. In general cases, the resource broker may select the suitable scheduler for the resource execution task, and collaborate with the scheduler to execute the task(s).

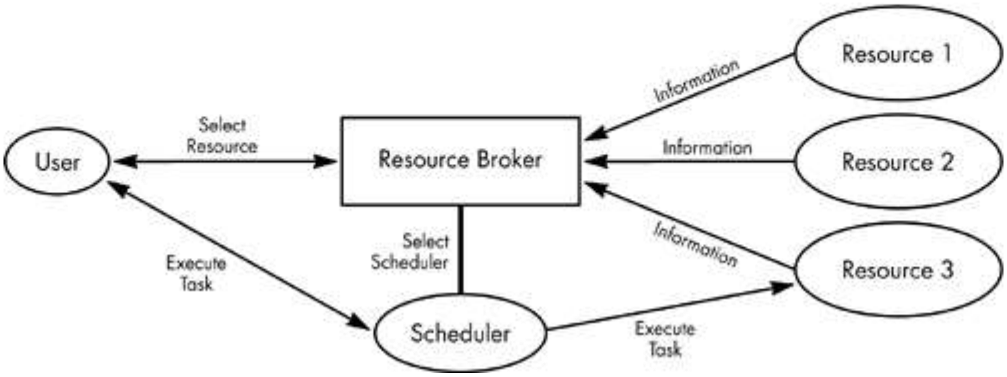


Figure 1.3. The resource broker collects information from the respective resources, and utilizes this information source in the pairing process.

The pairing process in a resource broker involves allocation and support functions such as:

- Allocating the appropriate resource or a combination of resources for the task execution
- Supporting users' deadline and budget constraints for scheduling optimizations

Load Balancing

The Grid Computing infrastructure load-balancing issues are concerned with the traditional load-balancing distribution of workload among the resources in a Grid Computing environment. This load-balancing feature must always be integrated into any system in order to avoid processing delays and overcommitment of resources. These kinds of applications can be built in connection with schedulers and resource managers.

The workload can be pushed outbound to the resources, based on the availability state and/or resources, and can then pull the jobs from the schedulers depending on their availability. This level of load balancing involves partitioning of jobs, identifying the resources, and queueing of the jobs. There are cases when resource reservations might be required, as well as running multiple jobs in parallel.

Another feature that might be of interest for load balancing is support for failure detection and management. These load distributors can redistribute the jobs to other resources if needed.

Grid Portals

Grid portals are similar to Web portals, in the sense they provide uniform access to the grid resources. For example, grid portals provide capabilities for Grid Computing resource authentication, remote resource access, scheduling capabilities, and monitoring status information. These kinds of portals help to alleviate the complexity of task management through customizable and personalized graphical interfaces for the users. This, in turn, alleviates the need for end users to have more domain knowledge than on the specific details of grid resource management.

Some examples of these grid portal capabilities are noted in the following list:

- Querying databases or *LDAP* servers for resource-specific information
- File transfer facilities such as file upload, download, integration with custom software, and so on
- Manage job through job status feedbacks
- Allocate the resources for the execution of specific tasks
- Security management
- Provide personalized solutions

In short, these grid portals help free end users from the complexity of job management and resource allocation so they can concentrate more on their domain of expertise. There are a number of standards and software development toolkits available to develop custom portals. The emerging Web services and Web service portal standards will play a more significant role in portal development.

Integrated Solutions

Many of the global industry sectors have witnessed the emergence of a number of integrated grid application solutions in the last few years. This book focuses on this success factor.

These integrated solutions are a combination of the existing advanced middleware and application functionalities, combined to provide more coherent and high performance results across the Grid Computing environment.

Integrated Grid Computing solutions will have more enhanced features to support more complex utilization of grids such as coordinated and optimized resource sharing, enhanced security management, cost optimizations, and areas yet to be explored. It is straightforward to see that these integrated solutions in both the commercial and noncommercial worlds sustain high values and significant cost reductions. Grid applications can achieve levels of flexibility utilizing infrastructures provided by application and middleware frameworks.

In the next section we introduce and explain the grid infrastructure. Today, the most notable integrated solutions in the commercial and industry sectors are utility computing, on-demand solutions, and resource virtualizations infrastructures. Let us briefly explore aspects of some of these infrastructure solutions. We will provide an additional, more focused treatment in subsequent chapters of this book.

Grid Infrastructure

The grid infrastructure forms the core foundation for successful grid applications. This infrastructure is a complex combination of a number of capabilities and resources identified for the specific problem and environment being addressed.

In initial stages of delivering any Grid Computing application infrastructure, the developers/service providers must consider the following questions in order to identify the core infrastructure support required for that environment:

1. What problem(s) are we trying to solve for the user? How do we address grid enablement simpler, while addressing the user's application simpler? How does the developer

(programmatically) help the user to be able to quickly gain access and utilize the application to best fit their problem resolution needs?

2. How difficult is it to use the grid tool? Are grid developers providing a flexible environment for the intended user community?
3. Is there anything not yet considered that would make it easier for grid service providers to create tools for the grid, suitable for the problem domain?
4. What are the open standards, environments, and regulations grid service providers must address?

In the early development stages of grid applications, numerous vertical "towers" and middleware solutions were often developed to solve Grid Computing problems. These various middleware and solution approaches were developed for fairly narrow and limited problem-solving domains, such as middleware to deal with numerical analysis, customized data access grids, and other narrow problems. Today, with the emergence and convergence of grid service-oriented technologies,[3] including the interoperable XML[4]-based solutions becoming ever more present and industry providers with a number of reusable grid middleware solutions facilitating the following requirement areas, it is becoming simpler to quickly deploy valuable solutions. Figure 1.4 shows this topology of middleware topics.

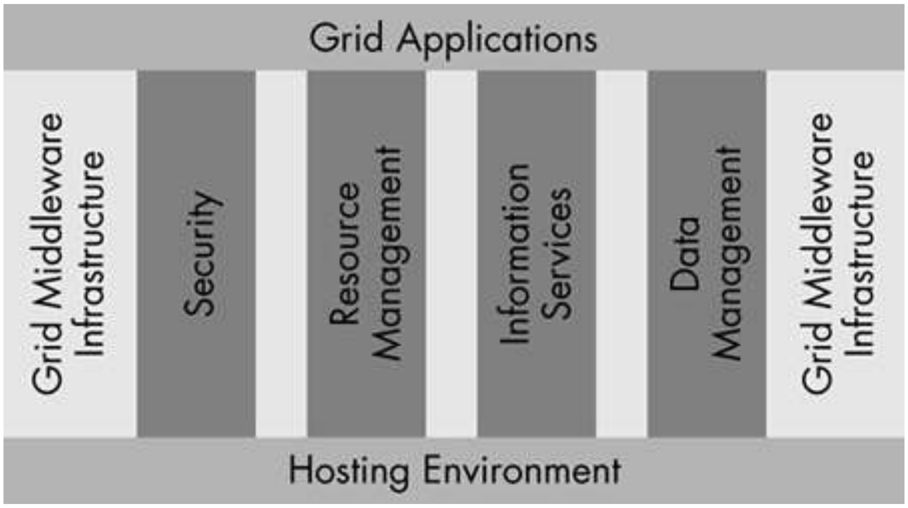


Figure 1.4. Grid middleware topic areas are becoming more sophisticated at an aggressive rate.

In general, a Grid Computing infrastructure component must address several potentially complicated areas in many stages of the implementation. These areas are:

- Security
- Resource management
- Information services
- Data management

Let us further examine the significance of each of these above components.

Security

The heterogeneous nature of resources and their differing security policies are complicated and complex in the security schemes of a Grid Computing environment. These computing resources are hosted in differing security domains and heterogeneous platforms. Simply speaking, our middleware solutions must address local security integration, secure identity mapping, secure access/authentication, secure federation, and trust management.

The other security requirements are often centered on the topics of data integrity, confidentiality, and information privacy. The Grid Computing data exchange must be protected using secure communication channels, including *SSL*/TLS and oftentimes in combination with secure message exchange mechanisms such as WS-Security. The most notable security infrastructure used for securing grid is the Grid Security Infrastructure (*GSI*). In most cases, *GSI* provides capabilities for single sign-on, heterogeneous platform integration and secure resource access/authentication.

The latest and most notable security solution is the use of WS-Security standards. This mechanism provides message-level, end-to-end security needed for complex and interoperable secure solutions. In the coming years we will see a number of secure grid environments using a combination of *GSI* and WS-Security mechanisms for secure message exchanges. We will discuss the details of security mechanisms provided by these standards later in this book.

Resource Management

The tremendously large number and the heterogeneous potential of Grid Computing resources causes the resource management challenge to be a significant effort topic in Grid Computing environments. These resource management scenarios often include resource discovery, resource inventories, fault isolation, resource provisioning, resource monitoring, a variety of autonomic capabilities,[5] and service-level management activities. The most interesting aspect of the resource management area is the selection of the correct resource from the grid resource pool, based on the service-level requirements, and then to efficiently provision them to facilitate user needs.

Let us explore an example of a job management system, where the resource management feature identifies the job, allocates the suitable resources for the execution of the job, partitions the job if necessary, and provides feedback to the user on job status. This job scheduling process includes moving the data needed for various computations to the appropriate Grid Computing resources, and mechanisms for dispatching the job results.

It is important to understand multiple service providers can host Grid Computing resources across many domains, such as security, management, networking services, and application functionalities. Operational and application resources may also be hosted on different hardware and software platforms. In addition to this complexity, Grid Computing middleware must provide efficient monitoring of resources to collect the required matrices on utilization, availability, and other information.

One causal impact of this fact is (as an example) the security and the ability for the grid service provider to reach out and probe into other service provider domains in order to obtain and reason about key operational information (i.e., to reach across a service provider environment to ascertain firewall and router volume-related specifics, or networking switch status, or application server status). This oftentimes becomes complicated across several dimensions, and has to be resolved by a meeting-of-the-minds between all service providers, such as messaging necessary information to all providers, when and where it is required.

Another valuable and very critical feature across the Grid Computing infrastructure is found in the area of provisioning; that is, to provide autonomic capabilities for self-management, self-diagnosis, self-healing, and self-configuring. The most notable resource management middleware solution is the Grid Resource Allocation Manager (GRAM). This resource provides a robust job management service for users, which includes job allocation, status management, data distribution, and start/stop jobs.

Information Services

Information services are fundamentally concentrated on providing valuable information respective to the Grid Computing infrastructure resources. These services leverage and entirely depend on the providers of information such as resource availability, capacity, and utilization, just to name a few. This information is valuable and mandatory feedback respective to the resources managers discussed earlier in this chapter. These information services enable service providers to most efficiently allocate resources for the variety of very specific tasks related to the Grid Computing infrastructure solution.

In addition, developers and providers can also construct grid solutions to reflect portals, and utilize meta-schedulers and meta-resource managers. These metrics are helpful in service-level management (*SLA*) in conjunction with the resource policies. This information is resource specific and is provided based on the schema pertaining to that resource. We may need higher level indexing services or data aggregators and transformers to convert these resource-specific data into valuable information sources for the end user.

For example, a resource may provide operating system information, while yet another resource might provide information on hardware configuration, and we can then group this resource information, reason with it, and then suggest a "best" price combination on selecting the operating system on other certain hardware. This combinatorial approach to reasoning is very straightforward in a Grid Computing infrastructure, simply due to the fact that all key resources are shared, as is the information correlated respective to the resources.

Data Management

Data forms the single most important asset in a Grid Computing system. This data may be input into the resource, and the results from the resource on the execution of a specific task. If the infrastructure is not designed properly, the data movement in a geographically distributed system can quickly cause scalability problems. It is well understood that the data must be near to the computation where it is used. This data movement in any Grid Computing environment requires absolutely secure data transfers, both to and from the respective resources. The current advances surrounding data management are tightly focusing on virtualized data storage mechanisms, such as storage area networks (*SAN*), network file systems, dedicated storage servers, and virtual databases. These virtualization mechanisms in data storage solutions and common access mechanisms (e.g., relational SQLs, Web services, etc.) help developers and providers to design data management concepts into the Grid Computing infrastructure with much more flexibility than traditional approaches.

Some of the considerations developers and providers must factor into decisions are related to selecting the most appropriate data management mechanism for Grid Computing infrastructures. This includes the size of the data repositories, resource geographical distribution, security requirements, schemes for replication and caching facilities, and the underlying technologies utilized for storage and data access.

So far in this introductory chapter we have been discussing the details surrounding many aspects of the middleware framework requirements, specifically the emergence of service provider-oriented architectures[6] and, hence, the open and extremely powerful utility value of *XML*-based interoperable messages. These combined, provide a wide range of capabilities that deal with interoperability problems, and come up with a solution that is suitable for the dynamic virtual organizational grids. The most important activity noted today in this area is the Open Grid Service Architecture (*OGSA*) and its surrounding standard initiatives. Significant detail is recorded on this architecture, and will be given full treatment in subsequent chapters in this book. The *OGSA* provides a common interface solution to grid services, and all the information has been conveniently encoded using *XML* as the standard. This provides a common approach to information services and resource management for Grid Computing infrastructures.

This introductory chapter has discussed many of the chapters and some of their detail that will be presented throughout this book. This introductory discussion has been presented at a high level, and more detailed discussions with simple-to-understand graphics will follow.

Conclusion

So far we have been describing and walking through overview discussion topics on the Grid Computing discipline that will be discussed further throughout this book, including the Grid Computing evolution, the applications, and the infrastructure requirements for any grid environment.

In addition to this, we have discussed when one should use Grid Computing disciplines, and the factors developers and providers must consider in the implementation phases. With this introduction we can now explore deeper into the various aspects of a Grid Computing system, its evolution across the industries, and the current architectural efforts underway throughout the world.

The proceeding chapters in this book introduce the reader to this new, evolutionary era of Grid Computing, in a concise, hard-hitting, and easy-to-understand manner.

UNIT – II

GRID COMPUTING ORGANIZATIONS AND THEIR ROLES

Grid Computing organizations and their roles can be broadly classified into four categories based on their functional role in Grid Computing.

- Organizations developing grid standards and best practices guidelines.
- Organizations developing Grid Computing toolkits, framework, and middleware solutions
- Organization building and using grid-based solutions to solve their computing, data, and network requirements.
- Organizations working to adopt concepts into commercial products, via utility computing, and Business On Demand Computing.

The basic classifications o Grid Computing Organizations:

There are many organizations in the world striving to achieve new and innovative Grid Computing environments. The IBM Corporation is a leader in the pursuit of Business On Demand Grid Computing environments and the corporation itself has enabled a global Business On Demand environment. IBM is, today, working with a large number of global customers in the same endeavour.

Organizations Developing Grid Standards and Best Practice Guidelines

These organizations are responsible for refining the grid standardization process and defining the best practice guidelines for the scientific and industry usage of grid.

The most prominent among such organizations is Global Grid Forum (GGF). There are other standards organizations working closely with GGF in this process, including OASIS (Organization for the Advancement of Structured Information Standards), W3C (World Wide Web Consortium), IETF (the Internet Engineering Task Force), and DMTF (the Distributed Management Task Force). [2] GGF is mainly working in the Grid arena while others have more broad-based programs covering other parts of the computing industry such as network, resource, business, and Internet standards. For example, W3C is working on the standardization of Web and Web- related technologies, including Web services, eXtensible Markup Language (XML), and Semantic Web. GGF is working closely with these organizations in defining the grid standards aligned with the other open standard processes and providing inputs and requirements to other standards organizations.

Global Grid Forum (GGF)

GGF enables a means of coordinating Grid Computing technology efforts, promoting reuse and interoperability, and sharing the results. As of now, there are more than 400 organizations involved with GGF from around the world. This includes scientific research institutions, universities, and commercial organizations.

The GGF's primary objective is to promote and support development, deployment, and implementation of grid technologies and applications via creation and documentation of best practices ”specifications, use cases, architecture, and implementation guidelines.

The basic goals of the GGF are to:

- Create an open process for the development of grid agreements and specifications
- Create grid specifications, architecture documents, and best practice guidelines
- Manage and version controls the documents and specifications
- Handle intellectual property policies
- Provide a forum for information exchange and collaboration
- Improve collaboration among the people involved with grid research, grid framework builders, grid deployment, and grid users
- Create best practice guidelines from the experience of the technologies associated with Grid Computing
- Educate on advances in the grid technologies and share experiences among the people of interest

The organization consists of different work areas, with research groups and work groups for each area. The work groups are the main activity centers of the GGF. These work groups are created to address a research, implementation, and operational area related to the infrastructure for building any "grid."

The major work areas of the GGF are as follows :

- Application and programming environments
- Architecture
- Data
- Information systems and performance
- Peer-to-peer: Desktop grids
- Scheduling and resource management
- Security

As of today, one of the major activities in GGF that is attracting the grid community is the architecture model based on the open standard Web service architecture, called Open Grid Service Architecture (OGSA).

ORGANIZATIONS DEVELOPING GRID COMPUPTING TOOLKIT AND THE FRAMEWORK:

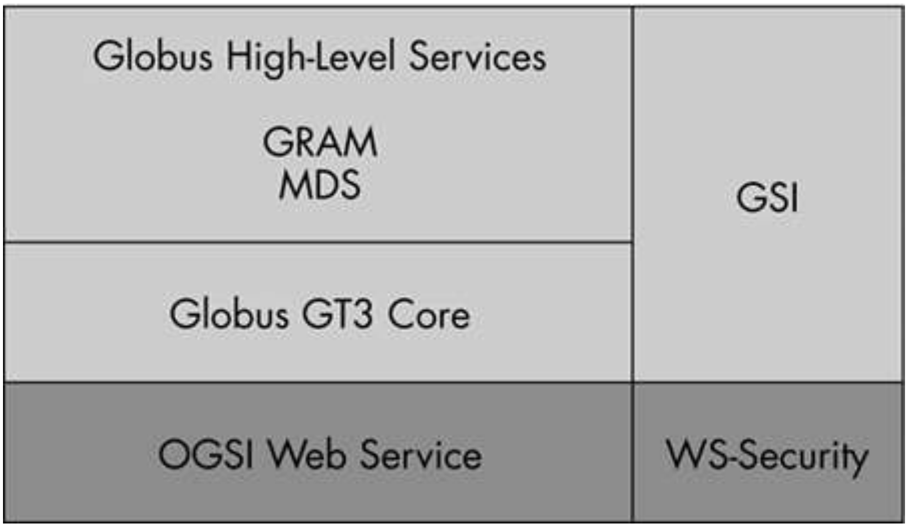
To achieve a successful adoption of Grid Computing requires an adequate infrastructure, security services, key services, applications, and portals. Let us now explore and identify some of the most prominent organizations responsible for the toolkits, middleware, and framework for Grid Computing.

Globus

The Globus [4] project is a multi-institutional research effort to create a basic infrastructure and high-level services for a computational grid. A computational grid is defined as hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities (Foster & Kesselman, 1998). They have now evolved into an infrastructure for resource sharing (hardware, software, applications, and so on) among heterogeneous virtual organizations. These grids enable high creativity by increasing the average and peak computational performance available to important applications regardless of the spatial distribution of both resources and users.

The details on Globus infrastructure provided in Figure 2.3 are based on the latest release from Globus called Globus GT3. Globus provides layered software architecture with a low-level infrastructure to host high-level services defined for grid. These high-level services are related to resource discovery, allocation, monitoring, management, security, data management, and access. The lower layer infrastructure (GT3 Core) provides a framework to host the high-level services.

Figure: Globus GT3 middleware, core, and high-level services present a wide variety of capabilities.



Some of the core high-level services included with the existing Globus toolkit are found in the following discussion.

Globus Resource Allocation Manager (GRAM)

GRAM provides resource allocation, process creation, monitoring, and management services. GRAM simplifies the use of remote systems by providing a single standard interface for requesting and using remote system resources for the execution of "jobs." The most common use of GRAM is the remote job submission and control facility. However, GRAM does not provide job scheduling or resource brokering capabilities. We could see that the job scheduling facilities are normally provided by the local system. GRAM uses a high-level Resource Specification Language (RSL) to specify the commands and maps them to the local schedulers and computers.

Grid Security Infrastructure (GSI)

GSI provides a single-sign-on, run anywhere authentication service with support for local control over access rights and mapping from global to local user identities. While keeping the existing GSI mechanisms, the current GSI3 standard is in alignment with the Web service security standards by defining a GSI profile for WS-Security. [5]

Information Services

A GT3 Information service provides information about grid resources, for use in resource discovery, selection, and optimization.

The Monitoring and Discovery Service (MDS) is an extensible grid information service that combines data discovery mechanisms with the Lightweight Directory Access Protocol (LDAP). The MDS provides a uniform framework for providing and accessing system configuration and status information such as computer server configuration, network status, or the locations of replicated datasets. The current GT3 framework merges the MDS with the XML data framework for better integration with existing Web services and OGSA.

The latest Globus Toolkit (GT3) is a java implementation of the OGSI specification. The discussion on the architecture and programming model of the GT3 infrastructure software and the details on the high-level services are deferred to the last section of this book.

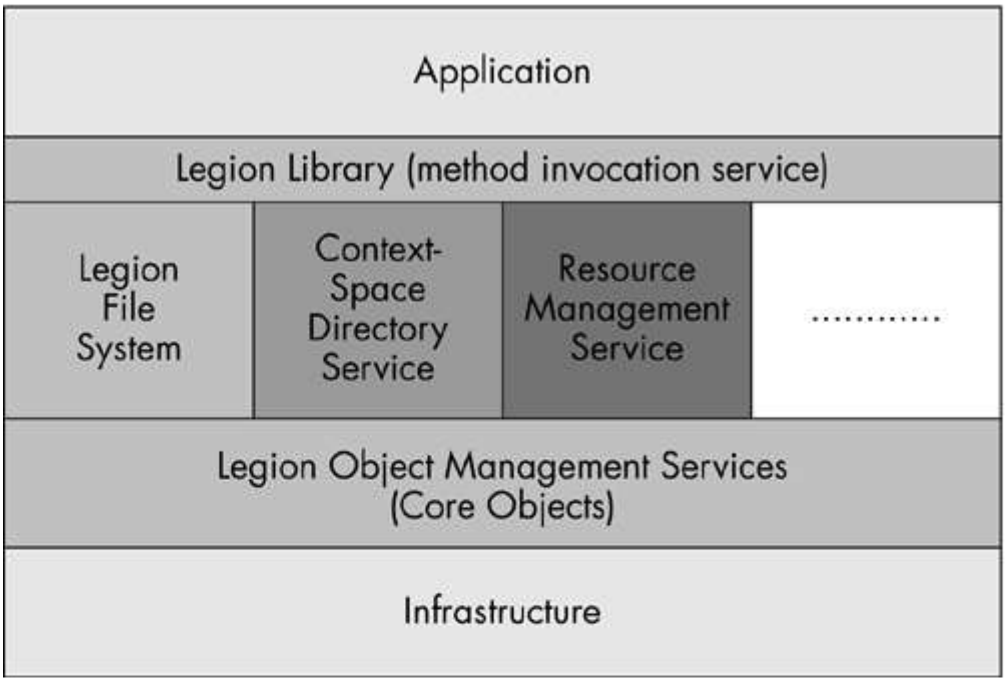
Legion

Legion, a middleware project initiated by the University of Virginia, is object-based metasystems software for grid applications. The goal of the Legion project is to promote the principled design of distributed system software by providing standard object representations for processors, data systems, file systems, and so on. Legion applications are developed in terms of these standard objects. Groups of users can construct a shared virtual workspace to collaborate on research and exchange information.

Figure shows the architecture of a Legion system. Legion sits on top of the user's operating system and acts as mediator between its own host(s) and other required resources.

Legion's scheduling and security policies act on behalf of the user in undertaking time-consuming negotiations with outside systems and system administrators. To allow users to take advantage of a wide range of possible resources, Legion offers a user-controlled naming system called context space , so that users can easily create and use objects in distributed systems.

Figure Legion application architecture.



An Interface Definition Language (IDL) is defined to describe the method signatures (name , parameter, and return values) supported by the object interface. We could see that these objects provide a scalable persistence mechanism by storing the inactive objects (objects in "inert" state) to the secondary storage.

Some of the important characteristics of Legion systems are summarized below.

Everything is an object

In a Legion system, Legion Object represents a variety of hardware and software resources, which respond to member function invocations from other objects in the system. Legion defines the message format and high-level protocol for object interaction (through IDL), but not the programming language or the communications protocol.

Classes manage their own instances

Every Legion object is defined and managed by its class object. Class objects are given system-level responsibility; classes create new instances, schedule them for execution, activate and deactivate them, and provide information about their current location to client objects. These classes whose instances are themselves classes are called metaclasses .

Users can provide their own classes

Legion allows its users to define and build their own "class" objects. This enables the Legion programmers to have a flexible architecture model for their "metaclasses" with the capabilities to determine and even change the system-level mechanisms of their objects.

Core objects implement common services

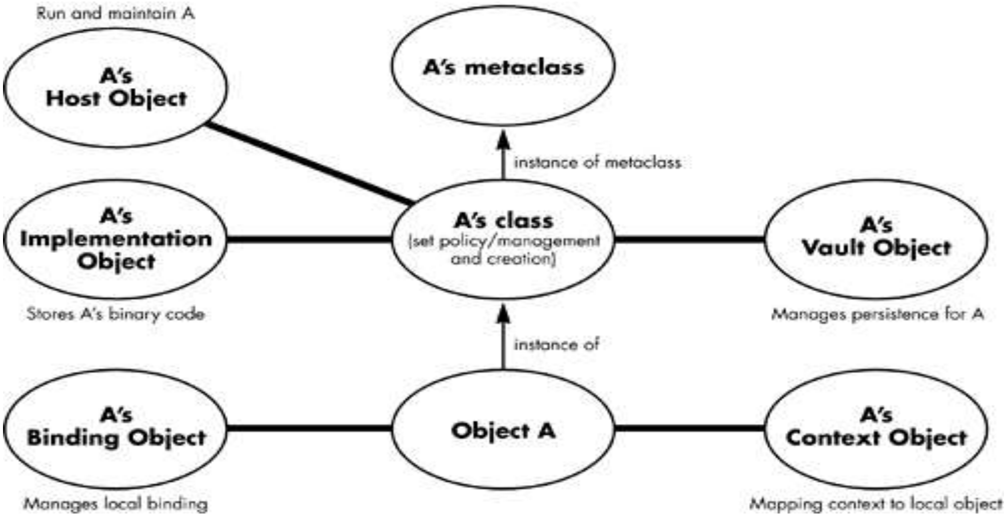
Legion defines the interface and basic functionality of a set of core object types that support basic system services, such as naming, binding, object creation, activation, deactivation , and deletion.

Some of the core objects defined by the Legion system are:

- Host objects : Abstractions of processing resources which may represent a single processor or multiple hosts and processors
- Vault objects : Provide persistent storage for scalable persistence of the objects
- Binding object : Maps the object IDs to the physical addresses
- Implementation objects : Allow legion objects to run as processes in the systemand contain a machine code that is executed on a request to create the object or activate it.

Figure shows Legion object A with its class object (metaclass) and the corresponding basic system services.

Figure . Legion core object and relationship.



In 1997, the first Legion toolkit was released, and in the following year, Applied Metacomputing (later relaunched as Avaki Corporation) was established to exploit the toolkit for commercial purposes.

Condor and Condor-G

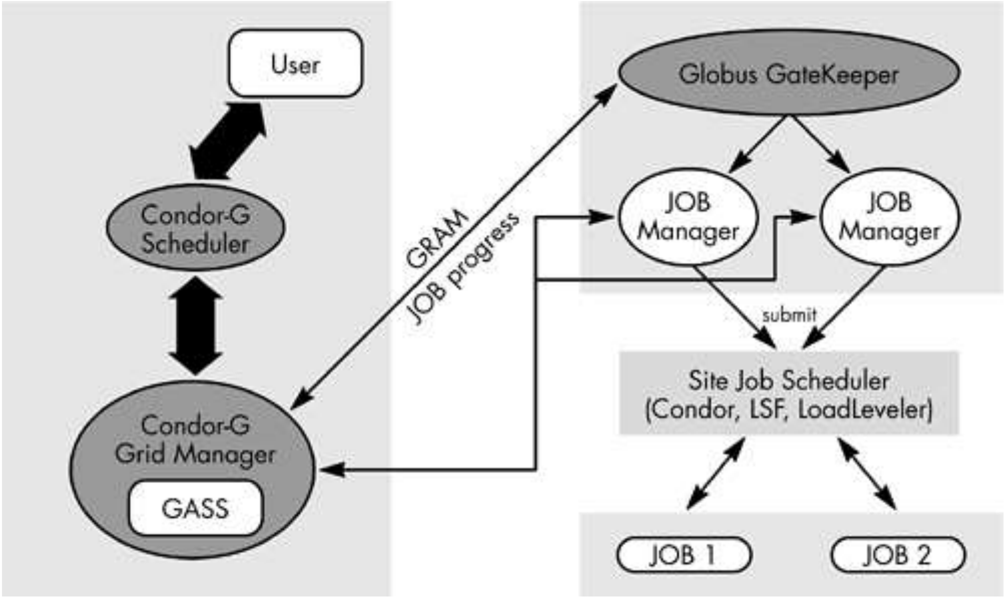
Condor is a tool for harnessing the capacity of idle workstations for computational tasks . Condor is well suited for parameter studies and high throughput computing, where jobs generally do not need to communicate with each other.

We can classify Condor as a specialized workload management system for computation- intensive jobs. Like other full-featured batch systems, Condor provides a job queuing mechanism, scheduling policy, priority scheme, resource monitoring, and resource management. Upon receiving serial or parallel jobs from the user, the Condor system places them into a queue, chooses when and where to run the jobs based upon a policy, carefully monitors their progress, and ultimately informs the user upon completion.

We can make use of Condor to manage a cluster of dedicated compute nodes. It is suitable for effectively harnessing the CPU power from idle workstations. Condor has mechanisms for matching resource requests (jobs) with resource offers (machines).

While Condor software tools focus on harnessing the power of opportunistic and dedicated resources, Condor-G is a derivative software system, which leverages the software from Condor and Globus with major focus on the job management services for grid applications. This is a combination of interdomain resource management protocols of Globus (GRAM, Index Services) with the intradomain resource management methods of Condor. Figure 2.6 shows a sample usage of Condor-G in combination with Globus. As shown, Condor-G contains a GASS Server, which is used to transfer jobs to and from the execution center. The Condor-G Grid manager uses GRAM to get the Job progress information from Globus Gate Keeper.

Figure : Remote execution of Condor-G on Globus-managed resource using Globus Job manager.



Condor software is used by both scientific and commercial organizations. The major scientific initiative that uses Condor includes NSF Middleware Initiative (NMI), Grid Physics Network (GriPhyN), International Virtual Data Grid laboratory (iVDGL), TerraGrid, and so on. Some of the prominent commercial uses of condor software involve solving computational Grid Computing problems, as done by Micron Technologies, CORE Digital Pictures, and NUG30 Optimization Problem Solver.

Nimrod

Nimrod provides a user interface for describing the "parameter sweep" problems, with resulting independent jobs being submitted to a resource management system.

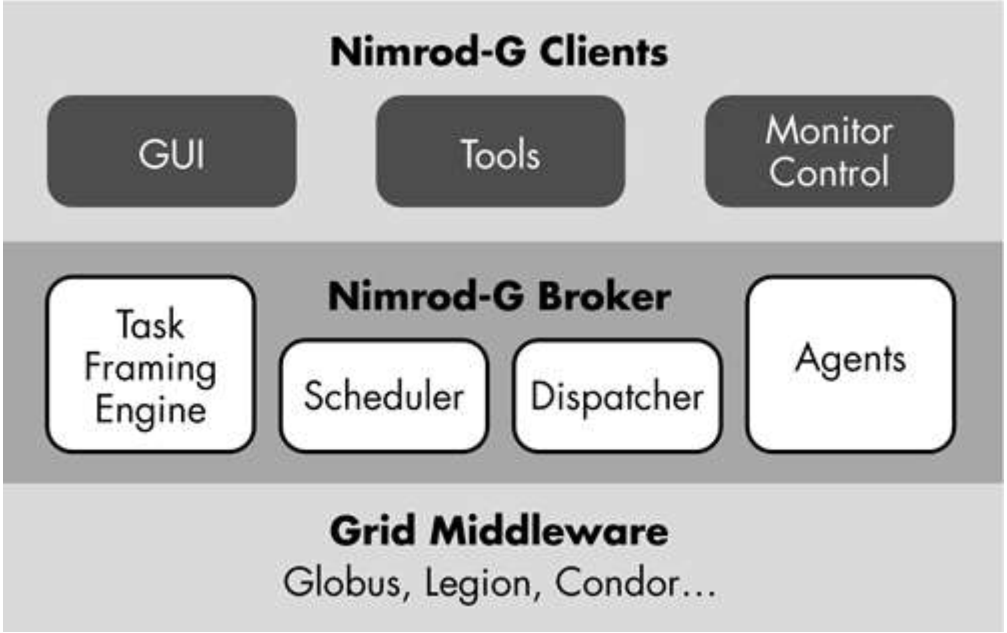
Nimrod-G is a derivative software system, which harnesses the software from Nimrod and Globus to harness multi-domain resources as if they all belong to the one personal domain. It provides a simple declarative parametric language for expressing the parameters for execution. This system exposes novel resource management and job scheduling algorithms based on the economic principles of computing. Such a set of resource trading services is called GRACE (Grid Architecture for Computational Economy). GRACE provides mechanisms to negotiate on the QoS parameters, deadlines, and computational costs. In addition, it offers incentive for relaxing requirements. We could see that depending on users' QoS requirements, these resource brokers dynamically lease Grid services at runtime depending on their cost, quality, and availability.

Leveraging the services provided by grid middleware systems develops the Nimrod-G toolkit and resource broker. These middleware systems include Globus, Legion, GRACE, and so forth.

As illustrated in Figure the Nimrod architecture defines the following components :

1. **Nimrod-G clients , which can provide tools for creating parameter sweep applications, steering and control monitors, and customized end-user applications and GUIs**
2. The Nimrod-G resource broker, which consists of a Task farming engine (TFE), a scheduler that performs resource discovery, trading and scheduling features, a dispatcher and actuator, and agents for managing the jobs on the resource

Figure Architecture of Nimrod-G.



It is important to note that the Nimrod-G broker provides its services by leveraging the grid middleware systems including Globus, Legion, Condor, and so on.

As we have previously discussed, the core feature of the Nimrod-G toolkit is the support for user-defined deadlines. For example: "Get this simulation done in 10 minutes with a budget of USD $200." Also, budget constraint for scheduling optimizations is a part of the core features.

Nimrod-G facilitates the execution of the user requirement by managing supply and demand of resources in the grid using a set of resource trading services.

The most important scheduling algorithms used in Nimrod-G are:

- Cost optimization ” uses the cheapest resource
- Time optimizations ” results in parallel execution of the job
- Cost-time optimization ” similar to cost optimization but if there are multiple jobs with the same cost, then the time factor is taken into consideration
- Conservative time strategy ” similar to time optimization, but guarantees that each unprocessed job has a minimum budget per job

Parametric Computational Experiments

Parametric computational experiments are becoming increasingly important in science and engineering as a means of exploring the behavior of complex systems. For example, a flight engineer may explore the behavior of a wing by running a computational model of the airfoil multiple times while varying key parameters such as angle of attack, air speed, and so on.

The results of these multiple experiments yield a picture of how the wing behaves in different parts of parametric space.

Many practitioners of Grid Computing believe that economic policy/criteria-driven Grid Computing, as depicted by Nimrod-G, is a major interest to the utility computing world.

UNICORE (UNiform Interface to COmputer REsource)

The UNICORE project is funded by the German Ministry of Education and Research with the design goal including a uniform and easy-access graphical user interface (GUI), open architecture based on the concept of an abstract job, a consistent security architecture, minimal interface with local administrative procedures, and exploitation of the existing and emerging technologies including Web and Java.

UNICOREpro was produced within the UNICORE to provide a uniform interface for job preparation and secure submission of the job similar to a portal. This enables users to create workflow for job execution and control execution behaviors. This is an open source project developed using Java technology. The UNICOREpro server provides capabilities for authorization, job management, data transfer, and batch interface.

A project called GRIP (GRid Interoperability Project) was started in 2002 to achieve the interoperability between UNICORE and Globus. The EUROGRID software is based on the UNICORE system developed and used by the leading German HPC centers.

NSF Middleware Initiative (NMI)

NMI was created by the National Science Foundation (NSF) to help scientists and researchers use the Internet to effectively share instruments, laboratories, and data and to collaborate with each other. Middleware is software that connects two or more otherwise separate applications across the Internet or local area networks.

Middleware makes resource sharing seem transparent to the end user, providing capabilities, consistency, security, and privacy.

NMI consists of two teams :

Grid Research Integration Deployment and Support (GRIDS) Center. The GRIDS [11] center is responsible for defining, developing, deploying, and supporting an integrated and stable middleware infrastructure created from a number of open source grid and other distributed computing technology frameworks. It intends to support 21st-century science and engineering applications by working closely with a number of universities and research organizations.

Some of the open source packages included in this middleware are Globus Toolkit, Condor-G, GSI-OpenSSH, Network Weather service, Grid Packaging Tools, GridConfig, MPICH-G2, MyProxy, and so on.

Enterprise and Desktop Integration Technologies (EDIT) Consortium. EDIT develops tools, practices, and architectures to leverage campus infrastructures to facilitate multi-institutional collaboration.

EDIT provides software to support a wider variety of desktop security, video, and enterprise uses with a directory schema. This facilitates the federated model of directory-enabled interrealm authentication and authorization. In addition, they are responsible for conventions and best practice guidelines, architecture documents, policies, and to provide services to manage the middleware. Some of the open sources packages included in this middleware are: LDAP Operational ORCA Kollector (LOOK), Privilege and Role Management Infrastructure Standards Validation (PERMIS), openSAMIL, and others.

The latest release (Release 3) of the NMI middleware consists of 16 software packages. The above two teams of the NMI is creating production-quality middleware using open-source and open-standards approaches. They continue to refine processes for team-based software development, documentation, and technical support. The software packages included in the NMI solution have been tested and debugged by NMI team members , so that various users, campuses, and institutions can easily deploy them. In addition, it helps to facilitate directory-enabled (LDAP) sharing and exchanging of information to support authentication and authorization among campuses and institutions.

The aforementioned best practices and policy deliverables have been reviewed and deployed by leading campuses and institutions. Some of the major initiatives using this middleware suite include NEESgrid (Network for Earthquake Engineering Simulation), GriPhyN, and the iVDGL.

ORGANIZATIONS BUILDING AND USING GRID-BASED SOLUTIONS TO SOLVE COMPUTING, DATA, AND NETWORK REQUIREMENTS

These organizations and individuals are the real users of Grid Computing. They are benefiting from resource sharing and virtualization. As of now these projects are mostly in the scientific areas. We will be discussing some of the major grid projects and infrastructures around the world. In general, these grid users need:

- On-demand construction of virtual computing system with the capabilities to solve the problems at hand including scarcity of computing power, data storage, and real-time processing
- A provision for collaborative visualization of the results of the above process
- A dynamic construction of virtual organizations to solve certain specific problems at hand

United States Department of Energy: Science Grid (DOE)

The DOE Science Grid aims to provide an advanced distributed computing infrastructure based on Grid Computing middleware and tools to enable a high degree of scalability in scientific computing. The vision is to revolutionize the use of computing in science by making the construction and use of large-scale systems of diverse resources as easy as using today's desktop environments.

The following describes characteristics of DOE:

- Most of the DOE projects are widely distributed among collaborators and non-collaborators. It requires a cyberinfrastructure that supports the process of distributed science with sharable resources including expensive and complex scientific instruments.
- All of the science areas need high-speed networks and advanced middleware to discover, manage, and access computing and storage systems.

The DOE Science Grid is an integrated and advanced infrastructure that delivers:

- Computing capacity adequate for the tasks in hand
- Data capacity sufficient for scientific tasks with location independence and manageability
- Communication power sufficient for the above tasks
- Software services with rich environments that let scientists focus on the science simulation and analysis aspects rather than on management of computing, data, and communication resources

The construction of grids across five major DOE facilities provides the computing and data resources. To date major accomplishments include the following:

- Integration of DOE's Office of Science supercomputing center providing large-scale storage systems into the grid
- Design and deployment of a grid security infrastructure for collaboration with U.S. and European High Energy Physics projects, helping to create a single-sign-on solution within the grid environment

The following work is used by the DOE's Particle Physics Data Grid, Earth Systems Grid, and Fusion Grid projects:

- A resource monitoring and debugging infrastructure for managing these widely distributed resources
- Several DOE applications use this grid infrastructure including computational chemistry , ground water transport, climate modeling, bio informatics, and so on.

European Union: EUROGRID Project

The EUROGRID project is a shared-cost Research and Technology Development project (RTD) granted by the European Commission, with the participation of 11 partners and 6 European Union countries , in order to create an international network of high performance computing centers. This project will demonstrate the use of GRIDs in selected scientific and industrial communities in order to address the specific requirements of these communities, and highlight the benefits of using GRIDs.

The major objectives of the EUROGRID project are:

- To establish a European GRID network of leading high performance computing centers from different European countries
- To operate and support the EUROGRID software infrastructure
- To develop important GRID software components and to integrate them into EUROGRID (fast file transfer, resource broker, interface for coupled applications, and interactive access)

- To demonstrate distributed simulation codes from different application areas (biomolecular simulations, weather prediction, coupled CAE simulations, structural analysis, real-time data processing, etc.)
- To contribute to the international GRID development and work with the leading international GRID projects

The application-specific work packages identified for the EUROGRID project are described in the following areas:

Bio Grid. The BioGRID project develops interfaces to enable chemists and biologists to submit work to high performance center facilities via a uniform interface from their workstations, without having to worry about the details of how to run particular packages on different architectures.

Metro Grid. The main goal of the Metro Grid project is the development of an application service provider (ASP) solution, which allows anyone to run a high resolution numerical weather prediction model on demand.

Computer-Aided Engineering (CAE) Grid. This work project focuses on industrial CAE applications including automobile and aerospace industries. It aims at providing services to high performance computing (HPC) customers who require huge computing power to solve their engineering problems.

The major partners in this work package are Debis SystemHaus and EADS Corporate Research Center. They are working to exploit the CAE features like code coupling (to improve system design by reducing the prototyping and testing costs) and ASP-type services (designing application-specific user interfaces for job submission).

High Performance Center (HPC) Research Grid. This HPC research grid is used as a test-bed for the development of distributed applications, and as an arena for cooperative work among major scientific challenges, using computational resources distributed on a European scale. The major partners in this work-package are the HPC centers.

The EUROGRID software is based on the UNICORE system developed and used by the leading German HPC centers.

European Union: Data Grid Project

DataGrid is a project funded by the European Union that aims to enable access to geographically distributed computing power and storage facilities belonging to different institutions. This will provide the necessary resources to process huge amounts of data coming from scientific experiments in different disciplines.

The three real data- intensive computing applications areas covered by the project are:

- High Energy Physics
- Biology and Medical Image Processing
- Earth Observations

High Energy Physics (led by CERN, Switzerland)

One of the main challenges for High Energy Physics is to answer longstanding questions about the fundamental particles of matter and the forces acting between them. In particular, the goal is to explain why some particles are much heavier than others, and why particles have mass at all . To that end, CERN is building the Large Hadron Collider (LHS) , one of the most powerful particle accelerators.

The search on LHS will generate huge amounts of data. The DataGrid Project is providing the solution for storing and processing this data. A multitiered, hierarchical computing model will be adopted to share data and computing power among multiple institutions. The Tier-0 center is located at CERN and is linked by high-speed networks to approximately 10 major Tier-1 data-processing centers. These will fan out the data to a large number of smaller ones .

Biology and Medical Image Processing (led by CNRS, France)

The storage and exploitation of genomes and the huge flux of data coming from post-genomics puts growing pressure on computing and storage resources within existing physical laboratories. Medical images are currently distributed over medical image production sites (radiology departments, hospitals).

Although there is a need today, as there is no standard for sharing data between sites, there is an increasing need for remote medical data access and processing.

The DataGrid project's biology test-bed is providing the platform for the development of new algorithms on data mining, databases, code management, and graphical interface tools. It is facilitating the sharing of genomic and medical imaging databases for the benefit of international cooperation and health care.

Earth Observations (led by ESA/ESRIN, Italy)

The European Space Agency missions download 100 gigabytes of raw images per day from space. Dedicated ground infrastructures have been set up to handle the data produced by instruments onboard the satellites . The analysis of atmospheric ozone data has been selected as a specific test-bed for the DataGrid. Moreover, the project will demonstrate an improved way to access and process large volumes of data stored in distributed European-wide archives.

TeraGrid

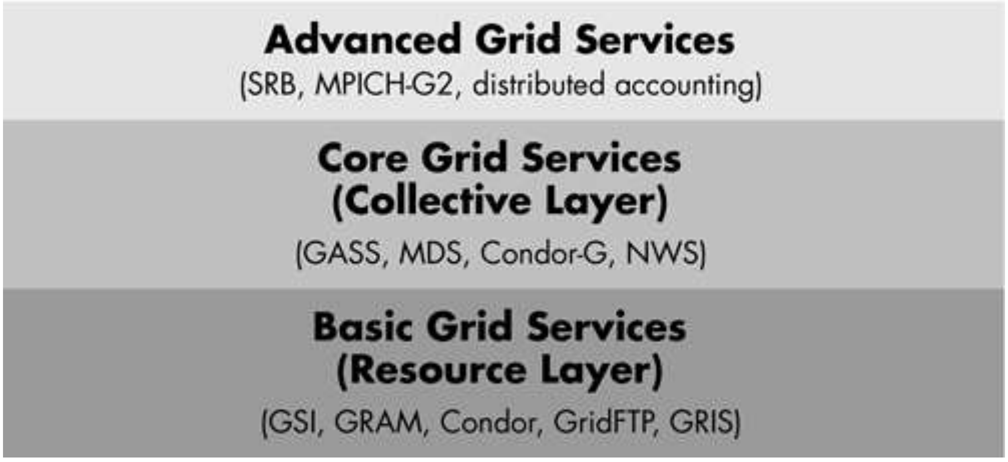
The TeraGrid project was first launched by the NSF and was a multiyear effort to build and deploy the world's largest, fastest distributed infrastructure for open scientific research. The TeraGrid includes 20 teraflops of computing power distributed at five sites, facilities capable of managing and storing nearly 1 petabyte of data, high-resolution visualization environments, and toolkits for Grid Computing. These components will be tightly integrated and connected through a network that will operate at 40 gigabits per second ”this is the fastest research network on the planet today.

The major objective of this project includes creation of a high-speed network; grid services that provide data sharing, computing power, and collaborative visualization; and to provide facilities that create the technology requirements (e.g., data storage, bandwidth, etc.).

The five sites in the project are:

- National Center for Supercomputing Applications (NCSA) at the University of Illinois
- San Diego Supercomputer Center (SDSC) at the University of California
- Argonne National Laboratory in Argonne, Illinois
- Center for Advanced Computing Research (CACR) at the California Institute of Technology in Pasadena
- Pittsburgh Supercomputer Center (PSC)

The TeraGrid project is sometimes called a "cyberinfrastructure" that brings together distributed scientific instruments, terascale and petascale data archives, and gigabit networks. Figure shows different layers of the TeraGrid architecture.



Base Grid Services Layer (Resource Layer)

Some of the base services required for the TeraGrid are authentication and access management, resource allocation and management, data access and management, resource information service, and accounting. This layer forms the building block for the other high-level services.

Core Grid Services (Collective Layer)

With a main focus on coordination of multiple resources, core grid services include functionalities for data movement, job scheduling, monitoring, and resource discovery.

Advanced Grid Services

These are high-level application services, which provide super schedulers , repositories, categorization, resource discovery, and distributed accounting.

Based on the above architecture, the TeraGrid is defining protocols, schema, and interfaces at each layer of the above architecture but not implementation-specific details. These interfaces provide interoperability between the sites implementing the TeraGrid project.

NASA Information Power Grid (IPG)

NASA's Information Power Grid [18] (IPG) is a high-performance computational and data grid. Grid users can access widely distributed heterogeneous resources from any location, with IPG middleware adding security, uniformity , and control.

Some of the major projects undertaken by IPG are:

Resource Broker

A grid user has to make a resource selection from a large number and variety of resources that they could use for an application. For each potential resource, the resource selection system considers the following factors:

- Computer system characteristics, such as amount of memory, amount of disk space, CPU speed, number of CPUs, type of operating system, available software, and so on
- The time required for the execution of the job
- The cost to use that resource or computer system

Performance Prediction

There are several types of predictions that are useful when deciding where to run applications. These include job/application execution time on different computer systems, wait time in scheduling queues before the job begins executing, and the time to transfer files between computer systems.

Job Manager

Job Manager is used to reliably execute jobs and maintain information about jobs. These jobs consist of file operations (i.e., copy a file between machines, create a directory, delete a file or directory, and so on) and execution operations (i.e., execute an application on a specific computer system).

Portability Manager (PM)

Portability is a key issue with the grid environment and PM is responsible for the establishment of a suitable environment for the execution of the user application by automatically identifying the dependencies of each user program.

Framework for Control and Observation in Distributed Environments (CODE)

The CODE project provides a secure, scalable, and extensible framework for making observations on remote computer systems. It then transmits this observational data to where it is needed, performing actions on remote computer systems and analyzing observational data to determine what actions should be taken. Observational data is transmitted using a distributed event service.

Test and Monitoring Service

The IPG Test and Monitoring Service will provide a framework for examining the health of the grid, so that problems with, or degradation of, grid resources are promptly detected ; the appropriate organization, system administrator, or user is notified; and solutions are dispatched in a timely manner.

Dynamic Accounting System (DAS)

DAS provides the following enhanced categories of accounting functionality to the IPG community:

- Allows a grid user to request access to a local resource via the presentation of grid credentials
- Determines and grants the appropriate authorizations for a user to access a local resource without requiring a preexisting account on the resource to govern local authorizations
- Exchanges allocation data between sites to manage allocations in a grid-wide manner instead of a site-specific manner
- Provides resource pricing information on the grid
- Collects and reports the necessary data to ensure accountability of grid users for the use of resources and to enable resource providers to better manage their grid resources

CORBA-IPG Infrastructure

The CORBA-IPG infrastructure gives CORBA-enabled applications, such as object-oriented propulsion systems being developed at NASA Glenn Research Center, the ability to utilize the widely distributed resources made available by the NASA IPG.

COMMERCIAL ORGANIZATIONS BUILDING AND USING GRID-BASED SOLUTIONS

In the last couple of years we have seen a tremendous commercial interest in Grid Computing solutions. These commercial aspects are centered on the concept of resource sharing and resource virtualization principles.

Every computing resource including clusters, servers, blades, operating systems, and applications are viewed as utilities . The advancement of Grid Computing through the principles of open technologies, standard-based integration, and hardware and software technology maturity are behind these utility concepts.

The key strategy areas of grid applicability in the commercial world are utility computing, resource virtualization, and on-demand computing. Some of the prominent technologies helping the commercial organizations in their vision are:

- Advancement of service-oriented architectures, in particular Web services, enables organizations to start working on interoperable software solutions
- Hardware virtualizations capabilities including clusters, blades, and so forth
- Software capabilities in resource management and provisioning including policy-driven architectures to meet quality of service, usage and accounting measurements, and so on
- Autonomic computing principles enable high availability of resources

Some of the core concepts introduced by the major commercial organizations include Business On Demand solutions by IBM, the Utility computing and Data centers of HP, N1 technology initiative from Sun Microsystems, and Microsoft's '.Net' strategies. There are other organizations already playing a major role in Grid Computing infrastructure deployment. These participants include IBM Corporation, Avaki, Platform, and others.

The emerging Grid Computing technologies, especially the Open Grid Service Architecture (OGSA), is playing a major role in the standardization of the activities in the grid space.