The Vega Grid and Autonomous Decentralized Systems

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Abstract

In this paper, we compare the two research fields of grid computing and autonomous decentralized systems (ADS). We point out that these two fields are closely related at the basic research level, and have a lot to offer each other. A grid computing system can be viewed as an autonomous decentralized system in many aspects, and as such, it needs inputs from the ADS research community. At the same time, grid computing could provide a powerful tool for the study, implementation, simulation, and operation of other autonomous decentralized systems. Such inter-discipline work could be fruitful for research in both grid and ADS.

1. Introduction

Ever since Professor Kinji Mori proposed the concept of *Autonomous Decentralized Systems* (ADS) [6], we have witnessed the ADS technology growing and spreading into an active research area worldwide. IEEE now sponsors a bi-annual *International Symposium on Autonomous Decentralized Systems*, which will see its sixth meeting next year in Pisa, Italy.

Another research area, which has become quite active in recent years, is *Grid Computing* or simply *Grid* [3] [4]. This area has not only attracted significant research funding from public sectors, but also seen heavy involvement from big computer companies. A *Global Grid Forum* is established to work out industry standards (see www.gridforum.org), and an *International Journal on Grid Computing* is set up for publishing research articles.

A prevailing problem facing the world's Information Technology (IT) industry, as well as some other disciplines, is complexity. To realize interoperability and avoid duplication in development efforts, many enterprises and governmental agencies tried to consolidate their multiple islands of individual IT systems into a unified whole. In China (as well as in other parts of the world), many people advocate "unified planning, unified construction, and unified deployment". The reality is that such centralized, top-down efforts often failed. In contrast, there have been many cases of non-unified, seemingly autonomous "grass root" development projects, which blossomed.

ADS and grid both argue that maybe we should not use a centralized approach in developing distributed IT systems. The centralized methodology cannot handle the complexity of distributed systems, which, by their very nature, are autonomous and decentralized. Instead, we should try to build a large system by effectively integrating autonomous subsystems.

In this paper, we compare and contrast the two research fields of ADS and grid. In Section 2, we discuss the grid concept and present the basic concept of the *Vega Grid* developed at Institute of Computing Technology, Chinese Academy of Sciences. In Section 3, we discuss the relationship between grid and ADS. In section 4, we highlight several potentially fruitful research directions related to both grid computing and ADS. Section 5 offers some conclusion remarks.

2. Grid Computing and the Vega Grid

2.1 What is Grid?

Ian Foster et al [1] [2] [4] offered several definitions of grid: "A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities". Grid computing is concerned with "coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations (VO). … [A VO is] a set of individuals and/or institutions defined by [some highly controlled] sharing rules."

"A grid is a system that (1) coordinates resources that are not subject to centralized control, (2) using standard, open, general-purpose protocols and interfaces, (3) to deliver nontrivial qualities of service."

2.2 The Vega Grid Project [8] [9] [10] [11] [12]

The Vega Grid is a research project conducted at Institute of Computing Technology, Chinese Academy of Sciences. It aims to learning fundamental properties of grid computing, and developing key techniques that are essential for building grid systems and applications. The Vega Grid team currently consists of more than 100 people, and is conducting research work in the following areas:

- **Dawning 4000 Superservers**: Terascale grid enabling clusters on Linux/Intel and AIX/PowerPC platforms.
- **Vega Grid Software Platform**: This work includes research on grid system software, grid application development tools, and grid user interface. The objectives are to enable resource sharing, collaboration, service composition, and dynamic deployment, utilizing open standards such as OGSA, Globus and web services.
- **Vega Information Grid**: Research on enabling technology for information sharing, information management, and information services in an ASP environment or a wide-area enterprise environment.
- **Vega Knowledge Grid**: Research on knowledge sharing, knowledge management, and knowledge services in a wide area Web environment.

Central to the Vega Grid project is the *VEGA Service Grid* principle. The Service Grid concept abstracts three aspects of applications requirements: (1) The Vega Grid should enable user visible services, not just providing an infrastructure. (2) Service is the main mechanism for users to interact with grid. (3) The criteria used to evaluate grid functionality and performance should evolve from traditional criteria (e.g., speed and throughput) to service-oriented criteria, such as Service Level Agreement (SLA). To realize the service grid concept, the Vega Grid project follows the following VEGA principles:

- ***V****ersatile Services*. The grid should have the ability to support various services and resources, not just scientific computation. The Vega Grid project aims to satisfying the minimal common requirements of various grid applications.
- ***E****nabling Intelligence*. The grid should support intelligent computing, such as automatic production of information, knowledge and services. However, the grid itself is not the intelligence provider, but it provides enabling technology to assist developers and users to achieve intelligent grid applications.
- ***G****lobal Uniformity*. From the user's viewpoint, the grid can be viewed as a single virtual computer, supporting single system image (e.g., single sign-on). Heterogeneous resources among geographically distributed grid nodes should form a uniform, connected, inter-operable resource pool, instead of many islands.
- ***A****utonomous Control*. The grid should not be ruled by a central administration. All components can freely join or leave the grid at their own will. A resource provider has full control of its resource exported, and a user can use resources as he likes within the purview of his right.

2.3 The Vega Grid Architecture [9]

A three-layer architecture of the Vega Grid is illustrated in Figure 1. At the grid hardware layer, we are developing Dawning 4000 superservers, which are clusters with enabling technology to support grid platforms and applications. Other components at the grid hardware layer include a client device and a router. The *Vega Grid Client* is an easy to use client device for grid users. The *Vega Grid Router* enables application-level connectivity and allows resources to be efficiently deployed and discovered. The grid software platform layer includes grid system software and middleware, such as Globus, OGSA, web services, and other commercial grid software, as well as technologies developed by the Vega team. The application layer includes various application software servers, such as database servers, web servers, and business application servers. The Vega Grid adds two new components at this layer, one at the client side and one at the server side. The Vega Grid "Browser" is different from a traditional web browser, in that it allows users to write to and to operate the grid. The Vega Grid Server (the GSML server) is a portal to the grid, which provides a logically single entry point for users to interact with the grid, and handles processing tasks that are common to all grid services.

The Vega Grid "Browser" and the Vega Grid Server interact through a new protocol, called the Grid Service Request Protocol (GSRP). Another new feature is the Grid Service Markup Language (GSML), which allows users (not necessarily programmers) to specify grid services and user interface in an easy to use fashion.

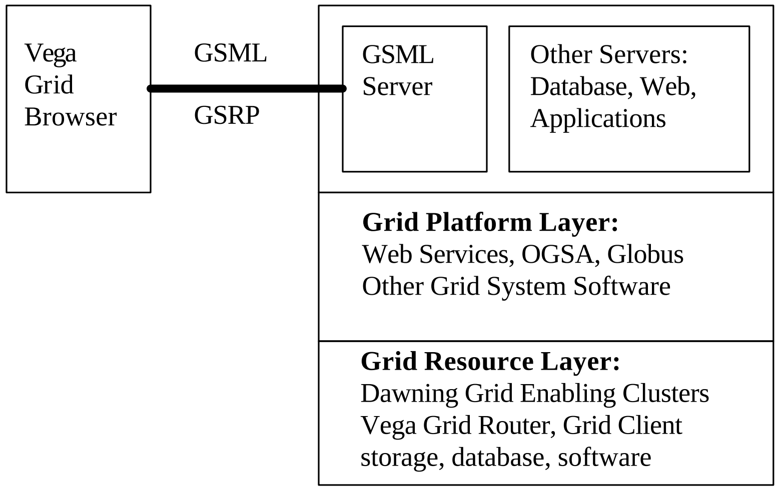

Figure 1. The Vega Grid Three-Layer Architecture

3. Grid versus ADS

Traditional IT application systems, either centralized or distributed, do not meet the requirements of dynamically changing social and economic situations, in which systems need to be constructed by integrating existing subsystems and newly developed components and subsystems, and faults of system components are not avoidable.

In a centralized system, the centralized controller makes the decision based on the overall system information and usrer's requirments, and commands the subsystems accordingly to achieve optimal system performance. In a large scale system, it is undesirable to have a centralized controller for several reasons:

- **Centralized systems lack reliability**. If the centralized controller is broken down, the overall system will be disabled.
- **Uncertainties of comunication.** Since too much information about different subsystems ditributed widely in different places need to be collected, communicaton resources around the centalized controller may become a bottleneck. And accutate information of subsystems may not be received due to the uncertain communication lantancy of messages, dynamically changing subsysems and the fallibility of communication systems.
- **Each subsystem may not get its own command from the centalized controller in time**. Since the computation of the centalized controller may be too intensive.

To avoid the shortages of centralized system, traditional distributed systems are developed. But both centralized systems and distributed systems are designed under the assumption that the total system must be complete and previously determined. As a result, these systems have little flexibility, and are unable to meet requirements of on-line expansion, fault tolerance and on-line maintenance.

Two new technologies are proposed to solve the above problems. They are grid and autonomous decentralized systems.

Professor Kinji Mori proposed a concept of ADS [6]: A system composed of subsystems is called a autonomous decentralized system, if it has the following two properties:

- **Autonomous controllability**. Each subsystem manages itself to achieve its own goal. If any subsystem fails, is repaired and/or newly added, other subsystems can continue running.
- **Autonomous coordination.** Subsystems can coordinate their individual objectives, and work in a coordination fashion to optimize their own goals.

The general topology of an ADS is a graph. Each node of the graph is a subsystem of the ADS, and each subsystem is composed of components managed by a controller. Subsystems are required to have the following characteristics:

- **Equality**. The relationship among subsystems is equal, in that no master-slave relation exists among subsystems.
- **Locality**. Each subsystem decides its behavior by its own controller based on local information. This includes information from the subsystem itself and its neighboring subsystems.
- **Self-Containment**. Each subsystem has at least the basic control and decision function to manage itself and coordinate with the others.

There is no central controller in an ADS, which has complete information of system states and user requirements and complete control over subsystems and components.

An ADS must meet system requirements such as on-line expansion, fault tolerance and on-line maintenance.

- **On-line expansion** means that new components or subsystems can join the existing system without suspending the operation of other subsystems.
- **Fault tolerance** means that even if some subsystems fail, the system can continue running, and its major performance can still be retained as normal or with a reasonable degradation.
- **On-line maintenance** means that repairing and testing failed subsystems will not suspend the system operation.

By Ian Foster's latest grid definition and Kinji Mori' ADS definition, a grid system can be viewed as an autonomous decentralized system in many aspects.

After comparing grid and ADS technologies, we find several similarities between the two, such as openness, autonomous controllability, autonomous coordination, integration, and decentralization.

- **Openness**. Both ADS and grid are not previously determined, closed systems. The totality of either system cannot be previously defined and is not required to be determined in advance. This is a different point compared to traditional IT application systems, such as Management Information System, which require that the totality has to be defined before design and construction.
- **Autonomous Controllability**. Each subsystem of an ADS has its own local controller. It manages itself to achieve its own goal. The local controller of each subsystem makes its own local decision based on local information to optimize its own performance. The local controller has an intelligence to decide what to do. Failed or newly added subsystems will not suspend the operation of other subsystems. The collection of local decisions made by each subsystem will achieve an optimal (or at least good) system performance within system constraints.

Many people believe that a grid should possess the same autonomous controllability as an ADS. A grid system is composed of interconnected nodes. Most nodes have their own management systems, which control the component resource's activities of its domain. Grid nodes are not subjected to centralized control. These nodes belong to different administrative units of the same institutions or different institutions. Resources belonging to different people or institutions can freely join or leave the grid system at their own will without disturbing the running of other administrative domains. A resource provider has full control of its resource exported. For example, resources of each of grid systems such as Vega Grid and EU Grid are from multiple institutions, each with their own sharing policies and mechanisms.

- **Autonomous coordination**. The controller of each subsystem of an ADS can cooperate and work in a coordination way. Subsystems can coordinate their individual objectives in case any other subsystem fails or is newly added. The coordination behavior of each subsystem is also decided by its own local controller. Especially when the requirements of executing an application task are beyond the capability of one subsystem, cooperation between two or more subsystems is necessary.

Grid supports the sharing and coordinated use of diverse resources in dynamic, distributed virtual organizations. Geographically distributed nodes operated by different organizations and customers with different policies are effectively coordinated to deliver the desired quality of service.

- **Integration**. An ADS is not constructed from scratch. It is built by integrating existing autonomous subsystems and newly developed subsystems to meet the increasing requirements of services. The resulting system is also autonomous. The integration can be implemented in two levels. In the system level integration, new ADS subsystems are integrated with existing ADS system. In the subsystem level, new components or modules are installed into the ADS subsystem. Due to the autonomous controllability and autonomous coordination, the integration can be done on-line. Thus, the system can continue running during upgrading and integration. This is especially important for on-line and real-time services.

Grid is not constructed from scratch either. It integrates existing systems, such as enterprise systems, service provider systems and customer systems etc. with newly developed grid technologies. For example, Vega Grid technologies such as Vega Grid architecture, Vega Grid Router, Grid Service Markup language (GSML) Server, Vega Grid Browser and Grid Service Request Protocol (GSRP), effectively support the integration and use of Web Services, Globus, and other grid system software and hardware.

Grid is concerned with the creation of virtual computing systems from dynamic collections of resources and services. These collections can be small or large, homogeneous or heterogeneous and geographically distributed. Service components from these collections can be integrated dynamically and flexibly both within and across various organizational boundaries.

- **Decentralization**. ADS is decentralized and distributed. There is no centralized controller, which makes decisions for the overall system based on the overall system state information. Each subsystem decides its own behavior. In addition, an ADS can be geographically distributed. Subsystems are distributed in different places. Another meaning for distribution is that a complex function is decomposed into some subfunctions and these subfunctions are deployed into or implemented by different subsystems. These subsystems cooperate to provide a complex service.

Grid is a typical decentralized and distributed system. Grid resources, such as intelligent networks, switching devices, storage systems or storage area network management systems, caching services, appliance servers, which do not subject to centralized control, are geographically and organizationally distributed. Services deployed in distributed components can cooperate to create virtual computing systems to deliver various qualities of service.

ADS and grid are different from each other in these aspects such as standardization, scale, versatility, evaluation criteria, equality, self–containment and locality.

- **Standardization**. The process of standardization of grid is going well. A Global Grid Forum has been established to work out the general-purpose standards, and the open source Globus Toolkit is emerging as a de-facto software standard for construction of grid systems [3]. Grid's standardized protocols enhance the ease of construction of grid systems.

It seems that ADS lags behind in setting up general-purpose standards. Although the importance of open standards has been mentioned in many ADS literatures, the process of standardization needs to be accelerated.

- **Scale**. The scale of grid systems ranges from family grid to global grid that has billions of components distributed worldwide.

It seems that some ADS, which use broadcast communication mechanism to support on-line expansion, fault-tolerance and on-line maintenance, do not have a worldwide scale. New technologies need to be developed to enlarge such kind of ADS.

- **Versatility**. Grid is build for general-purpose applications to provide versatile services. Although the ADS concept is a versatile concept, most implementations are special purposed systems, such as transportation systems, manufacturing systems or robotic systems. This is probably because ADS still lacks general-purpose standardization efforts.
- **Evaluation criteria**. To evaluate the functionality and performance of a system, grid stresses the service-oriented criteria, such as Service Level Agreement. It is not clear whether ADS has this feature. Some ADS applications use technical criteria to evaluate system performance.
- **Equality**. An ADS requires that each subsystem is equal. Master–slave relation never exists among subsystems. However, this kind of relation may exist among some nodes in some grid systems.
- **Self–Containment and Locality**. Each subsystem of an ADS has the characteristics of self–containment and locality. However, some nodes in current grid systems are not self-contained and do not have locality.

4. Several Research Problems

In e-business and e-science etc., heterogeneous resources and services, not subject to centralized control, from enterprise systems, service provider systems and customer systems need to be used in a coordinated fashion to deliver various qualities of service to meet complex user demands. How to build powerful, efficient, reliable, scalable and secure e-business and e-science systems etc. are great challenges faced by ADS and grid researchers. The two research fields need inputs from each other to address these challenges. Research problems related to ADS and grid are as follows:

- **More clear definitions of Grid and ADS**. ADS currently has at least a good definition which specify its functions, such as on-line expansion, fault tolerance, on-line maintenance, and some necessary characteristics of subsystems, such as autonomous controllability, autonomous coordination, equality, locality, and self-containment. However, for grid, a uniform definition does not exist yet. Different people have different understanding of grid.

Nevertheless, both need more clear definitions so that people can tell what is grid/ADS and what is not grid/ADS. This is important to educate people and to help them to decide if grid or ADS are suitable for solving their problems.

- **Architectures of ADS and Grid**. There are already some good architectures of grid. For example, a layered architecture [4] used by Globus toolkit is illustrated in Figure 2. In this architecture, the *Fabric* layer supplies grid resources to be shared and the interface to local control. The *Connectivity* layer implements the easy and secure communication mechanism. The *Resource* layer provides resource management functions to support the sharing of single resource. The *Collective* layer defines protocols and services to support global coordination and sharing of multiple resources. In addition, the *Application* layer contains various user applications based on other layers. From Figure 2, we know that the grid system has a layered and explicit architecture design.

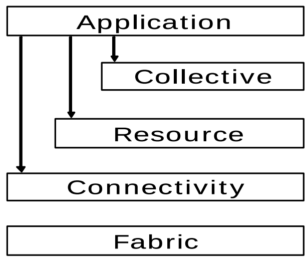

Figure 2. The layered architecture of Globus Toolkit

On the contrary, the ADS system does not have a definition of such a layered architecture. A referential layered architecture will be a research problem in future development of ADS.

- **Communication of subsystems**. Although the broadcasting communication mechanism is suited for the ADS system, it may not be practical to adopt this mechanism in a large-scale grid system, due to factors such as worldwide scale, unreliable communication medium, poor security protection and long latency. The Globus toolkit has supplied a secure communication mechanism at the Connectivity layer. How to support reliable and efficient communication is still an important problem for grid.

In an ADS, the broadcasting communication is not secure and will have trouble when used in large scale. Therefore, it is necessary to develop reliable, secure and efficient communication mechanisms for the ADS system.

- **Resource naming and discovery**. There could be a huge number of resources in both the grid system and the ADS system. Therefore, it is fundamental for both systems to name and identify different resources. Because the grid system and the ADS system are distributed systems, how to discovery and locate the resource in wide area is also a challenge problem.
- **User interface research.** The idea of grid is to supply many resources to end users, so it is necessary to develop user-friendly interfaces that help users to use grid resources and services effectively and easily in order to achieve their goals. Grid Service Markup Language and Grid Browser are being developed by our Vega team to enable end users to use grid easily. For general-purpose ADS, this is also an important research work.
- **System evaluation**. Both ADS and grid lack clear and standard evaluation criteria. A series of criteria used to evaluate ADS and grid should be set up such that developers can optimize their system design and users can select the most cost effective system.
- **Setting up the industry standards of ADS**. Setting up the industry standards helps the development of ADS. With the industry standards, it will be easy to form a large scale ADS to support various kind of application, such as distributed transportation systems, electronic commerce, telecommunications, information service systems, manufacturing systems, real-time event management etc.
- **Application of ADS concept to the research of various kinds of Grid systems**. Introduce the concept of ADS that simulates the living systems into the design of Science grid, Information grid, Knowledge grid, and Commercial grid etc. to produce desired systems.

5. Conclusions

The Vega Grid research project at Institute of Computing Technology, Chinese Academy of Sciences is summarized, and two active research fields of ADS and Grid are compared. Similarities and differences between ADS and grid are pointed out. Both technologies share the goals of openness, autonomous controllability, autonomous coordination, integration and decentralization. Differences exist in the following aspects: standardization, scale, versatility, evaluation criteria, equality, self-containment and locality. ADS and grid need inputs from each other to improve themselves. Finally, we point out several research problems related to ADS and grid, such as more clear definitions of grid and ADS, architectures of ADS and grid, communication of subsystems, resource naming and discovery, user interface research, system evaluation, setting up the industry standards of ADS, application of ADS concept to the research of various kind of grid systems.

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