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November 2006

TECHNICAL REPORT – No. 2006.11

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Technical Report No. 2006.11, November 2006
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An Accounting Model for Dynamic Virtual Organizations

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Abstract

The provisioning of remote and composed services in support of various application areas has dramatically increased over recent times. Thus, the concept of Grids has evolved, in the sense of a common platform for electronic service provisioning in multi-domain environments. While, traditionally, Grids have seen a quite static existence, many new service compositions have to take place on-demand and for certain periods of time only. To tackle those issues the concept of Virtual Organizations (VO) delivers a highly suitable representation of such dynamic Grids. However, one important open problem at this stage is the lack of applicable, distributed, and efficient accounting schemes for commercial resource and service consumptions. Even for simple management purposes, e.g., *sampling or archiving, this functionality is essential.*

Therefore, a comprehensive model for Grid accounting has been developed and suitable accountable units have been defined, in which an underlying activity- and resource-based accounting model covers economic cost theory. Furthermore, this work is based on a service model proposed for service provisioning in dynamic VOs, overcoming the typically static nature of traditional Grids.

1. Introduction

Grid systems have evolved over time from traditional Grid computing to service Grids. Grid computing focused on high performance computing, based on the concepts of cluster-building and resource sharing. By applying these concepts, Grid systems are able to solve data- and computationally intensive tasks. Service Grids address in addition the virtualization of resources and services across administrative borders. Thus, they dispose of mechanisms needed for geographically and organizationally distributed service provisioning within a Virtual Organization (VO).

Based on the embracing analysis performed in [33], comparing traditional Grid computing and today's service Grids with other related concepts, service Grid VOs are characterized as follows: Virtualization allows for an inter-domain service provisioning and resource coordination. Resources are encapsulated by services that, in turn, can be aggregated into more complex service bundles. Services are accessible via open interfaces and they implement standard protocols so that interoperability between heterogeneous Grid nodes is achieved. In contrast, implementation details as well as information about service composition and the overall organizational alignment of the VO are hidden from service users.

From an economic point of view, virtualization refers not only to the concept of resource coordination between legally independent organizational entities, it also covers dynamics with respect to organizational composition and business process execution [28]. Depending on the specific service user needs, representing the market's demand side, suitable service providers need to be bound to a VO. Changes in either, demand or supply side, result in other operational VO instances. Furthermore, processes need to adapt to changing contexts so that, *e.g.*, aggregated services have to be newly composed. In order to reflect such highly relevant dynamic aspects explicitly, Dynamic Virtual Organizations (DVO) are introduced and used subsequently.

Inter-domain resource coordination and service provisioning in DVOs traditionally finds most deployment cases in research-oriented Grids. But such approaches are required for fully competitive commercial environments as well, which are strengthened by respective Grid initiatives lead by industrial supporters, like [25]. Either for statistical and planning reasons only, or with charging for consumed resources in mind, accounting of resource usage records is in a service provider's interest — both, in academic and commercial environments. Usage records feed accounting systems with metered information on what resources have been consumed how and by which service.

In economic terms, resource consumption is reflected by cost elements. An accounting system has to specify accountable units that need to follow the principles of the economic cost theory. Moreover, accountable units have to consider the specific requirements on accounting for electronic services that are offered in DVOs. This covers particularly the fact that — once a Grid service has been produced, thus, being available for service delivery — electronic services are characterized by a high share of indirect cost elements that are not directly attributable to a specific service provided.

Accordingly, the main objective of this paper consists in the design of an accounting model that addresses inter-domain provisioning of electronic services in DVOs. This model needs to satisfy, on one hand, DVO-specific requirements, while, on the other hand, it has to consider generic requirements on accounting systems that are based on the economic cost theory. This approach is followed in order to establish an accounting system that integrates both, perspectives of economic and technical accounting. In particular, the relevant set of accountable units for Grid services has to be specified, constituting base components of the accounting model.

In order to reach this goal a thorough investigation in existing Grid accounting concepts is performed in Section 2, including an analysis of approaches considered. This is followed by a close inspection of DVOs and the respective service model in Section 3. The insights gained on existing approaches and Grid service characteristics lead to a set of generic and DVO-specific requirements on accountable units as determined in Section 4. Driven by these characteristics, the accounting model is developed in turn, which is followed by a functional evaluation performed in Section 5. Finally, the work is summarized and conclusions are drawn in Section 6.

2. Related Work

The area of Grid accounting has already been investigated in other Grid projects and by other researchers. Therefore, various approaches on accounting for Grids currently can be observed in the literature. Based on a comprehensive analysis in [19] and [30], the following provides an overview of the "status quo" of existing accounting systems and accounting tools from European as well as international Grid projects, and it finally presents an evaluation of fundamental characteristics in a compact manner.

2.1 Accounting Processor for Event Logs (APEL)

The web-based accounting tool APEL, which has been deployed within the EGEE/LCG project [18], is a log processing application used to interpret batch system and gatekeeper logs in order to generate accounting records [6]. The APEL Log Processor parses log files to extract job information and publishes it using R-GMA, an implementation of the Grid Monitoring Architecture (GMA) proposed by the Global Grid Forum (GGF) [5].

In LCG accounting, each site publishes its own accounting data using an R-GMA primary producer, which makes use of its locally assigned R-GMA server. Currently, only PBS (Portable Batch System) and LSF (Load Sharing Facility) batch systems are supported by the underlying architecture. The architecture, however, can easily be extended to develop other variants. Via a secondary producer, the aggregated accounting data is streamed to a centrally administrated, relational database management system in the Grid Operations Centre (GOC), which is used to provide a web front end, generating a summary of resource usage across the Grid [6]. Furthermore, various plug-ins exists to provide access to a MySQL database in the GOC in order to publish accounting records through R-GMA for presentation on the web.

2.2 Distributed Grid Accounting System (DGAS)

The DataGrid Accounting System was originally developed within the EU DataGrid Project (EDG) [7] and has been maintained and re-engineered within the European EGEE project since April 2004 [1]. DGAS is designed to support an economy-based approach to regulate the distribution of Grid resources among authorized Grid users and to implement resource usage metering, accounting, and account balancing in a distributed Grid environment [29].

In accordance with the SweGrid Accounting System (SGAS, cf. Section 2.7) all currency transactions are mediated by decentralized bank services. The consumption of Grid resources by Grid users is registered in appropriate servers, called Home Location Registers (HLR), which manage both user and resource accounts. Similar to SGAS, the Distributed Grid Accounting System makes use of so-called "template accounts", which are temporarily linked to authorized Grid users for the duration of a job submission. Furthermore, the HLR takes care of the communication between different HLRs and it credits/debits the different users/resource owners for the respective amount of resource usage [13].

EDG makes use of an approach where each VO has their own HLR available for their members, although a finer granularity is possible. The Price Authority (PA) determines an optional component in the architecture that finds prices for all different resources in the Grid, either manually or by using different dynamic pricing algorithms. Similar to the HLR approach, each VO comprises at least one PA. The costs of the user job are finally determined by the HLR service, taken from resource prices and usage records. Account balancing is done by exchanging virtual credits (Grid Credits) between HLRs of the user and the resource under consideration [13].

2.3 Grid Accounting Services Architecture/ GridBank (GASA)

GridBank (GB), developed in Australia within the Gridbus project [24], is a secure Grid-wide accounting and payment handling system with a strong focus on economic structure and economic brokering. [3] presents several requirements on Grid accounting and various economic models within GridBank, based on the Grid Accounting Services Architecture (GASA) proposed. Implementation issues are available, mainly with respect to a detailed discussion of format variants to be maintained for various records/data bases, *e.g.*, Resource Usage Records (RUR). Also several protocols for the interaction between GridBank and various components within Grid computing environments are presented. In addition, the payment of resources is addressed in the approach by means of a comprehensive set of payment schemes, based on both, Grid Credits and real money.

In contrast to SGAS and DGAS, the accounting system of GridBank has a slightly different underlying infrastructure. Providers and consumers of Grid resources have to register themselves on a central server, so that resource owners do not have to establish accounts for every resource user [13]. Another interesting aspect of GridBank is that it makes use of decentralized Grid Trade Servers (GTS) to negotiate resource prices and to select an appropriate resource provider.

2.4 Grid Based Application Service Provision (GRASP)

The aim of the European GRASP project [22] consists in integrating network-enabled Application Service Provision (ASP) with Grid computing and Web Services in compliance with the OGSI.NET framework [14]. GRASP makes use of distributed and heterogeneous resources, which are integrated using Grid technologies, in order to implement current and future ASP business models.

A fundamental concept of the GRASP infrastructure, which is compliant with the Open Grid Services Infrastructure (OGSI) specification, is the Virtual Hosting Environment (VHE). VHE comprises various services and resources, which are provided within a VO [8]. The underlying accounting subsystem, supporting usage-based and service-level-based charging of jobs and applications, is implemented by means of two basic Grid services: the Financial Accounting (FA) service as well as the charging service. The FA Service allows for the execution of an application by coordinating other subsystems belonging to the Business Component Services Layer [14]. An important aspect of the accounting system is the usage of policies, which are supported by Web Service Level Agreements (WSLA) [23] as well as business extensions. The use of policies provides for accounting mechanisms that are flexible and dynamically configurable.

However, accounting and billing services within GRASP are still in an early design phase. For this reason, several interesting aspects remain unspecified, such as the range of supported resource types or accountable units.

2.5 Grid Service Accounting Extensions (GSAX)

GSAX represents an extensible OGSA (Open Grid Services Architecture) [21] accounting and logging framework as proposed by the GGF RUS-Working Group (RUS-WG) [20]. It emerged in the course of IBM’s “Extreme Blue” Grid accounting project [4].

GSAX is designed to provide a modular accounting framework, which can be expanded by adding or changing so-called core components. Furthermore, the underlying accounting system allows for the use of accounting at various application levels, and it provides information at different degrees of granularity, *e.g.*, real-time information or data on a per-job basis [4]. Another important aspect of this theoretical approach is the possibility to integrate Quality-of-Service (QoS) parameters and Service Level Agreements (SLA) at different levels into the accounting framework. For instance, this provides economy-based QoS parameters and SLAs to be implemented at the accounting level. The underlying accounting subcomponent comprises of two basic services: first, the account management service providing accounting-related information and accounting records to higher-level components via adequate interfaces; second, the accounting service handling metering events and, thus, establishing interfaces with the lower components of the framework [4]. The account management service and accounting service hold an instance of an account, which contains information, *e.g.*, the current balance or list of users authorized to use the account.

2.6 Nimrod/G

Nimrod/G is a Grid resource management and scheduling system based on Grid technologies, which was developed at the Monash University in Australia. The tool was designed to manage the deployment of parametric experiments in a global computational Grid [2]. Nimrod/G supports an integrated computational economy in its scheduling system. This means that Nimrod/G can schedule jobs on the basis of QoS requirements, deadlines, and budget restrictions [2].

The Nimrod/G Agent records the amount of resources consumed during job execution, such as CPU time and wall clock time. The online measurement of resources consumed by an executed job helps the scheduler to evaluate resource performance and to change schedules accordingly. Furthermore, information from the metering component can be used in order to perform an accounting of the resource consumption.

Nimrod/G puts the focus on allocating and scheduling, however, not on the accounting of Grid resources. Thus, this approach lacks a specification of accountable and monetary units as well as a detailed description of user accounts and accounting records. As a result, Nimrod/G should not be considered as a single independent accounting system. Integrating Nimrod/G into existing accounting systems, *e.g.*, into GASA, proves to be reasonable [2], [3].

2.7 SweGrid Accounting System (SGAS)

The SweGrid Accounting System (SGAS) is an accounting system already implemented in the Swedish National Grid (SweGrid). SweGrid determines a computational Grid, initially joining together one cluster at each of the six high-performance computing centers across Sweden, and currently comprises approximately 600 nodes [31].

In contrast to DGAS or GASA, the SweGrid Accounting System is built on open, standard-based Grid protocols and existing toolkits, *e.g.*, OGSI. SGAS supports homogeneous computing nodes and a few accountable units only [13].

The underlying architecture of the system consists of a bank service, the Job Account Reservation Manager (JARM), and the Log and Usage Tracking Service (LUTS) [11]. In SGAS, each VO has an associated bank service in order to manage resource allocation for a given VO research project. The primary purposes of the SGAS bank are to keep track of resource consumption for individual projects/users and to enable coordinated quota enforcement across SweGrid sites. Among others, substantial features of the bank component include bank account administration, transaction history, a logging service, and soft state account holds. JARM provides a single point of integration of SGAS into various Grid middleware [13], [15]. Moreover, when placed on each Grid resource, JARM intercepts incoming service requests, performs account reservations, and charges the account of the requester after the resource usage. Finally, LUTS collects and publishes usage data and it allows users to query accounting information in a consistent way. Similar to GridBank, accounting data is stored using Resource Usage Records (RUR) as standardized by the Global Grid Forum (GGF) Working-Group [13].

2.8 Analysis of Existing Approaches for Grid Accounting

In order to conclude, the following section briefly summarizes several shortcomings of existing accounting approaches for Grid environments. A detailed summarization of fundamental characteristics of existing accounting systems is depicted in Table 1, which compares along a list of 23 criteria.

Table 1: Evaluation of Existing Approaches (+ "Yes", (+) "In Parts", — "No", n.s. "Not Specified")

Criteria	**Accounting System**						
	APEL	**DGAS**	**GASA**	**GRASP**	**GSAX**	**Nimrod/G**	**SGAS**
Interoperability and portability	(+)	(+)	(+)	n.s.	(+)	+	+
Scalability	+	(+)	—	n.s.	+	+	+
Integration	(+)	(+)	(+)	n.s.	(+)	+	+
Inter-organizational accounting	+	+	+	n.s.	+	n.s.	+
Flexibility and extensibility	+	n.s.	+	n.s.	+	(+)	+
Support of existing standards	—	—	(+)	(+)	(+)	n.s.	+
Support of multi-provider scenario	—	—	—	—	—	—	—
Customer-specific visualization of accounting data	+	—	—	n.s.	n.s.	n.s.	—
User transparency	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	(+)
Accounting of heterogeneous resources	(+)	+	+	(+)	n.s.	n.s.	—
Accounting of virtual resources	—	—	—	—	—	—	—
Accounting of virtual services	—	—	—	—	—	—	—
Virtualization concept	—	—	—	—	—	—	—
Support of high dynamics	+	(+)	(+)	n.s.	n.s.	+	+
Security	n.s.	+	+	n.s.	+	n.s.	+
Standardized, generic interfaces	—	—	—	n.s.	(+)	+	(+)
Support of various accountable units/metrics	+	+	+	n.s.	+	n.s.	—
Precision and abundance	+	+	+	+	+	n.s.	+
Support of different accounting policies	+	+	n.s.	n.s.	+	n.s.	(+)
Reliability and fault tolerance	n.s.	n.s.	(+)	n.s.	n.s.	n.s.	+
Administration and management	n.s.	(+)	n.s.	n.s.	n.s.	n.s.	+
Verification	n.s.	+	+	n.s.	n.s.	+	+
Open source	+	+	+	—	—	+	+

One of the major drawbacks of existing accounting systems is that they do not offer a comprehensive concept for the virtualization of resources and services with respect to accounting. Neither none of the considered accounting approaches defines virtual resources or virtual services, nor do they provide mechanisms for the accounting of virtual resources and virtual services as they are offered within VOs. Generally, the focus of existing systems and accounting tools is on the accounting of physical Grid resources. Accounting of complex services — as for instance information services or computation services — is considered only partially. In addition, the aspect of accounting of composed virtual resources and services is also not reflected: this is of particular importance to multi-provider scenarios, where several real and virtual organizations provide in a collaborative manner a virtual resource or virtual service. Furthermore, to some extent only static environments with Grid resources of homogeneous nature are considered by underlying accounting systems. Dynamic Grid environments with a high level of heterogeneity with respect to resources, operating systems, and Grid middleware are in most cases not taken into consideration.

3. Service Model for Dynamic Virtual Organizations

Due to the lacking support of virtualization concepts and multi-provider scenarios in existing Grid accounting approaches, a closer look at characteristics of electronic service provisioning in DVOs is needed. To this purpose, a generic service model for DVOs has been developed. This section refines the DVO model introduced in [10] based on the model proposed in [32] in order to specify a comprehensive service model for Dynamic Virtual Organizations. Figure 1 illustrates the respective overview.

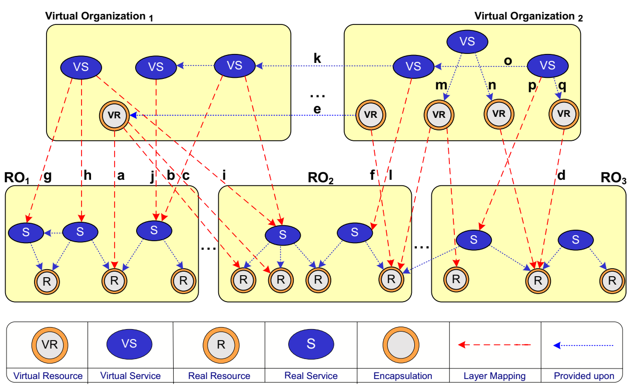

Figure 1: Service Model for Dynamic Virtual Organizations, extended from [32]

In the process of creating DVOs, multiple autonomous organizations — so-called Real Organizations (RO) — are involved in providing VO's resources and services by contributing some of their local resources and services, respectively. DVOs are characterized by strong dynamics in their organizational composition and business processes. Furthermore, in a highly dynamic VO, resources are not necessarily dedicated to a single service or a single organization only. In the context of Grid computing, virtualization can be seen as the mapping of real objects (such as resources, services and organizations) into virtual objects, which may have functional characteristics of (different) real objects [34]. In Grid environments, the concept of virtualization provides an essential means to increase the flexibility within VOs with respect to, *e.g.*, the provisioning of resources and services. If, from a service-oriented point of view, the focus of VOs is on the provisioning of services, a VO can be defined as a set of virtual resources and virtual services that can be used by individuals to archive a common goal [10]. Furthermore, resources and services of a VO may also be provided to members of other VOs. This case visualizes how important it is for an accounting system to account for resource consumption and service usage in an accurate manner.

A virtual resource of a VO may consist of several physical resources provided by one or multiple ROs. A fundamental characteristic of Grid resource virtualization is that they may represent resources — or rather types of resources — that do not physically exist in this way within ROs. A VO, for example, may provide a virtual storage resource, which consists of several storage elements from ROs, *e.g.*, a RAID system of RO_1 (cf. line *a* in Figure 1), a file system, and a tape storage system of RO_2 (lines *b* and *c*). Altogether, these resources build a virtual storage resource offered by VO_1.

Normally, functional properties of a virtual resource are assumed to be the same as the ones of the real resource, but non-functional characteristics may be different [34]. In the simplest case, a virtual resource offered within a given VO consists of exactly one resource of an underlying RO (line *d*). In addition, virtual resources may also comprise a set of virtual and real resources. For instance, VO_2 could provide a virtual resource that consists of a virtual computing resource (line *e*) of VO_1, which in turn contains several computing clusters and a physically existing resource of RO_2 (line *f*), *e.g.*, a high-performance computer. Finally, the concept of virtualization can be applied also to virtual resources itself so that a virtual resource may consist of several other virtual resources of potentially different VOs in order to provide a compound virtual resource.

In Grid environments, physical Grid resources, such as computing elements, storage resources, networks, software licenses, or scientific devices, may exhibit a high level of heterogeneity. Therefore, resource virtualization is also used to provide a homogenized view on heterogeneous resources. For that reason, resource virtualization can be seen an essential means to reduce the complexity of managing heterogeneous systems and to handle diverse resources in a uniform way [12].

In order to provide the functionality of a resource, as for example access to a database or computational elements, real as well as virtual resources are encapsulated by the use of a trivial service, which provides standardized access to these resources in an abstract manner. From a technical perspective, these encapsulation services for example may be implemented as Web Services. Beside resources, a VO can also comprise of a set of virtual services that are composed of several services of one or more real organizations participating in the VO (lines *g*, *h*, and *i*). These so-called compound virtual services [10] are perceived as instantiations of multiple, potentially different services from real organizations onto one virtual service. Underlying services of ROs — which themselves are provided upon physical resources — can be of homogeneous or heterogeneous nature. Similar to the provision of virtual resources, a VO may also offer virtual services, which use several real services in order to build up a new type of service having a new functionality and which is not provided as such within the underlying organizations.

3.1 Example: Virtual Information Service

The virtual information service sketches an example on how a compound virtual service comprising several services from underlying RO might look alike: The virtual information service collects information on experiments in the domain of particle physics, using a data service of RO_1. It performs several calculations on this information via a computation service, offered by RO_2, and finally presents results in graphical form using a visualization service offered within RO_3. In this example, the virtual information service makes use of several underlying services from ROs, which are provided upon physical resources that altogether build a composed virtual service. Through the virtualization, a virtual service in most cases becomes a more complex service than underlying services of the RO [10]. In the simplest case, a virtual service may consist of exactly one service from the underlying RO (line *j*). In this case, a one-to-one mapping from the real service onto the virtual service takes place. Furthermore, a virtual service may also comprise several real and/or virtual services in order to build a new compound service. For example, a virtual service of VO_2 may use another virtual service from VO_1 together with a real service from RO_2 in order to provide a new compound virtual service (lines *k* and *l*).

In analogy to service provisioning in ROs, a VO may also offer virtual services that are not composed of virtual and/or real services, but which are provided upon virtual resources (lines *m* and *n*). An example for this case would be a virtual computation service offered by VO_2 that is provided upon virtual computing resources within VO_2, which in turn are composed of several computing facilities of underlying organizations. Finally, a virtual service can make use of real and/or virtual services and additionally may consume one or several virtual resources in order to offer a new virtual service (lines *o*, *p*, and *q*).

Generally, the set of virtual resources and virtual services needs to be mapped in an operational manner onto real resources and real services by applying an adequate mapping function [10]. The mapping function is also an important means to map accountable units for virtual resources/services onto real resources/services. In order to access services or resources of another VO, it is necessary to maintain an established trust relationship between VOs, which in turn is mapped to all services and resources of the underlying ROs. VO members only have immediate access to virtual services and virtual resources of another VO. Thus, they can not directly use resources and services of the underlying organizations, which are arranged in the lower layer of the service model.

4. Accountable Units for Grid Services

Driven by the comprehensive analysis of existing Grid accounting approaches above and the presented service model for DVOs, relevant requirements on accounting mechanisms in DVOs are identified in this section. This includes both, generic and DVO-specific requirements. In a second step, those requirements determined are considered in developing an integrated accounting model for DVOs.

4.1 Requirements on Accountable Units

In general, accounting systems rely on accountable units. These determine the range of possibilities for taking records of resources consumed during provision of a service or product. Resource usage records, thus, form the basic input for accountable units that, in turn, serve as input for charge calculation. Accountable units depend on the respective range of measurable units of a specific resource. Resources may be both, tangible and intangible, *e.g.*, a piece of hardware or software.

Accountable units, in their role of the basic constituting elements of an accounting model, have to satisfy a set of generic and application environment-driven requirements. The first category embraces generic accounting practices, while the latter covers in this context DVO-driven requirements, well considering the applicable service model for DVOs presented. With respect to generic accounting requirements, the following issues are of particular concern:

Typically, accounting is divided into internal/managerial and external accounting. This separation is reasoned by different objectives the variants take. While external accounting (also referred to as financial accounting) is bound to informing organization-external entities, such as investors or authorities, internal accounting serves mainly business-optimizing purposes. Accordingly, external accounting is highly regulated, whereas organizations are free on what accounting approach they follow for internal aims. Internal or managerial accounting is also called cost accounting, since costs are perceived as an important element, on one hand, to estimate process efficiency. On the other hand, incurred costs also serve as an input to price calculation. Driven by the main aim of this work — consisting in the design of an integrated accounting model for DVOs — accounting is understood as *internal* or *cost accounting* only. In the context of a DVO, which deals with resource coordination across administrative borders, cost accounting is particularly relevant, since costs, by definition, directly express resource consumption.

In accounting, the causality between given facts to be conceived by an accounting system and assigned accountable units is essential. Transferring this concept to cost accounting means that for every cost element the corresponding cost driver needs to be determined. Cost drivers, hence, stand for the event or fact that primarily has caused costs in the first place.

Besides those generic requirements, application domain-specific requirements need to be considered. In a DVO, primarily electronic products – in terms of electronic Grid services – are offered. With the focus on electronic service provisioning often comes a high relative amount of indirect costs (overhead costs). While labor and material costs are relatively easy to be assigned directly to products, it is more difficult to allocate indirect costs to products. Where products use common resources differently, a weighting mechanism is needed for the cost allocation process. This assumption is valid for any electronic service that is not production-oriented, *i.e.*, once a given service has been produced for the first time, re-provision of the same or similar service does not cause costs that grow linearly with the number the service has been delivered. In such a case, the share of costs being directly assignable to the provision of a service diminishes, while the relative amount of indirect costs (*e.g.*, depreciation on infrastructure) increases with the overall number of service deliveries. As a consequence, for DVOs facing a high amount of indirect costs to be assigned the chosen accounting model needs to provide methods in support of the allocation of indirect costs.

Another DVO-specific requirement is derived from the applicable service model presented that lays the focus on virtual services and resources in a multi-provider environment. Allowing basic services to be aggregated into more complex service bundles demands for an accounting model that provides the means to generate different views of aggregation on accounted for data. In doing so, the consistent use of the same accounting practices on all aggregation levels is desired. Hence, the accounting model is required to be highly flexible and universally applicable, so that it can reflect, in the same way, the respective views of a single Grid service provider or of a VO as a whole.

If all those generic and DVO-specific requirements on accountable units are taken into consideration, the following overall claim is determined: Accountable units have to be specified in the most flexible way, since they form the base building blocks every Grid service can be composed of. These accountable units have to act as the cost objects on which indirect cost elements can be assigned according to suited cost drivers. By means of the set of specified accountable units, the accounting model needs to bridge the gap between financial data, originating from the traditional cost accounting systems, and the technical accounting system.

4.2 Development of an Accounting Model for Dynamic Virtual Organizations

As Section 2.8 revealed, the latest Grid research focused primarily on the accountability of Grid services from a technical perspective and on a meta level of VOs. All presented Grid accounting models and architectures deal with resource usage records or offer a usage tracking service. In order to use Grid services in a commercial environment, economic and financial principles have to be considered and actual costs have to be allocated to the resource usage of a service. Furthermore, DVOs are characterized by virtualization and dynamics, which makes service provisioning very complex as managing heterogeneous systems and diverse resources from different service domains need to be considered. These facts demand for the definition of accountable units and an accounting systematic that satisfies all of the above mentioned characteristics and that fills in the identified gap of already existing accounting models. Accountable units presented in this paper determine the link between the financial world and the technical Grid environment.

Although Grid services are very heterogeneous and rely on the usage of different resources, accountable units need to be determined from the consistent set of base building elements out of which every Grid service is composed. This approach facilitates both, flexible and consistent accounting and charging. These universal accountable elements are called service constituent parts, covering namely Processing, Storage, Transferring, and Output, as Figure 2 shows. These four service constituent parts represent the four basic hardware functionalities, out of which any intangible digital service is assembled by some amount. This does not imply that all four service constituent part types have to be used for generating a given service. In order to allow for a better understanding of a service constituent part, the four service constituent part types are explained in Table 2 with respect to detailed descriptions, cost elements, applicable metrics, and relevant cost drivers.

The accounting model introduced considers the requirement to support virtual multi-provider scenarios. The main target of any participant in the DVO is to know costs for providing one specific service request. Figure 2 provides an overview of this idea of the accounting system and the central role of service constituent parts. The accounting model relies on two well-known accounting systems.

The first of those is the Traditional Cost Accounting System (TCAS) as specified in supposably every cost accounting text book, such as [16]. TCAS is used to allocate costs first from financial data to cost centers and then

Table 2: Service Constituent Part Characteristics

Constituent	Characteristics (Description, Costs, Metrics, and Cost Drivers)
Processing	It is very unlikely that Grid service provisioning without data processing is possible at all. As a result, the service constituent part "Processing" receives strong importance. Basically, this service constituent part type calculates the cost for processing data in a CPU. The IT resource for this service constituent part type, thus, is considered to be a CPU. Processing costs primarily depend on the used hardware (CPU Type) and also the used application logic (software). In addition to that, other costs like cooling devices for CPUs as well as cache memory could be considered too. The activity metric for "Processing" is based on CPU usage, which can be either measured as CPU seconds or million instructions per second. Therefore, the service cost driver for "Processing" is the time of CPU usage (CPU cycles).
Storage	This service constituent part type calculates costs for storing data during a certain amount of time. The main cost-causing resources for this service constituent part type are data storage devices, such as hard disks or any portable data carriers. The costs for this service constituent part type also depend on the costs of all hardware components around the storage system, such as racks, software for managing the hard drives as well as back-up systems, magnetic tapes, and robot systems for exchanging and transportation. Possible activity metrics for this service constituent part type are: I/O operations, transmitted volume, used disk or tape space over a certain time period. The more data has to be stored, and the longer it has to be saved, the more costs are incurred. In consequence, a suitable service cost driver for "Storage" is the mathematic product of volume and time.
Transferring	This service constituent part type calculates costs on the one hand of transferring data between resources within a real organization (internal transferring). On the other hand, costs for external data transfers between virtual resources are considered, *e.g.*, between RO and VO or VO and VO. Basically, these transferring costs can be separated in WAN costs and LAN costs, since both categories typically show different cost structures. Moreover, external and internal data transfer might differ in the way of what Quality-of-Service levels can be guaranteed. The IT resource consumed by this service constituent part type is a "Network" of a specific administrative domain. Service cost drivers for "Transferring" could be the transferred data volume or the provided bandwidth.
Output	This service constituent part type calculates costs for generating a tangible output. Possibly, this could be a printed document, *e.g.*, an invoice for charging purposes, forms, or photos. For example, this service constituent part type is provided by a printing centre in a bank, generating an overview of the monthly transactions of a bank account. The cost-causing IT resource for this service constituent part depends on the hardware (*e.g.*, printers) used. Apparently, printing is the only service constituent part that uses directly clearable material consumption. From a cost-effectiveness perspective, this service constituent part type is characterized by a relatively high share of direct cost elements and variable cost when compared with the other service constituent part types where indirect overhead costs prevail. Thus, the more pages printed, the more toner, ink and paper will be used, and the higher the costs will be. Cost-influencing factors are output device-dependent characteristics (ink printer or laser printer), time (priority), print quality, and paper quality. An adequate metric for measuring the consumption of this service constituent part is printed pages or printed lines. Instead of printing a document, it is also possible that this service constituent part describes the process of storing data on a portable data carrier such as recordable CDs or magnetic tapes. Accordingly, other service cost drivers have to be defined (*e.g.*, MB burned, used CDs or DVDs).

to cost objects, which are the corresponding service constituent parts. TCAS is, therefore, used to determine cost rates for the service constituent parts involved in providing a specific service.

The second accounting system is Activity Based Costing (ABC) [27], [26], [17]. The main idea of ABC is that cost objects consume activities. Activities, in turn, consume resources, and the consumption of resources determines the event that drives cost. Instead of using broad, arbitrary percentages to allocate costs, ABC seeks to identify cause-and-effect relationships in order to assign costs objectively. Once costs of activities (represented by service constituent parts) have been identified, costs of every activity are attributed to each product to the extent that the product uses the activity. In this way, ABC often identifies areas of high overhead costs per unit and, thus, directs attention to finding ways to reduce costs or to charge more for costly products. An important advantage of ABC is its hierarchical and modular structure, which is useful for accounting at various levels of application and granularity. This allows for a universal applicability. A more detailed illustration of ABC accounting is provided in Figure 3.

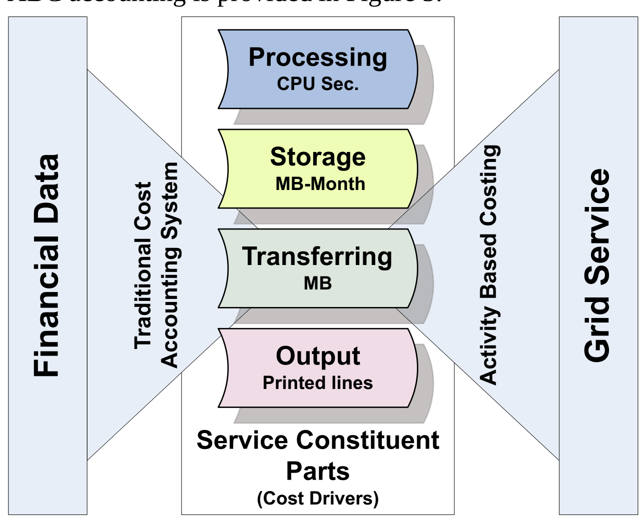

Figure 2: Accountable Units Overview

The most difficult task, however, consists in finding the appropriate amount of service constituent parts. The higher the number of service constituent parts to be considered, the more accurate costs will be collected, but the more expensive the measurements will be as well. Therefore, careful considerations about economic cost/benefit calculation have to be made.

There is no generic rule for choosing the right amount of service constituent parts so far — RO may use a bottom-up approach while VO may use a top-down approach. The bottom-up approach identifies first every service constituent part offered by an IT resource, while the top-down approach starts with the offered service and identifies the real and virtual resources (from different VOs or ROs) with their corresponding service constituent parts used for service provisioning.

As shown in Figure 3, the usage of ABC accounting allows to allocate also other costs for service provisioning, which are not chargeable to any of the above mentioned service constituent parts. These could be organization-specific cost elements such as, *e.g.*, administrative costs that accrue due to service provisioning. From the perspective of a VO, external services (virtual services) could be charged in a flat fee scheme or per service request.

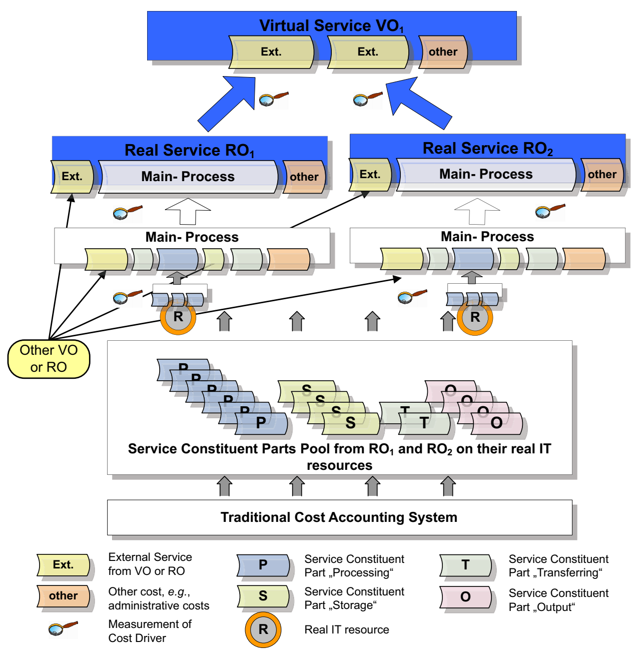

Figure 3: ABC Accounting Model for a DVO

In the example given in Figure 3, VO_1 offers a virtual service that is composed out of two external services, the first provided by RO_1 and the second provided by RO_2. In addition to the costs incurred by sourcing those external services, additional costs are included on the VO level, for instance for administrative activities. Focusing now on the first external service provided by RO_1, the example shows which cost-relevant activities are needed for RO_1 to provide this service to VO_1. To repeat, an external service is sourced from a third party, followed by RO_1's main process, plus other, at this stage not specified in more detail, cost elements. Within the administrative domain of RO_1, several information aggregating steps are taken, leading in a top-down approach to a fine-granular process cost analysis, until, on the lowest level, the respective service constituent part assignment per real IT resource is conducted.

Even though the example depicted in Figure 3 features real resources only, the accounting model is applicable in the same way to virtual resources and virtual services (cf. Section 3) as well.

5. Evaluation of the Accounting Model

To provide an evaluation of the accounting model with regard to those requirements determined, benefits as well as shortcomings of the accounting systematics presented are discussed.

From a theoretical viewpoint, the accounting model proposed fully matches the set of generic as well as DVO-specific requirements on accountable units. The approach is compliant with the service model introduced in Section 3, and it covers all relevant aspects of service provisioning in DVOs from an accounting perspective. Furthermore, the accounting model provides the possibility to bridge concepts of the Traditional Cost Accounting System and technical accounting, allowing to allocate financial expenses to resources and to calculate costs for resource usage by means of cost drivers. In addition, the proposed accounting model is also highly flexible as it is able to reflect different views within the same model *e.g.*, the view of a single Grid service provider and multiple Grid service providers as well as the view of a VO as a whole. Thus, the accounting model is universally applicable in highly dynamic environments being capable to reflect the perception of different Grid service providers. Moreover, the accounting model for DVOs is extensible in the sense that, on one hand, it can be adapted and expanded concerning the objectives of different Grid service providers. On the other hand, costs for additional resources — as for example scientific devices — may also be taken into consideration by the accounting model by the use of the service constituent part „other". The underlying idea of allocating costs first to IT resources and then to the four service constituent parts additionally makes the accounting model very powerful for an application in dynamic environments. Due to the fact that within the approach presented basically only fixed overhead costs are allocated to the service constituent parts, the accounting model allows for the detection of inefficiencies, whereas an economical analysis is simply done by identifying IT resources, which do not run at a high workload level.

Since accounting on a fine-granular basis causes a considerable effort, which stands in contrast to the overall benefit of an accounting system, a cost/benefit analysis still has to be performed. Within this work, the initial requirements match has been performed from a theoretical viewpoint. The accounting model as such, however, cannot be evaluated easily in practical terms. Thus, its application in a real-world scenario has to be envisaged, as for instance within the German D-Grid [9] where several so-called Community-Grids (*e.g.*, MediGrid, AstroGrid, or HEP-Grid) and resource providers (*e.g.*, supercomputing centers or universities) jointly offer a broad range of complex Grid resources and Grid services to the German scientific community.

6. Summary and Conclusions

The emerging importance of service Grids and its associated concept of DVOs, to allow for a flexible and dynamic grouping of virtual services and resources, has pin-pointed the importance of accounting in such highly dynamic environments.

A comprehensive investigation into accounting models for Grid systems has revealed that existing approaches do not consider the full set of requirements on Grid accounting in DVOs, particularly not covering aspects of resource and service virtualization as well as accounting in multi-provider scenarios. This has led to the need for an integrative Grid accounting model to be determined. Since DVOs provide virtual services with certain service levels and costs, the identification of accountable units and accounting models is essential as well.

This paper has proposed activity based costing as the suited accounting model for DVOs. In addition, accountable units have been identified, *i.e.*, four basic service constituent parts of processing, storage, transferring and output. Due to the fact that the model was designed following economic accounting principles, rather than feature-driven requirements only, it qualifies as the first Grid accounting model to bridge the apparent gap between financial and technical accounting systems. This provides the theoretical basis as well as initial technical approach to design, implement, and operate a commercially viable Grid accounting system.

From a conceptual point of view, the accounting model developed is sustainable. Results at this stage are of theoretical nature. Therefore, it is planned to verify its bearing strength in a real-word scenario in the area of D-Grid, an initiative to establish e-science in Germany.

Acknowledgements

This work has been performed partially in the framework of the EU IST Network of Excellence EMANICS "Management of Internet Technologies and Complex Services" (IST-NoE-026854).

References

[1] C. Anglano, S. Barale, L. Gaido, A. Guarise, G. Patania, R. Piro, F. Rosso, A. Werbrouk: *The Distributed Grid Accounting System (DGAS)*; (Accessed) June 2006. http://www.to.infn.it/grid/accounting/main.html.

[2] A. Barmouta*: Authorization and Accounting Services for the World Wide Grid*; Master thesis, University of Western Australia, June 2004, pp. 1-154.

[3] A. Barmouta, R. Buyya: *GridBank: A Grid Accounting Services Architecture (GASA) for Distributed Systems Sharing and Integration*; 17th Annual International Parallel and Distributed Processing Symposium (IPDPS 2003), April 2003, pp. 22-26.

[4] A. Beardsmore, K. Hartley, S. Hawkins, S. Laws, J. Magowan, A. Twigg: *GSAX Grid Service Accounting Extensions*; September 2002, pp. 1-30. http://www.doc.ic.ac.uk/~sjn5/GGF/ggf-rus-gsax-01.pdf.

[5] Byrom, R., R. Cordenonsi, L. Cornwall, M. Craig, D. Abdeslem, A. Ducan, S. Fisher, J. Gordon, S. Hicks, D. Kant, J. Leake, R. Middleton, M. Thorpe, J. Walk, A. Wilson: *APEL: An Implementation of Grid Accounting Using R-GMA*; September 2005, pp. 1-2. http://www.gridpp.ac.uk/abstracts/allhands2005/apel.pdf.

[6] Byrom, R., J. Walk, D. Kant: *User Guide for APEL - Accounting Using PBS Event Logging*; March 2005, pp. 1-32. http://hepunx.rl.ac.uk/edg/wp3/documentation/apel/apel-user-guide.pdf.

[7] The DataGrid Project: *The DataGrid Project*; (Accessed) June 2006. http://eu-datagrid.web.cern.ch/eu-datagrid/.

[8] D-Grid Initiative: *D-Grid AK2 Middleware und Services Bestandsaufnahme*; Mai 2004, pp. 1-8. http://grid.desy.de/d-grid/ak2/DGrid_AK2_Ergebnisbericht.pdf.

[9] D-Grid Initiative: D-Grid Initiative; June 2006. http://www.d-grid.de/.

[10] G. Dreo Rodosek, H.-G. Hegering, B. Stiller: *Dynamic Virtual Organizations as Enablers for Managed Invisible Grids*; 2006 IEEE/IFIP Network Operations and Management Symposium (NOMS 2006), April 2006, pp. 1-11. ftp://ftp.ifi.unizh.ch/pub/techreports/TR-2005/ifi-2005.09.pdf.

[11] E. Elmroth, P. Gardfjäll, O. Mulmo, A. Sandgren, T. Sandholm: *An OGSA-Based Bank Service for Grid Accounting Systems*; 2nd International Conference on Service Oriented Computing, June 2004, pp. 279-288.

[12] I. Foster, H. Kishimoto, A. Savva, D. Berry, A. Djaoui, A. Grimshaw, B. Horn, F. Maciel, F. Siebenlist, R. Subramaniam, J. Treadwell, J. Von Reich: *The Open Grid Services Architecture*; Version 1.0: Informational Document, Global Grid Forum (GGF), January 2005, pp. 1-61. http://www.ggf.org/documents/Drafts/draft-ggf-ogsa-spec.pdf.

[13] C. Frogner, T. Mandt, S. Wethal: *Cluster and Grid Computing: Accounting and Banking Systems*; Study Project Report, May 2004, pp. 1-59. http://hovedprosjekter.hig.no/v2004/data/gruppe05/files/cgc2004_report.pdf.

[14] Gagliardi, F., P. Graham, M. Heikkurinen, J. Nabrzynski, A. Oleksiak, M. Parsons, H. Stockinger, K. Stockinger, M. Stroinski, J. Weglarz: *GRIDSTART Project: IST Grid Projects Inventory and Roadmap*; March 2005, pp. 1-281. http://www.gridstart.org/download/GRIDSTART-IR-D2.2.1.4-V1.6.doc.

[15] P. Gardfjäll: *SweGrid Accounting System Bank*; December 2003, pp. 1-14. http://www.sgas.se/docs/SGAS-BANK-DD-0.1.pdf.

[16] R. H. Garrison, E. Noreen, P. C. Brewer: *Managerial Accounting*; 11th Edition, McGraw-Hill/Irwin, December 2004.

[17] J. Gerlach, B. Neumann, E. Moldauer, M. Argo, D. Frisby: *Determining the Cost of IT Services*; Communications of the ACM, Vol. 45, No. 9, September 2002, pp. 61-67.

[18] J. Gordon: *Accounting, 'the last A'*; Workshop Presentation, May 2005, pp. 1-18. http://www.e-irg.org/meetings/2005-NL/johngordon-accounting.pdf.

[19] M. Göhner, C.-P. Rückemann: *Existing Grid Accounting Approaches*; D-Grid (in German), Area of Monitoring, Accounting and Billing within the D-Grid Integration Project, April 2006, pp. 1-24. https://www.d-grid.de/fileadmin/dgi_document/FG2/koordination_mab/mab_accounting_ansaetze.pdf.

[20] The Global Grid Forum: *OGSA Resource Usage Service WG (RUS-WG)*; (Accessed) June 2006. https://forge.gridforum.org/projects/rus-wg.

[21] The Globus Alliance: *Globus: OGSA - The Open Grid Services Architecture*; (Accessed) June 2006. http://www.globus.org/ogsa/.

[22] The Grid-based Application Service Provision (GRASP) Project: *GRASP*; (Accessed) June 2006. http://eu-grasp.net/english/default.htm.

[23] The Grid-based Application Service Provision (GRASP) Project: *GRASP Tutorial, First Presentation: SLA Document, Manageability and Accounting Subsystem*; February 2005. http://eu-grasp.net/english/SalernoMeeting/GRASP%20Tutorial%20Final%20-%20Verdino.ppt.

[24] The Gridbus Project: *The GRIDS Lab and the Gridbus Project*; (Accessed) June 2006. http://www.gridbus.org.

[25] IBM: *IBM Grid Computing*; September 2005. http://www-1.ibm.com/grid/.

[26] R. S. Kaplan, W. Bruns: *Accounting and Management: A Field Study Perspective*; Harvard Business School Press, December 1987.

[27] R. S. Kaplan, A. A. Atkionson: *Advanced Management Accounting;* Third Edition, Prentice Hall, January 1998.

[28] B. R. Katzy: *Design and Implementation of Virtual Organizations*; Thirty-First Hawaii International Conference on System Science, Vol. 4, January 1998, pp. 142-151.

[29] R. Piro, A. Guarise, and A. Werbrouk: *An Economy-based Accounting Infrastructure for the DataGrid*; Fourth International Workshop on Grid Computing, November 2003, pp. 202-204.

[30] C.-P. Rückemann, M. Göhner: *Evaluation of Existing Accounting Approaches in the Area of Grid Computing*; D-Grid (in German), Area of Monitoring, Accounting and Billing within the D-Grid Integration Project, pp. 1-16, April 2006. https://www.d-grid.de/fileadmin/dgi_document/FG2/koordination_mab/mab_accounting_bewertung.pdf.

[31] T. Sandholm, P. Gardfjäll, E. Elmroth, L. Johnsson, O. Mulmo: *An OGSA-Based Accounting System for Allocation Enforcement Across HPC Centers*; 2nd International Conference on Service Oriented Computing, November 2004, pp. 279-288.

[32] M. Schiffers: *Modelling Virtual Organizations in Grids*; Technical Report, Department of Informatics, Ludwig-Maximilian University, Munich, Germany, 2006, to appear.

[33] M. Waldburger, B. Stiller: *Toward the Mobile Grid: Service Provisioning in a Mobile Dynamic Virtual Organization*; University of Zurich, IFI Technical Report 2005.07, August 2005, pp. 1-12. ftp://ftp.ifi.unizh.ch/pub/techreports/TR-2005/ifi-2005.07.pdf.

[34] T. Weishäupl: *Business and the Grid - Economic and Transparent Utilization of Virtual Resources*; PhD thesis, University of Vienna, December 2005, pp. 1-133. http://www.pri.univie.ac.at/~weishaeupl/tw-thesis.pdf.