# GRIDSpace: Semantic Grid Services on the Web — *Evolution towards a SoftGrid*

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## Abstract

*This paper advances the notion of software in existing Grid services as discussed in OGSA, which provides software middleware or wrappers for accessing hardware resources towards the notion that the resources provided can be hardware, software, or hybrid hardware/software. It also proposes an approach using the integration of Grid service, Semantic Grid, and Web2.0 to overcome some of the limitations of the existing Web services architecture which relies on having the Web version of the RPC mechanism and thus has difficulty in dealing with massive scale of user participation and communication across the Internet. The new approach produces a novel Grid architecture – GRIDSpace.*

## 1. Introduction

The Grid [1] is a powerful distributed computing infrastructure that dynamically brings together heterogeneous computing resources at local or geographical scales that can solve complex problems. As Grid computing has evolved, two prominent research directions emerge in recent years. The first direction, using Web services as the wrapper and hence the 'embodiment' of virtual Grid resources, has become increasingly popular and led to the Open Grid Services Architecture (OGSA) [2], which provides a standardised yet extensible set of services to define the Grid system reference architecture. Meanwhile, the Semantic Grid [3] is a recent Grid computing initiative, aiming to achieve a high degree of automatic collaboration amongst intelligent Grid services on a global scale by means of semantically rich information associated with Grid resources.

The work presented in this paper builds on our observation that the three important technologies – Grid Services, Semantic Grid, and Web2.0 – have increasingly received momentum in both research and industry, however, their development has largely been separated. Hence, it would be interesting and reasonable to integrate them into an organic Grid ecosystem to solve complex distributed computing problems on the Web.

The remainder of the paper is organised as follows. Section 2 provides a state-of-the-art review of three primary research fields – Grid services, Semantic Grid, and Web2.0. The motivation of this paper is then summarised in Section 3. In Section 4, we first discuss the conceptual model of GRIDSpace, then propose the reference architecture of GRIDSpace. The paper concludes in Section 5.

## 2. Overview of Technologies

In this section, we would like to provide an overview of three technologies, on which the GRIDSpace is built, which emphasises both technical and philosophical issues that have inspired the GRIDSpace architectural design.

### 2.1 Grid Service

Service Oriented Architecture (SOA) and Web services provide dynamic and reusable end-to-end resource integration solutions in a loosely-coupled manner. Inspired by SOA and Web services, OGSA [2] aims to define a core set of capabilities and behaviours of Grid systems using SOA, thus aligning Grid technologies with Web services technologies to leverage the integration capability of the SOA. First, and foremost, OGSA defines the concept of **Grid service**: "a potentially transient Web service based on Grid protocols expressed by WSDL" [4]. Grid service

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represents the convergence of principles and technologies from both the Grid computing and Web services communities. From the Grid service definition, one can ascertain that what makes Grid service different from traditional Web services is their "transient" nature. This is due to the different original purposes of these two computing paradigms. Grid computing emphasises the concept of a "virtual" resource pool, where the user of the resource pool have little or no a priori knowledge about the actual state, type, and features of the resources. This is in contrast with contemporary Web services computing, where an end-to-end "function-based" service consumption is often pursued by the service consumer, who discovers, selects, and invokes desirable Web services.

Therefore, Grid services generally require additional support for the virtual pool, service instantiation and state management as defined in OGSA. In effect, OGSA provides several categories of services in the Grid middleware layer that can fulfil such requirements. These are: Infrastructure Services, Data Services, Resource Management Services, Execution Management Services, Security Services, Self Management Services, and Information Services. These services constitute the second logic layer in the 3-tier view in the OGSA specification. The application layer and the Grid infrastructure layer sits above and underneath respectively. Recently, some research has proposed alternative approaches to address the integration of Web services and Grid. For example, Naseer and Stergioulas [5] have envisioned a trend to use Web services as "wrappers" or "transporters" of Grid services. In their first approach, Grid resources are embedded in to the Web services as dedicated functions in an XML document. This gives rise to *Grid-based Web services*. On the other hand, Web services can also be inherited into the existing Grid resources, this results in their second approach – *Web-based Grid services*.

## 2.2 Semantic Grid

Observing the gap between aspiration and practice in Grid computing, Roure et al. [3] first identify the need for a **Semantic Grid**, and argue for a Semantic Grid as "an extension of the current Grid in which information and services are given well-defined meaning [6]. However, they have not indicated how such a Semantic Grid can be realised. We believe the techniques of the Semantic Web (SW) and Semantic Web Services (SWS) need to be applied to the Grid environment so that resources and services on the Grid can be described in a machine understandable manner. This way, heterogeneous data and their associated various tasks on the Grid can be integrated and performed in a (semi) automatic fashion with little human intervention. Recent research efforts have provided concrete architectures, models, and algorithms for the Semantic Grid. Corcho et al. [7] propose a Semantic Grid reference architecture – S-OGSA, which extends OGSA by defining a lightweight mechanism that will allow for the explicit use of semantics along with the associated knowledge services to support Semantic Grid services. More importantly, they defined six design principles for architecting the Semantic Grid and articulated the requirements of *semantic capabilities* to aid "migration" the Semantic Grid from the current OGSA environment. Toma et al. [8] provides an integrated infrastructure for Semantic Web Services and Grid that uses Web Services Modelling Ontology (WSMO) and its associated language WSML to semantically describe Grid services functions in order to achieve the automation of Grid service tasks. Zhuge and Li [24] have defined concepts, axioms, tuples, and set operations which constitute the "Semantic Space" for P2P networks. One possibility would be to extend their semantic space approach for Grid services discovery in a peer-to-peer system.

## 2.3 Web2.0

Research into Web2.0 [9] has flourished in recent years. One of the main principles of Web2.0 is to think of Web as a platform of services [10] (vs. applications), in which (1) distributed applications are built by composing services, and (2) users not only manage private data, but add extra value to the Web2.0 services through a deeper level of participation, e.g. contributing content and capabilities. We believe Web2.0 principles have several important implications in Grid computing on the Web. First, Grid resources must be formalised into services based on open standards, which has been partly addressed in the OGSA specification. However, the issue yet to be tackled is the integration of Web2.0 into GRIDSpace. Second, service composition is the key for applications and users. In current Web2.0 settings, service composition comes as the **Mashup**, Web applications that combine information from several sources and is provided through simple Web APIs. In Grid computing settings, we believe Mashup plays a key role in forming the Virtual Organisation, in which Grid services users actually sit. In Section 4, we will illustrate that both Service mashup (server-side) and User mashup (client-side) can facilitate the user-centred Virtual Organisation in GRIDSpace. Third, Grid users at varying levels (i.e. end users, scientists, professionals) shall all contribute to the Grid platform during their participation.

Lin [11] and Hogg et al. [12] suggested that Web2.0 is an '**attitude**' or a philosophy respectively. Following this idea, in our previous work [13], we have successfully introduced the Web2.0 attitude into our research of SOA. In particular, we leverage Web2.0 connection and usage technology (e.g. REST, RSS, and Atom) to realise a user-centred service discovery architecture. On the other hand, Lin [11] also illustrated how research in SOA can benefit Web2.0 in achieving 3S: Scale, Simple, and Sense. To our understanding, these three goals resemble the convergence of Grid services, Web2.0, and Semantic Grid respectively.

## 3. Motivation

The roadmap of current Grid computing development reflects the early negligence of the "soft" aspect of the Grid computing. Grid computing originated from sharing and virtualising computing resources, mostly hardware such as disk storage, CPU, memory, etc. in order to conduct computationally intensive scientific research. Such an initial constraint results in the low-level hardware 'flavour' rooted in the Grid protocols. This is evident from the layered Grid protocol architecture [1], where three out of four Grid architectural layers correspond to (or are below) the transport layers in the IP protocol stack. The "soft" work is done in the 'collective' layer consisting of many different underlying technologies with adhoc, non-standardised solutions essential for Grid applications to coordinate multiple resources serving end user requirements. Aiming to provide systematic solution to "soften" problems in Grid computing, OGSA takes advantage of important Web services properties such as service description, discovery, invocation, etc, and allows resources to be described using a unified format and protocol. However, we believe that OGSA only offers a "soft middleware" that provides access to resources that are mainly hardware.

A closer introspection at the "hard" problem further reveals the cause of the problem – i.e. the choice between the resources sharing vs. service orientation. Resource sharing, as suggested in the Grid literature, is the ultimate goal (i.e. the holly grail) of Grid computing. However, we believe that resource, a concept originally evolved from a physical entity, differs a great deal from a (Web) service, which has its root in software. Web service is purposefully provided to be consumed by various consumers from the Internet. It is a logical entity that has been "lifted up" from a number of low level components or resources in order to satisfy users' requirements, and is optimised for accommodating users (i.e. coarse granularity, messaging, loose-coupling, business process, data isolation, etc.). Since resource in Grid computing constitutes an 'as is' unit, it is not as ready, or cooperative for massive scale of usage and sharing as are (Web) services. The aim of Grid computing is thus to provide an infrastructure that can facilitate such a resource exploitation and sharing. Differently, in our approach, rather than providing an all-powerful yet monolithic infrastructure, we leverage collective efforts (e.g. contribution and capabilities of Web2.0 users, semantic annotations of domain experts) to gradually augment each individual resource into a Grid service "on the Web" ready for end users. OGSA has attempted to bridge the gap between resources and services by providing a Web services wrapper or 'transporter' to existing Grid resources. We need to achieve a radical transformation from resource to service in order to "soften" Grid computing. This is where Web2.0 comes into play. With the help of domain-specific community support, collective intelligence in conjunction with formal semantic techniques, we envision a Grid that natively supports both software and hardware resources, i.e. in the form of unified semantic Grid services. For example, consider a data mining service analysing trillions of data fed by a virtual storage and serving for CRM applications. We thus generalise the notion of resources to being hardware resources, software resources, or hybrid hardware/software resources. This software expands from its role of merely providing software middleware or wrappers for accessing hardware resources. Such a notion is truly a "SoftGrid".

Following the shift from resource to service, we need to formally deal with the concept of "transient" as mentioned in Section 2.1. It is clear that OGSA has addressed this issue through the OGSI and WSRF specifications. Going beyond the individual resource state management, a higher level or wider scope of "transient service(s)" is essential for fulfilling end users applications in the SoftGrid. Adopting both the service-oriented and user-oriented strategy to approach this level of service state management gives rise to the notion of "Transient Virtual Organisation", which involves the lifecycle management of self-organised, dynamic *Service Space*. (See Section 4.2). Previous studies ([14] and [15]) suggested that the existing Web services architecture based on Remote Procedure Call (RPC) is not indeed "Web-oriented" because RPC is more suitable for a closed local network and raised concern that "Web services do not have much in common with the Web" [16], and leading to potential weakness such as scalability, performance, flexibility, and implementability [17]. Grid services thus can be reasonably argued suffer the same issues of these potential weaknesses. This requires us to reconsider the underlying architectural design of the Grid services. In particular, the discovery, interaction, and composition styles amongst different Grid services shall take into account core Web elements and perhaps keep themselves in line with successful scalable Web2.0 technologies and communities. In summary, GRIDSpace architecture is motivated by four major factors – Soft aspect of Grid, service-orientation, transient service space, and Web-oriented architecture – that are built on top of Grid services, Service-Oriented Computing, Semantic Grid, and Web2.0.

## 4. GRIDSpace

In this section, we discuss the conceptual model and architecture of the GRIDSpace.

### 4.1. Conceptual Model

First we define a core concept: a **Service Space** is a supportive environment where a collection of Grid services gather for the purpose of fulfilling user demands. Service space is the 'first class' concept in GRIDSpace to cope with challenges inherent in distributed Grid services. It should be noted that a service space does not host, manage, or run services as do most services containers [18]. Rather, it provides infrastructure to enable service discovery and "mashup" at various levels. Grid services within a Service Space are referred to as 'members' of that Service Space. In GRIDSpace, we have identified and instantiated three types of Grid Service Spaces: *OGSA Space*, *Semantic Grid Space*, and *Virtual Organisation*.

As shown in Figure 1, three layers are presented in the conceptual model – Grid, Service Space, and Application. The Grid layer contains the Grid Middleware Fabric that implements fundamental Grid protocols and Grid resource management. This layer does not differ from existing Grid computing techniques and tools (e.g. the Globus Toolkit). It also serves as the interface for Grid service providers who want to expose, publicise, or advertise computing resources "on the grid" in return for business benefits and/or scientific research reputations.

The Service Space Layer is the focal point of this section. In this layer, regular Grid resources are 'augmented' to Semantic Grid Services which are then integrated into various Virtual Organisations in response to user requirements from the application layer. Three major Service Spaces are defined for 'lifting up' Grid services, i.e. the OGSA Space, the Semantic Grid Space, and the Virtual Organisation Space. In Figure 1, texts with bold and italic face represent the three technologies utilised in service spaces. While Web 2.0 technology and 'attitude'[11] is to be entrenched in all three types of service spaces, Semantic Grid and Grid Service are particularly helpful in building Semantic Grid Space and OGSA Space respectively.

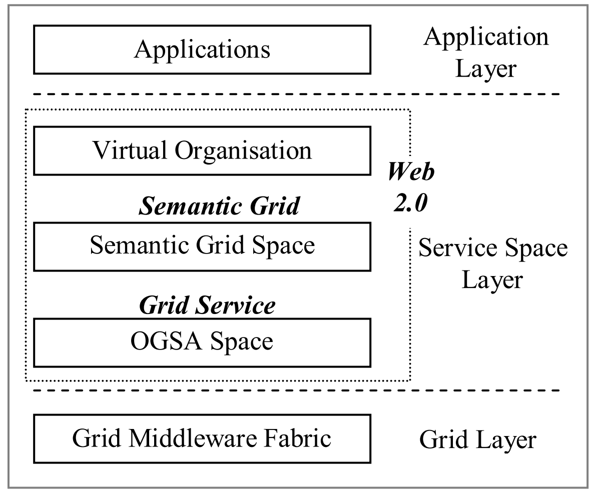


**Figure 1 Layered Conceptual Model**

**OGSA Space** (OS) is a preliminary form of *Service Space* that complies with the latest OGSA specification (OGSI or WSRF). It provides fundamental infrastructure that enables the discovery of a large number of basic Grid services in a loosely-coupled manner regardless of their locations, categories, and qualities. OGSA Space appears as an initial stage of evolving Service Spaces. From the perspective of the Service-Oriented Computing, it resembles a number of contemporary global Web service registries such as public UDDI Business Registry, XMethods, StrikeIron, IBM SOA Catalog, etc. that can facilitate essential keyword-based service discovery. In addition to the OGSA environment and simple service discovery, OGSA Space also supports service subscription that allows *Scientist* and *Professionals* to track down interesting Grid services.

**Semantic Grid Space** (SGS) refers to a focused *Service Space* where a group of related Grid services forms a domain-specific Grid service community in order to facilitate dependable collaboration through trust-driven service selection and semantic-based service discovery. Domain here refers to areas with limited boundaries such as a specific geographical region, a particular industry, etc. Semantic Grid Space shall provide sufficient elements for the establishment and enforcement of trust for users (e.g. Chang, Dillon, and Hussain in [19]) and 'sense of community' [20] for member Grid services. In this paper, we do not intend to rigorously analyse the motivation of the Semantic Grid Space. However, we have recently observed that numerous Web 2.0 communities (e.g. 43things, Youtube, MySpace, del.icio.us) prosper for various reasons that can be studied in a number of disciplines including economy, social science, biology, and information science. The Semantic Grid Space respects this phenomenon. Moreover, it utilises and extends such 'collective intelligence' by providing formal semantic-enabled and semantic-aware instruments that help to build long-lasting Grid service communities beneficial for all Grid service providers and consumers.

**Transient Virtual Organisation** (VO) is a demand-driven *Service Space* that allows a small group of Grid services to form an ad hoc team working collectively in order to fulfil particular user demands during a given period of time. The main reasons for spawning such a transient VO lies in the gap between the complexity of actual user requirements and the limitation of each individual Grid service obtained from both OGSA and Semantic Grid Space. In addition to distributed resource sharing as suggested in Ian et al. [1], where several scenarios call for the emergence of virtual organisations, we believe ad-hoc **Grid service mashup** – Grid service mediation, expansion, customisation, and integration are essential for a VO to satisfy real-world user requirements. Presumably, VO members often come from the same Semantic Grid Space so that most collaboration grounding – trust establishment, shared mission and value, agreed-upon business protocol, and essential technical interfaces, etc. – has been addressed by the semantic-based augmentation prior to the SGS formation. This well-established SGS is defined as the **enclosing SGS** of the VO. During the VO member selection, preferences are given to enclosing SGS members. It is however possible that external Grid services (from the OS or another SGS) are sometimes 'invited' to join a VO in case that appropriate Grid services cannot be found solely from a single *enclosing SGS*. It is also possible that a SGS member is engaged in several VOs. In this case, the proportion of its commitment to a particular VO becomes an important criterion for the VO member selection.

## 4.2. Overall Architecture

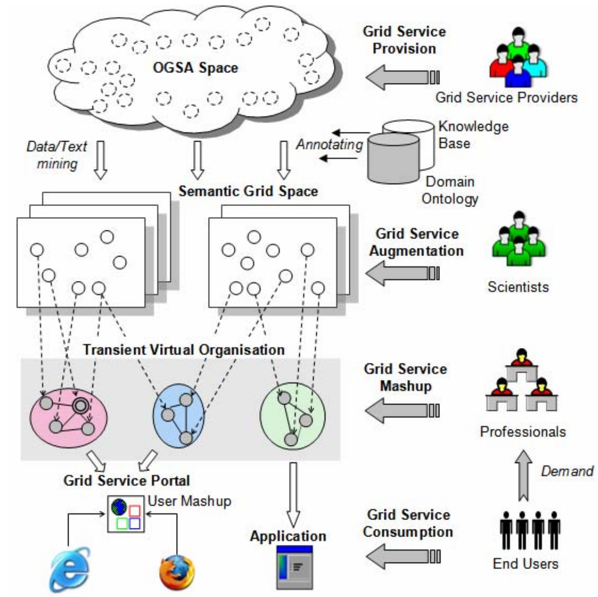


**Figure 2 Overall architecture**

Derived from the Conceptual Model is the overall architecture of GRIDSpace illustrated in Figure 2. On the right side of the overall architecture, we have defined four types of GRIDSpace participating stakeholders from the top to the bottom – Grid Service Provider, Scientists, Professionals, and End Users. Using the Grid Middleware Fabric, a **Grid Service Provider** (GSP) is able to create and deploy useful computing resources "on the Grid" for its own benefits and profits. The OGSA Space provides tools that can wrap Grid resources and protocols using WSDL, thereby exposing appealing computing resources in the form of Internet-accessible Grid services. For the purpose of advertisement, a GSP may explicitly register its Grid services with the OGSA Space. On the other hand, the OGSA Space also supports the index-based (vs. the registry-based) services discovery approach [21], where a focused Grid service crawler actively and periodically retrieves available Grid services metadata across the Internet. As a result, the OGSA Space has included numerous Grid services with various functionalities and different qualities.

A **Scientist** conducts in-depth search in the OGSA Space and selectively collects Grid services from various GSPs into several Semantic Grid Spaces based on his or her long-term research interests and the semantics of these Grid services. During this process, a great number of anarchic Grid services are 'clustered' into a well-organised Semantic Grid Space dedicated in one specific domain. In general, we envisage that scientists can apply two approaches to semantically enrich existing Grid services. The first top-down approach is based on the concept of ontology engineering [22], where scientists and domain experts manually annotate relevant Grid services using specific domain ontologies and/or knowledge databases. The second empirical approach builds on practical methods such as data/text mining, business intelligence, machine learning that can be carried out (semi-) automatically without intensive human involvement. The semantic enrichment onto the Grid aims to "achieve a high degree of easy-to-use and seamless automation to facilitate flexible collaborations and computations on a global scale" [6]. Towards this end, the Semantic Grid Space nurtures Grid services mainly through three means: semantic enrichment, semantic classification, and semantic discovery. Furthermore, from the value chain [23] perspective, scientists thus add premium values to the OGSA Spaces by providing unlimited 'views' – the Semantic Grid Space – of existing basic Grid services in a refreshed, specialised, and tailored fashion. This results in reduced cost of locating Grid services for both *Professionals* and *End Users*. It also significantly helps Grid Service Providers to advertise their Grid services by bringing them 'closer' to the potential users in a professional view.

A **Professional** directly deals with End User's demands and selects appropriate Grid services from existing Semantic Grid Space to conduct **Grid Service Mashup** – a process where related Grid services are rapidly integrated, customised, expanded, and mediated in an ad-hoc manner – in order to form a Virtual Organisation fulfilling the customer requirements. Professionals free End Users from having to spend huge amount of time on (1) searching and selecting amongst millions of Service Providers; (2) adapting selected Grid services to their specific requirements within applications using proprietary programming techniques. From a Semantic Grid Space, professionals and end users can always find a list of Grid services based on the matching between requirements and service capabilities. Prior to the actual service consumption, they have to spend lots of time in choosing the right Grid services (e.g. desirable quality and reasonable prices). This undoubtedly increases difficulties of end users, who often cannot afford to conduct a comprehensive service assessment due to time and cost constraints. Moreover, the business environment is always changing caused by fierce global competition as well as abundant business opportunities. This means that rules and results of service selection may differ a great deal from one time period to another, from one context to the next. Hence, end users and professionals need an effective mechanism to efficiently select the most appropriate service amongst tens or even hundreds of similar Grid services in order to fulfil their requirements. Moreover, the service selection mechanism needs to take into account specific user requirements and preferences given the same business context. Thus both objective and subjective factors need to be supported by the selection solution. Our previous work in [19] has made the first endeavours to address service assessment and selection using the trust model and methodology.

An **End User** represents the business demands from the customers. It is the dynamic force for the demand-driven business model, where a personalised and complex user demand requires several customised Grid services to work together to deliver satisfactory service invoked from within the applications built by the End User. End users often delegate all requirements to a specific Professional, who may be found through some well-known broker database or recommended by other users. Alternatively, rather than relying exclusively on the Service Broker, end users can also track down constantly-changing Grid services in any Service Spaces through the user-centred **Grid Service Portal** (GSP). A GSP refers to a locally-accessible and highly-customisable user interface that provides a personalised view of activities and information essential to performing Service Space functions. In other words, GSP acts as a proxy on behalf of the end users to maintain a list of communication channels to involved Service Spaces. Unlike a traditional HTTP proxy server shared by a group of corporate users, SSP is dedicated to serve only one user, thus creating the 'user-centred' view. SSP also reveals the notion of 'User Mashup'– a core concept underpinning the attitude of Web2.0 [9]. **User Mashup** (see Figure 3) in the context of GSP refers to an activity in which the user can 'hack' standard Service Space communication protocols, and hence extensively customises user interface or features based on his own preferences. User Mashup has a far-reaching influence on the development of user-centred Service Space. It endows users with a broader control over the information flow across the Service Space as well as a refined user experience seamlessly integrated with end user applications in a loosely-coupled manner. Most significantly, User Mashup provides a powerful yet simple mechanism by which infinite 'virtual' syndications of Service Spaces can be created for each SSP. A **Virtual Syndication** of Service Spaces is a fresh, highly filtered, and combinatory view of several Services Spaces within a GSP. It is created, customised, and solely owned by each individual SSP user and does not affect other users or existing Service Spaces in any ways.

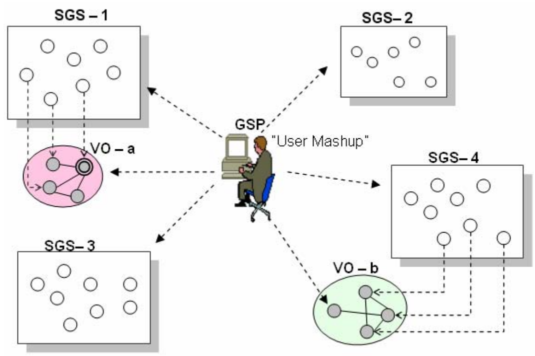


**Figure 3 User-centred Grid Service Portal**

## 5. Conclusions

Grid computing is about resource sharing through dynamic formation and disbanding virtual organisations. It aims to solve large-scaled distributed computing problems that need intensive computational resources. With the recent surge of Service-Oriented Computing, the concept of Grid service proposed in OGSA has made the first step towards integrating these two technologies through providing software middleware (i.e. Web services wrapper) that enables open access to transient computational resources.

In this paper, we advanced the notion of software middleware in current OGSA Grid services towards the notion that the resources provided can be hardware, software, or hybrid hardware/software. This constitutes a truly 'SoftGrid', which requires a radical transformation from resources to services. Wrapper-based methods (e.g. OGSA) that partially address this issue however do not fully support service-orientation. We propose an approach using the integration of Grid service, Semantic Grid, and Web2.0 to realise such a transformation. This leads to the GRIDSpace architecture that supports a completely service-oriented *SoftGrid* on the Web.

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