Journal of Technology Management & Innovation

Received May 5, 2007 / Accepted June 10, 2007

GRID INFORMATION TECHNOLOGY AS A NEW TECHNOLOGICAL TOOL FOR E-SCIENCE, HEALTHCARE AND LIFE SCIENCE

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Abstract

Nowadays, scientific projects require collaborative environments and powerful computing resources capable of handling huge quantities of data, which gives rise to e-Science. These requirements are evident in the need to optimise time and efforts in activities to do with health. When e-Science focuses on the collaborative handling of all the information generated in clinical medicine and health, e-Health is the result. Scientists are taking increasing interest in an emerging technology – Grid Information Technology – that may offer a solution to their current needs. The current work aims to survey how e-Science is using this technology all around the world. We also argue that the technology may provide an ideal solution for the new challenges facing e-Health and Life Science.

Keywords: Grid, Grid Information Technology, e-Science, e-Health, Healthcare, Life Science.

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1. Introduction

In this work we understand "e-Science" to mean the set of scientific activities conducted through the use of distributed resources accessible via the internet (FECYT, 2004, p. 3) and where the computational infrastructure plays a central role in the collaborative research (Buyya and Venugopal, 2005, p. 9). Within the life sciences (Oberdorfer and Gutowski, 2004), the focus of e-Science in the area of health gives rise to "e-Health".

Various scientific disciplines have gone from using supercomputers (Smarr and Catlett, 1992) as support resources to using "computing farms" more recently. These systems are made up of clusters of computers with redundant elements (Patterson *et al*., 1988). They seek cost reductions (Brewer, 1997; Fox and Furmanski, 1999), and they are the most economic solution available (Abbas, 2004, p. 47). But needs in computing and storage resources (Moore *et al*., 1999) continue to grow, and these solutions are proving insufficient for certain requirements (Messina, 1999). Indeed, it was in scientific research that information and communication technology first proved to be essential (Berman and Hey, 2004). The large amount of data generated (Hey and Trefethen, 2003) and the geographic dispersion of the researchers, who are participating in increasingly globalised projects and need to interact and share data and results (Berman and Hey, 2004, p. 15), means that a new technology is becoming necessary, one that allows users to share the dispersed resources and that improves upon the benefits currently made possible by the internet. Grid Information Technology, or GRIT (Maqueira and Bruque, 2005) is emerging as an innovative solution to these needs (Hey and Trefethen, 2002; Buyya, 2005). GRIT exploits the heterogeneous computing resources available to build a virtual supercomputer of a computing power simply unimaginable up to now (Foster and Kesselman, 1999).

The current work aims to survey how Grid Information Technology is being used in numerous e-Science projects in the US, Europe and the Asia-Pacific region, and how the new challenges facing e-Health could possibly find a solution in these technologies. Our contribution may prove useful as a starting point for reflection about the possible applications of Grid Information Technology in both areas (e-Science and e-Health). With this purpose, we have structured the work as follows. The second section introduces the concept of Grid Information Technology. Section 3 provides a brief outline of the e-Science projects using these technologies currently under way around the world. Section 4 looks at the particular case of e-Health: it discusses how Grid Information Technology is being used in this area, and how it may offer a solution to the huge challenges facing the field. In section 5 we describe the main conclusions of the work.

2. Grid Information Technology

The definition of the computing Grid has gone from positions emphasising the access to high-end computing power (Foster and Kesselman, 1999) to others stressing the non-centralised, standard nature, and provision of the quality of service, or QoS (Coulouris *et al*., 2001, pp. 585-590) that is required (Foster, 2002). Thus, Foster and Kesselman (1999, p. 18) initially defined the computing Grid as "a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities". But this initial definition does not quite reflect the important implications of Grid technology. Foster, Kesselman and Tuecke (2001, p. 2) subsequently redefined the concept of grid computing, introducing a vision that is more useful for organisations. Grid computing, according to these authors now, is concerned with "coordinated resource sharing and problem-solving in dynamic, multi-institutional virtual organizations". The set of institutions and/or users that share these resources and comply with the rules for sharing them make up a virtual organisation, or VO (Foster, Kesselman and Tuecke, 2001, p. 2). Among practitioners the term grid has become a marketing slogan in recent years, which firms have hurried to use to describe their products, mirroring what occurred with internet technology in the 1990s (Foster, 2002). The term "grid" has consequently been distorted, being used to designate products that may conceivably fall within distributed computing, but should not be regarded as grids (Berstis, 2002). This made a new definition of the concept necessary. (Foster, 2002) offers a checklist of three basic points to determine if a particular system can be considered a grid or not: (1) it should involve the coordination of heterogeneous resources not subject to centralised control; (2) it should use standard, open, general-purpose protocols and interfaces; and (3) it should offer the necessary quality of service.

Foster's (2002) checklist introduces two competing positions. A first position (Foster, 2002) considers that only developments using the de facto standard OGSA (Open Grid Services Infrastructure) (Foster, Kesselman and Tuecke, 2004) based on the basic *Globus Toolkit* development (Foster and Kesselman, 1999b) should be regarded as Grid technology. A second position corresponds to a more commercial interpretation that regards the various proprietary developments from software companies as Grid technology (Bertsis, 2002). A new term has been proposed to resolve this dispute, embracing both positions from a broad perspective (Maqueira and Bruque, 2005): Grid Information Technology. The new term has two components: (1) Grid Information Technology in the strict sense, which coincides with Foster's (2002) position; and (2) potential Grid Information Technology, which coincides with the more commercial position (Berstis, 2002). The concept of Grid Information Technology in the broad sense is defined as follows: *GRIT is an innovative technological structuring of the existing computing and telecommunications resources distributed geographically, which, through the joining together and sharing of resources, transcends the individual organisation and supports the complex interrelations that are emerging in the new Virtual Organisations. GRIT thereby offers, via the virtualisation of resources, a homogeneous and reliable access to these resources to heterogeneous users* (Maqueira and Bruque, 2005). In the next section we see how Grid Information Technology is being used in e-Science.

3. Grid Information Technology and e-Science

Both e-Science and the health sciences are key scientific disciplines in the use of these new technologies (Baker and Perrott, 2000, p. 17). In this section we describe various examples of how Grid Information Technology is providing a solution to the greater computing and data-handling requirements of e-Science in the US, Europe and Asia.

Grid Information Technology and e-Science in the US

Although Grid Information Technology was born in the field of high-energy physics, it quickly spread to other scientific areas (meteorology, health and biology), as a consequence of the new opportunities that it opened up in practically all scientific or industrial fields. A growing number of e-Science projects that are using these technologies are currently running in the US.

The pioneering Globus project (Foster and Kesselman, 1999b) developed a middleware used in the main e-Science projects implemented in the US. Table 1 reports the most important e-Science projects in the US grouped into two different lines.

	e-SCIENCE GRID PROJECTS IN USA			
	PROJECT	URL	DEVELOPED BY	DESCRIPTION
	GLOBUS	http://globus.org	DARPA, DOE, NASA, NSF	Research on Grid infrastructure and tools, development of the open source software Globus Toolkit. This software has played a key role in the development of GRIT.
Line 1	PPDG (*Particle Physics Data Grid*)	http://www.ppdg.net	DOE Office of Science	Grid development for data analysis in nuclear and High Energy Physics.
Line 1	GriPhyN (*Grid Physics Network*)	htpp://www.griphyn.org	NSF	R+D on data analysis for Physics experiments: ATLAS, CMS, LIGO, SDSS.
Line 1	GRAPPA (*Grid Acces Portal for Physics Applications*)	http://iuatlas.physics.indiana.edu/grappa/	NSF	Point of access for Grid resources applied to experiments on High Energy Physics.
Line 1	Fusion Collaboratory	http://www.fusiongrid.org	DOE	Provides a national collaboration environment for nuclear fusion research.
Line 2	DOE ScienceGrid	http://www.sciencegrid.org	DOE Office of Science	Provides access to resources and applications to scientific laboratories of DOE and to several collaborating universities.
Line 2	DISCOM Grid	http://www.cs.sandia.gov/discom	DOE Office of Science	Provides access to distributed resources for 3 DOE laboratories.
Line 2	Earth System Grid	http://www.earthsystemgrid.org	DOE Office of Science	Provides an environment for large databases analysis related to climate change.
Line 2	Access Grid	http://www.accessgrid.org	DOE y NSF	Collaborative system for research groups using existing visualization technologies.
Line 2	Information Power Grid	http://www.ipg.nasa.org	NASA	Grid environment for Aerosciencies and NASA missions.
Line 2	NVO (*National Virtual Laboratory*)	http://www.srl.caltech.edu/nvo	NSF	Virtual observatory based on Grid Information Technology that enables the study of Galaxies morphology.
Line 2	NEESgrid (*Network for Earthquake Engineering Simulation Grid*)	http://www.neesgrid.org	NSF	Grid environment for earthquakes research. Analysis of data and simulations on Seismology.
Line 2	TERAGRID	http://www.teragrid.org	NSF (NCSA, SDSC, ANL, CACR, PSC)	Links the major supercomputing centres of USA with a bandwidth of 40 Gbps, providing a high computing capacity through the use of added High-Level resources.

Table 1.- Main projects in the USA based on Grid Information Technology in the e-Science area. Source: The authors.

A first line of projects (see Table 1) is made up of projects in particle physics, such as: (a) PPDG (*Particle Physics Data Grid*); (b) GriPhyN (*Grid Physics Network*); (c) GRAPPA (*Grid Access Portal for Physics Applications*) (Bunn and Newman, 2003); and (d) *Fusion Collaboratory* (Keahey *et al*., 2002). A second line includes projects extending to others scientific disciplines, among which (see Table 1): (a) *DISCOM Grid* and (b) *DOE ScienceGrid*, which provide an environment for e-Science among Department of Energy (DOE) laboratories and even collaborating universities; (c) *Earth System Grid*, for simulations and modelling of the climate change that the earth is experiencing (Atkinson *et al*., 2004, p. 424); (d) *Access Grid*, a generic collaborative system using visualisation technologies; (e) *Information Power Grid*: for aeronautical sciences and NASA missions; (f) NVO (*National Virtual Laboratory*) in astrophysics, facilitating for example study of the morphology of the galaxy (Williams, 2003, p. 849); and (g) NEESgrid (*Network for Earthquake Engineering Simulation Grid*), which analyses the effects of earthquakes on different structures (Kesselman, Foster and Prudhomme, 2004).

In both lines two research institutions lead many of the projects (see Table 1): the DOE Office of Science and the National Science Foundation (NSF). This second institution played a very active role in developing the internet.

But the most ambitious project carried out to date in the US is the TERAGRID project, which combines the main supercomputer centres in the country at a speed of 40 Gbps. The project started running in mid-2004, and includes the following centres: (1) National Center for Supercomputing Applications (NCSA); (2) San Diego Supercomputer Center (SDSC); (3) Argone National Laboratory (ANL); (4) Center for Advanced Computing Research (CACR); (5) Pittsburgh Supercomputing Center (PSC); (6) Oak Ridge National Laboratory (ORNL); (7) University of Indiana; (8) University of Purdue; and (9) Texas Advanced Computing Center (TACC). This network offers a huge number of high-level computing resources, and it will be able to support the various projects based on Grid Information Technology on an international scale (Bunn and Newman, 2003, p. 874). The TERAGRID project may play an important role in building a GRIT-based global network in the future. The configuration in this huge virtual computer, together with the existence of an international infrastructure of extremely high-speed networks, could quite possibly pass from the scientific to the commercial domain, as the internet did in the past.

Grid Information Technology and e-Science in Europe

In Europe, the European Union (EU) has financed more than 20 projects since the year 2000. The projects have been very varied, and include those focusing on purely scientific applications and those having a more industrial or commercial dimension. The first efforts were dedicated to developing the fundamental middleware, while the most recent work has focused on developing applications (Parsons, 2003, p. 1). Globus and OGSA are used as the basic development in various EU projects, but UNICORE (*Uniform Interface to Computing Resources*), a development backed by the German government, is also commonly used.

Within the EU's Fifth Framework R&D programme, the pioneering *European DataGrid* began in the year 2000. This project designs and develops scalable software solutions and testbeds (Catlett and Toole, 1999) at the European level, to handle distributed data of the order of petabytes (10^{15} bytes) and tens of thousands of distributed resources, including processors, storage systems and other devices, as well as thousands of simultaneous users. It is a solution for the new e-Science projects, which require intensive computing and the analysis of huge distributed databases. The DataGrid project was coordinated by the European Nuclear Research Centre (*Centre Européen pour la Recherche Nucléaire*, CERN), the institution largely responsible for the World Wide Web, and which promotes the development of Grid Information Technology. The following research organisations participated in the DataGrid project, all providing considerable computing power: INFN (Italy); PPARC (UK); CNRS (France); and NIKHEF (Holland). It used the infrastructure of the European high-speed scientific network GEANT (Davies, 2003; Robertson and Karapandzic, 2003; Clarke and Bright-Thomas, 2003). The project ended in 2004, and at its peak integrated more than 1000 computers and 15,000 gigabytes of data in 25 nodes distributed throughout Europe, Russia and Taiwan. The most significant result of this project, apart from the testbed, was an open-source software that is being used in three scientific fields: (1) high-energy physics: it will be used as the basis of the computing infrastructure for the particle accelerator LHC (Large Hadron Collider); (2) biomedicine (Breton, Medina and Montagnat, 2003): Data GridBlast, first case of use of GRIT in genomics comparative analysis; and (3) earth observation from satellites.

Table 2 reports the most important e-Science projects financed by the EU (project lines 1 and 2), and Table 3 reports those that are fundamentally scientific but have a dimension close to the business domain (lines 3 and 4).

	e-SCIENCE GRID PROJECTS IN THE EUROPEAN UNION			
	PROJECT	URL	USES	DESCRIPTION
	UNICORE	http://www.unicore.org	UNICORE	Development of basic software that enables remote access to Supercomputers by the German Administration. This software has played a key role in the development of GRIT.
Line 1	European DataGrid	http://www.edg.org	Globus	European test-bed. It manages a great amount of data (PetaBytes) and thousands of distributed resources: processors, storing, complex tools and thousands of concurrent users.
Line 1	GridLab	http://www.Gridlab.org	Globus	Simulation and visualization able to be adapted to changing environments, exploiting dynamic resources (autoadaptive applications).
Line 1	DataTAG (*Research & Technological development for a Transatlantic Grid*)	http://datatag.web.cern.ch/datatag	Globus	Design and implementation of High-Velocity network infrastructure that interconnects several national domains. Grids between the UE and USA including QoS and middleware that permits interoperativity.
Line 1	CrossGrid	http://www.eu-crossGrid.org	Globus	Test-bed. It gathers different collaborating organizations; large scale GRITs implementation. It enables simulation and visualization under real-time environments (e.g. virtual reality). Closely related to DataGrid.
Line 1	GRACE (*Grid SeArch & Categorization Engine*)	http://www.grace-ist.org	Middleware based on Globus	Search engine under distributed environments that enable quick and flexible localization of data and computing resources.
Line 1	SeLeNe (*Self e-Learning Networks*)	http://www.dcs.bbk.ac.uk/selene	Based on OGSA	Distributed educational data resources under a collaborative infrastructure. It describes learning objects available through the Web with open and public access (to share or to build new learning objects). It uses Knowledge Grids tools, providing a conceptual space that makes easy to discover relevant information
Line 1	MOSES (*Modular & Scalable Environment for Semantic Web*)	http://www.hum.ku.dk/moses	Globus & OGSA	Small and scalable ontological Knowledge Management System and search engine. It manages searches and responses using a natural interface
Line 2	EGSO (*European Grid of Solar Observations*)	http://www.egso.org	Globus	Solar virtual observatory. It combines heterogeneous data from observations in disperse locations of the Earth.
Line 2	AVO (*Astrophysical Virtual Observatory*)	http://www.eso.org/projects/avo	Globus & OGSA	Virtual observatory for the European Scientific Community.
Line 2	OpenMolGRID (*Open Computing Grid for Molecular Science & Engineering*)	http://www.openmolGrid.org	UNICORE	Provides a unified and extensible environment with information on simulation of molecular structures. It enables molecular design in Chemical Engineering, Life Sciences and Pharmacology.
Line 2	MammoGrid (*European Mammogram database*)	http://www.cordis.lu/ist	Others	Develops a database of mammographies throughout Europe with the aim of being used for research and diagnosis of tumors.
Line 2	BioGrid (*Bio-technology Information & Knowledge Grid*)	http://www.bio-Grid.net	UNICORE	Grid Information and knowledge, enabling localization and access to non-structured data for Biotechnology.
Line 2	EUROGRID (*European Testbed for Grid Applications*)	http://www.euroGrid.org	UNICORE	Test-bed that develops the main software components that permit applications testing based on Grid in the case of Biology (BioGrid), Meteorology and even business applications.
Line 2	GridStart	http://www.Gridstart.org	None	Gathers projects developed under the V Frame Programme with the aim of consolidating the advances in Grid Technology in Europe, fostering the reciprocal connection among similar initiatives, in Europe and abroad.

Tabla 2.- Main projects based on Grid Information Technology in e-Science in the EU. Source: Own work based on Parsons (2003) and Gagliardi *et al.* (2004).

GRID PROJECTS IN THE EU IN THE BUSINESS AREA				
	PROJECT	URL	USES	DESCRIPTION
Line 3	CoG (*Corporate Ontology Grid*)	http://www.cogproject.org	Own application	Commercial application of GRITs that, through the use of ontological models, manages corporate information. It enables access to heterogeneous and disperse data through various systems using a self-acting format conversion.
	DAMIEN (*Distributed Applications and Middleware for Industrial use of European Networks*)	http://www.hlrs.de/organization/pds/projects/damien	UNICORE	It develops tools, from others already existing, that improve the use of supercomputers under GRITs environments. It deepens performance and optimization analysis of HPC devices (e.g. applications on Computer Aided Engineering, CAE).
	FLOWGRID (*Flow-Simulation Grid*)	http://www.unizar.es/flowgrid	Globus	Collaborative environment in Virtual Organizations that improves Research on Fluids Dynamics. It enables, through computational support (CFD), simulations that would be not possible in experimentation (e.g. catastrophic episodes).
	GRIP (Grid Interoperability Project)	http://www.edg.org	Globus & UNICORE	Interoperativity between Globus and UNICORE.
Line 4	GRIA (*Grid Resources for Industrial Applications*)	http://www.gria.org	Own application	Design of business models and processes that may enable new offers and use of computing services based on GRITs under conditions of open markets and accurate prices.
	GEMSS (*Grid-Enabled Medical Simulation Services*)	http://www.ccrl-nece.de/gemss	OGSA & UNICORE	Enables the access by surgeons to image processing services and simulation with the aim of improving pre-operation and operation planning.
	GRASP (*GRid based Application Service Provision*)	http://www.eu-grasp.net	OGSA, OGSI, .NET & OGSI.NET	Integration of the Applications Services Providers into the network (ASP) and two innovative technologies: GRITs and Web services.

Table 3.- Main projects based on Grid Information Technology in the UE in relation to firms management. Source: Own work based on Parsons (2003) and Gagliardi *et al.* (2004).

Between 2000 and 2004, various projects were running in the scientific area (Parsons, 2003). A first line of projects (see Table 2) focused on developing the middleware and fundamental tools. Apart from the abovementioned DataGrid, in this line we find projects such as: (a) GridLab; (b) DataTAG (*Research & Technological development for a Transatlantic Grid*); (c) CrossGrid; (d) GRACE (*GRid seArch & Categorization Engine*); (e) SeLeNe (*Self e-Learning Networks*) (Loizou, 2003); and (f) MOSES (*MOdular & Scalable Environment for Semantic Web*), a system of proven viability in applications in academic web sites. A second line of projects (see Table 2) of a scientific nature focuses on areas of application (Parsons, 2003), such as: (a) EGSO (*European Grid of Solar Observations*); (b) AVO (*Astrophysical Virtual Observatory*) (Quinn, 2003); (c) OpenMolGRID (*Open Computing Grid for Molecular Science & Engineering*), a particularly useful project for simulating molecular structures applicable in molecular design in chemical engineering, the life sciences and applications in pharmaceuticals. For example, scientists will be able to use OpenMolGrid to synthesise and test 30,000 new components in cytology in order to detect several hundred components relevant in the production of anti-cancer drugs (Karelson, 2003); (d) MammoGrid (*European Mammogram database*) (Amendiola, 2003); (e) BioGrid (*Bio-technology Information & Knowledge Grid*); and (f) EUROGRID (*European Testbed for Grid Applications*).

A third line of projects consists of those projects which remain scientific, but have an orientation that is closer to business applications, focusing specifically on developing middleware and basic tools (Parsons, 2003) (see Table 3), and include: (a) CoG (*Corporate Ontology Grid*); (b) DAMIEN (*Distributed Applications and Middleware for Industrial use of European Networks*); (c) FLOWGRID (*Flow-Simulation Grid*): applicable in research Computational Fluid Dynamics (CFD) using an on-demand focus (Fueyo, 2003, p. 1); and (d) GRIP (*Grid Interoperability Project*): for interoperability between Globus and UNICORE, two key elements in the development of Grid Information Technology. Finally, a fourth line of projects is made up of projects that remain scientific but focus on areas of application of interest in business (see Table 3) (Parsons, 2003). This is the case of: (a) GRIA (*Grid Resources for Industrial Applications*); (b) GEMSS (*Grid-Enabled Medical Simulation Services*); and (c) GRASP (*GRid based Application Service Provision*). Figure 1 illustrates the above-mentioned EU projects and positions them according to their scope of application and level of development.

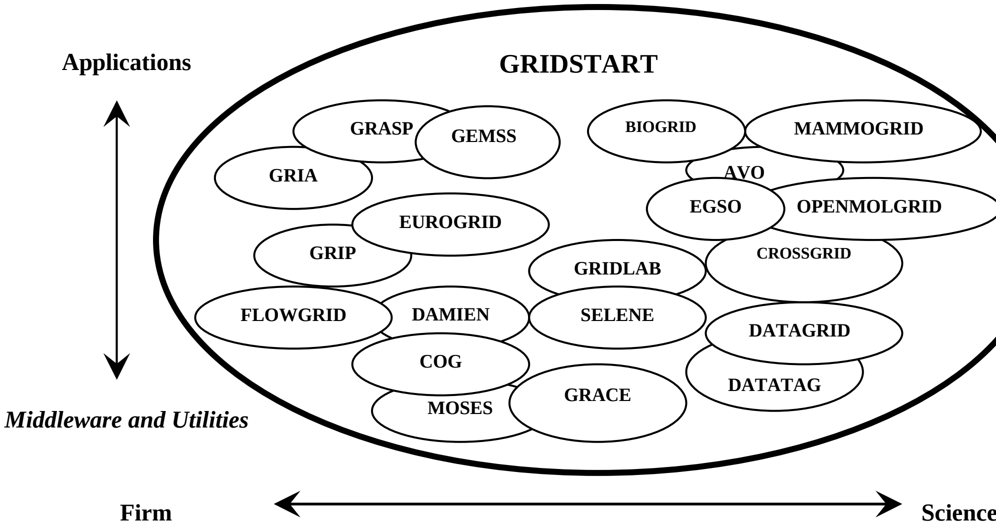

Figure 1.- Localization of the main UE projects according to their area and development level. Fuente: Parsons (2003, p. 2).

The EU initiative GRIDSTART (*Grid Dissemination*, *Standards*, *Applications*, *Roadmap and Training*) combines 10 projects developed within the Fifth Framework Programme and 10 additional projects, the first and second wave of projects (Gagliardi *et al*., 2004), including those projects presenting a purely scientific dimension and those showing a more commercial one. The objective is to consolidate advances in Grid Information Technology in Europe, and promote interaction between similar initiatives, both in Europe and the rest of the world. We should point out that some projects interact with others, so that later projects often use developments from previous ones as a starting point.

The EU's Sixth Framework R&D Programme includes a section especially dedicated to resolving complex scientific problems using Grid Information Technology. A particularly interesting proposal is the integrated project called EGEE[3] (*Enabling Grid for e-Science in Europe*) (Fernández, 2005), which aims to integrate the different national, regional and thematic initiatives in Europe in order to create a common European infrastructure upon the evolving GEANT network, providing a European framework that supports projects oriented to the different e-Science applications (Marco, 2002, p. 22; Fernández, 2005, p. 43).

Apart from the EU efforts, other national and multinational projects exist in Europe, the majority very recent (2002/2003), such as: (a) DutchGrid: a Grid Information Technology platform in the Netherlands, open to all research and testbed activities. Its objective is to coordinate and exchange Grid technology experiences; (b) INFN-Grid: a grid in development for connecting researchers in Italy; (c) NorduGrid: a testbed in the Nordic countries for implementing wide-area computing and data handling; (d) IRISGrid: a Spanish national organisation, run by the RedIris research network, which aims to develop a national e-Science programme in Spain; and (e) UK e-Science programme: the biggest Grid Information Technology initiative in Europe, and possibly the world. Table 4 reports the most important national and multinational efforts in Europe in the e-Science area.

[3] http://public.eu-egee.org.

NATIONAL OR MULTI-NATIONAL GRID INITIATIVES OF e-SCIENCE IN EUROPE			
PROJECT	URL	COUNTRY	DESCRIPTION
DutchGrid	http://www.dutchGrid.nl	The Netherlands	Grid in development in The Netherlands. Its objective is the co-ordination and inter-change of experiences on Grid technology.
INFN-Grid	http://www.infn.it/Grid	Italy	Grid in development that interconnects Grid Italian researchers.
NorduGRID	http://www.norduGrid.org	Scandinavian Countries	Grid in development in Nordic Countries for Wide Area Computing and Data Management implementation.
IRIS-GRID	http://irisgrid.rediris.es	Spain	National Grid Organization in Spain run by the "Iris" National Research Network with the main target of developing a National programme of e-Science.
eToile	http://www.urec.cnrs.fr/rubrique174.html	France	Grid in development for Research.
SweGrid	http://www.sweGrid.se	Sweden	Grid in development that inter-connects 600 computers located in 6 different centres.
CosmoGrid	http://www.grid-ireland.org	Ireland	National organization that pursues the development of a Grid environment for e-Science and Research.
PIONIER	http://www.kbn.gov.pl/en/pionier	Poland	Programme for infrastructure, test-beds, applications and services development including computing and data Grids.
D-Grid	http://www.d-grid.de	Germany	National Grid Organization in Germany for Research
HellasGrid	http://www.hellasgrid.org	Greece	National organization for Grid technology development.
RoGrid	http://www.grid.ro	Romania	National organization for Grid collaboration and development.
ArmGrid	http://www.escience.am	Armenia	National organization for Grid e-Science.
BELNET Grid Initiative	http://www.belnet.be	Belgium	National organization for consolidation of Grid Technologies research and Grid infrastructure development.
DCGC (*Danish Centre for Grid Computing*)	http://www.grid.dk	Denmark	National organization. Virtual centre in which there are located 5 different research centres.
Grid Russia	http://www.rgrid.ru	Russia	National organization. Telecommunications centre for e-Science and e-Society. This centre leads the development and implantation of several Grid information technology projects.
UK eScience programes	http://www.escience-Grid.org.uk	United Kingdom	It is the most important initiative developed in Europe for Grid applications promotion in the scientific as well the commercial area. It pursues the creation of a Grid infrastructure to support Grid-based e-Science. The programme includes a large number of projects on areas related to Health and Medicine, Genomics, Life-Sciences, Particle Physics, Astronomy, Environmental Sciences, Engineering Design, Chemistry and new Materials as well as on Social Sciences.

Table 4.- National and multi-national initiatives in GRITs in Europe in the area of e-Science. Fuente: The authors and Parsons (2003) and Berman, Fox and Hey (2003).

The e-Science programme in the UK

Because of its relative importance, we have dedicated a section apart for the projects being carried out in the United Kingdom. This is a multi-disciplinary programme that began in November 2000. It is the biggest initiative so far in Europe, and possibly the world, for promoting the development of Grid Applications both in the scientific and industrial domains. Its aim is to create a grid infrastructure providing support for e-Science. The programme includes a great variety of projects in areas such as health and medicine, genomics and the life sciences, particle physics and astronomy, environmental sciences, designs in engineering, chemistry and materials science, as well as the social sciences. Many of the projects have both academic and corporate participants (Berman, Fox and Hey, 2003, p. 10; Hey and Trefethen, 2002, 2003). In the two stages of the programme more than 30 projects have been developed in various research areas. Tables 5 and 6 report examples of the projects under way in the UK.

e-SCIENCE PROGRAMME IN THE UK; SCIENTIFIC PROJECTS			
PROJECT	URL	AREA	DESCRIPTION
RealityGrid	http://www.realitygrid.org	Materials Sciences	Grid in development trying to establish realistic and complex models on liquid systems at a molecular level making possible the study and subsequent proposal of new elements. High Performance Computing and Visualization are two key elements in this Project.
Comb-e-Chem	http://www.combechem.org	Chemistry	Grid in development that composes existing data on structural properties of chemical elements into a system that includes techniques for knowledge and information sharing. It permits new compounds synthesis through combinatorial methods providing new chemical knowledge. It constitutes the basis of the so-called e-Chemistry.
MyGrid	http://www.mygrid.org.uk	Several Areas	Development of a system tested on existing Grid infrastructure with the aim of building a collaborative environment for researchers, allowing the use of disperse and complex distributed resources for results sharing. The results have been used in Bio-Informatics applications.
GridPP (*Grid Particle Physics*)	http://www.gridpp.ac.uk	Particle Physics	Software Grid and Hardware infrastructure that permits the test of a Grid prototype for the CERN's LHC.
AstroGrid	http://www.astrogrid.com	Astronomy	Grid infrastructure for a Virtual Observatory that links the existing data bases on Astronomy and provides remote access to these data bases.
Discovery Net	http://www.discovery-on-the.net	Multiple areas of application	Grid in development for data processing in High Throughput devices that, furthermore, require of a real-time response. It has been used in Bio-Chemistry, e-Chemistry, Renewable Energies, Wind movement analysis, etc.

Table 5.- Examples of pilot projects in the area of e-Science in the UK, scientific area. Source: The authors and Hey and Trefethen (2002).

e-SCIENCE PROGRAMME IN THE UK; PROJECTS IN THE BUSINESS AREA			
PROJECT	URL	AREA	DESCRIPTION
DAME (*Distribuited Aircraft Maintenance Environment*)	http://www.cs.yord.ac.uk/dame	Aeronautics	Distributed system for errors forecast and diagnosis on aircrafts engines developed in co-operation with Rolls Royce. It includes a generic Grid application for distributed diagnosis that analyzes data coming from multiple sensors, an application for gas turbines maintenance and data mining techniques on distributed diagnosis. It arises as a powerful tool in preventive maintenance.
GEODISE (*Grid Enabled Optimasation and Desing Search for Engineering*)	http://www.geodise.org	Manufacturing Design	Provides a solid system for intelligent access to a knowledge centre using the most up-to-date and optimized tools of data management. It constitutes a support element in manufacturing design that requires of distributed simulations.

Table 6.- Examples of pilot Projects in the Programme of e-Science in the UK, Business area. Source: The authors based on Hey and Trefethen (2002).

Grid Information Technology and e-Science in Asia-Pacific region

Grid Information Technology is relatively less advanced in Asia than in the US or Europe. The main initiatives are coordinated by ApGrid (*Asia-Pacific-Grid*), a virtual organisation in the Asia-Pacific region that supports research in GRIT and the development of existing and future projects from academic, governmental and industrial initiatives. In May 2004, a total of 49 organisations from 15 different countries were participating in ApGrid. Another organisation that is helping to implement the necessary infrastructure and develop GRIT-based applications in the Pacific region is PRAGMA (*Pacific Rim Applications and Grid Middleware Assembly*) (Matsuoka, 2003), which has participating institutions from Japan, South Korea, Singapore, China, Australia, Taiwan and the US. Table 7 reports the participating countries in the ApGrid organisation.

COUNTRIES THAT CONSTITUTE THE ApGrid ORGANIZATION OF ASIA-PACIFIC		
Australia	Japan	Singapore
Canada	Malaysia	Taiwan
China	New Zealand	Thailand
Hong Kong	Philippines	USA
India	South-Korea	Vietnam

Table 7.- Participants countries in the organization ApGrid of Asia-Pacific. Source: ApGrid.

The different organisations from the participating countries in ApGrid provide resources making up a testbed with more than 1,000 PCs, supercomputers and access nodes. The Japanese National Institute of Advanced Industrial Science and Technology (AIST) plays a very active role in ApGrid, and used this infrastructure in 2003 to develop large-scale applications, such as simulations using the Monte Carlo method in computational chemistry, or computational applications for weather forecasting. In 2002, Japan launched the GTRC (*Grid Technology Research Centre*), initiating projects such as: (a) National Research Grid Initiative (NAREGI), an ambitious project that lasted for three years (2003-2005)[4]. Its aim was to build a national infrastructure (Miura, 2004) to support e-Science for scientific research and engineering. It included the development of middleware and applications, and sat on the SuperSINET network; (b) VizGrid: a collaborative visualisation environment that captures, processes, transmits and visualises 3D images, providing a virtual-reality environment in which objects and human beings intervene. This allows, for example, a realistic simulation of face-to-face conversations between people (Matsukura *et al*., 2004), which could be useful in e-Health applications, for example, in remote attention of patients by specialists; (c) Business Grid: which aims to go beyond the classic concept of the grid introducing an extended use of this technology. Based on OGSA, it develops middleware that simplifies and makes more flexible the operation of complex business applications. It is an extremely useful project that allows, for example, applications of electronic administration such as those pursued in the e-Japan programme[5] (Savva, Suzuki and Kishimoto, 2004, p. 254); and (d) Grid Datafarm: a project for intensive data computation (of the order of petabytes and exabytes) that exploits the local storage of PCs dispersed over a worldwide network[6] for intensive data handling.

Another relevant organisation in ApGrid is KISTI (*Korea Institute of Science and Technology Information*), which has also developed a testbed (KISTI *Grid Testbed*). South Korea also has a national-level development: the K*Grid, project, promoted by the Ministry of Information and Communication (MIC). Singapore has a national development too: NGPP (*National Grid Pilot Platform*). The national initiative in Taiwan is called KING (*Knowledge Innovation National Grid*), where the following projects stand out: (a) Eco-Grid: a development of a GRIT-based environment made up of computing resources spread over the island, including observation cameras, sensors, wireless networks, computers and databases, to study and manage ecological resources; and (b) Asthma Grid: for studying drugs to cure asthma. India began its I-Grid (*Information Grid*) in 2002, with the aim of building a national infrastructure based on GRIT. In Australia, the University of Melbourne has developed the middleware Gridbus (*Grid computing and Business*) to provide grid services at the user level in a "utility computing" model to manage resources in e-Science environments (Buyya and Venugopal, 2005). Australia also has a national initiative, GrangeNet (*GRid And Next GEneration Network*), while Canada has WestGrid (*Western Canada Research Grid*).

Table 8 shows the main GRIT initiatives in the Asia-Pacific region.

[4] The Japanese national GRIT initiative's starting point (fiscal year 2003) is indicative of the abovementioned backwardness of these technologies in Asia compared to Europe and the US.

[5] In 2004, the Japanese administration initiated the e-Japan programme (e-Japan Priority Policy Programme), which will allow electronic administrative services, electronic voting and the emission of residents' cards that will be processed in numerous applications. The use of centralised data processing centres in these cases represents a serious danger in the event of huge disasters, not only because of the unavailability, but also because of the possible loss of information about residents and other important data (Savva, Suzuki and Kishimoto, 2004, p. 254).

[6] We are referring to the World Wide Grid network (see section on global projects).

MAIN GRIT INITIATIVES IN THE ASIA-PACIFIC REGION			
INITIATIVE	URL	COUNTRY	DESCRIPTION
ApGrid (*Asia Pacific Grid*)	http://www.apgrid.org	Several countries	Virtual organization that, in 2004, gathered 49 organizations of 15 countries. It supports research and development of GRITs projects including academic, public and private initiatives.
PRAGMA (*Pacific Rim Applications and Grid Middleware Assembly*)	http://www.pragma-grid.net	Several countries	Promotes the implementation of the necessary infrastructure and the development of applications based on GRITs in the Asia-Pacific region. It has sponsors from Japan, South-Korea, Singapore, China, Australia, Taiwan and the USA.
GTRC (*Grid Technology Research Center*) **NAREGI** (*National Research Grid Initiative*)	http://www.gtrc.aist.go.jp/en/intro/index.html http://www.naregi.org	Japan	GRIT research centre. It has started projects such as: National Research Grid Initiative (NAREGI); National GRIT infrastructure building; VizGrid, collaborative visualization environment that captures, process, transmit and visualizes images in 3D, providing a virtual reality environment in which human and objects interact; Business Grid that extends the use of GRITs to the economic area, and Grid Datafarm, intensive data computing that uses local storing capacity of disperse PCs over a worldwide network.
K*Grid **KISTI**	http://www.gridcenter.org http://www.kisti.re.kr	South-Korea	Initiatives for the implementation of test beds for national GRITs.
ThaiGrid	http://www.thaigrid.net	Thailand	National initiative for GRITs test-bed implementation with projects such as the GRITs portal for new drugs design.
I-Grid (*Information Grid*)	http://www.cdac.in/html/betatest/betaidx.asp	India	National infrastructure based on GRITs.
CNGrid **(***China National Grid***)**	http://www.cngrid.org http://www.chinagrid.edu.cn http://www.hpcc.tongji.edu.cn	China	National GRITs infrastructure for development of projects such as ChinaGrid for university cooperation and the Application Grid for urban traffic information services.
GrangeNet (*GRid And Next GEneration Network*)	http://www.grangenet.net	Australia	National Grid infrastructure.
NGPP (*National Grid Pilot Platform*)	http://www.ngpp.ngp.org.sg/	Singapore	Recent Project based on the implementation of a national GRITs infrastructure.
KING (*Knowledge Innovation National Grid*)	http://www.nchc.org.tw/KING/KING_en/01_intro/intro.ene.php	Taiwan	National initiative including projects such as: Eco-Grid that integrates observation cameras, sensors, wireless networks, computers and databases for the study and management of ecological resources; Asthma Grid, for the study of new drugs for Asthma treatment.
WestGrid (*Western Canada Research Grid*)	http://www.wesgrid.ca	Canada	National initiative for GRITs test-bed implementation.

Table 8.- National and multi-national initiatives in GRITs in Asia-Pacific region in the area of e-Science. Source: The authors.

Grid Information Technology and e-Science: global projects

On the infrastructure of high-speed networks currently available at the global level various international initiatives are under way, aiming to combine different initiatives for the adoption and implantation of Grid Information Technology dispersed around the world. Implementations exist that extend across several continents. Since collaboration is one of the basic characteristics of these technologies, it seems reasonable to expect that in the future we will continue to advance towards a mammoth Cyberinfrastructure (Gagliardi, 2003, p.2) or eInfrastructure (Karlson, 2003, p. 2) at the global level for e-Science (Buyya 2005, p. 7). In this section we describe some examples of initiatives pursuing this goal.

Among the global scientific initiatives, the ones led by the European CERN and the US NSF stand out. They derive from the need in high-energy physics (HEP) experiments for the computation and handling of huge amounts of data, particularly when the new particle accelerator LHC starts operating in 2007. The scientific community collaborating in the LHC project includes more than 200 institutions spread around the globe. Many of the projects described in previous sections were designed to meet the needs of the LHC, and are coordinated by CERN. Recent global projects include: (1) iVDGL (*International*

Virtual Data Grid Laboratory), focusing on the storage and handling of huge quantities of data; and (2) LCG (*LHC Computing Grid*), centring on the integration of computing resources (Harris, 2003; Bunn and Newman, 2003).

Another global initiative, this time in astrophysics, is IVOA (*International Virtual Observatory Alliance*). This is a combination of the main development initiatives of national or regional virtual observatories in the world. The aim is to create a global virtual observatory called *World Wide Telescope* (Szalay and Gray, 2004, p. 96).

One global project that demonstrated the feasibility of creating a global infrastructure of Grid Information Technology was GGTC (*Global Grid Testbed Collaboration*), a testbed consisting of 69 machines, with a total of 7,345 processors, distributed in 14 countries (Australia, Canada, China, Czech Republic, Egypt, Germany, Hungary, Japan, South Korea, Poland, Singapore, the Netherlands, the UK and the US) (Nabrzyski, 2003, p. 4). This alliance was established in the framework of SuperComputing 2002 (SC2002)[7], and it was used in demonstrations of innovative applications, such as in the NeuroGrid project for the analysis of brain activity (Buyya *et al*., 2005).

The name of *World Wide Grid* (Buyya, 2002) is associated with the testbed resulting from the GGTC experiment, and the number of participating organisations and countries expanded in SC2003. At present, this infrastructure is used in the above-mentioned GridBus project (Buyya and Venugopal, 2004), which is designing and developing a new generation of systems and applications that bring together and hire the services of distributed resources depending on their availability, characteristics, performance, cost and the QoS required.

From a more commercial perspective, one of the most active firms in Grid Information Technology is IBM, which opened the world's first Grid Innovation Center in its Advanced Technical Solutions Center in Montpellier (France) in 2002. It also has the BlueGrid supercomputer, which connects this centre and R&D laboratories in the US, Israel, Switzerland, Japan and the UK into a global corporate intraGrid that has reduced its number of networks from 31 to 1.

Table 9 reports examples of global scientific projects, plus IBM's global project. Table 10 reports the national or regional projects included in IVOA.

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[7] The annual SuperComputing conference runs competitions involving various HPC computing challenges. In SC2002, the GGTC infrastructure was built, using high-speed networks and their international connections. This won two of the competition's three prizes: the most geographically distributed project and the most heterogeneous applications. The participants in the competition continued working together intermittently after SC2002 once they had achieved the objectives of the alliance, but GGTC demonstrated the viability of a broader project: the World Wide Grid.

GLOBAL PROJECTS IN e-SCIENCE			
PROJECT	URL	ORGANIZATION	DESCRIPTION
LCG (*LHC Computing Grid*)	http://www.lhcgrid.web.cern.ch	CERN	Provides necessary resources for the experiments in the new CERN's large Hadron Collider (LHC). This Project tries to integrate the capacity of disperse research centres throughout Europe, America and Asia into a Virtual Computing Organization.
iVDGL (*International Virtual Data Grid Laboratory*)	http://www.ivdgl.org	NSF	Large data management structure based on GRITs that gathers diverse worldwide developments such as the European DataGRid, DataTAG, GridPP and the American GriPhyN and PPDG.
IVOA (*International Virtual Observatory Alliance*)	http://www.ivoa.net	Varias organizaciones	Inter-connection of the main GRITs initiatives of national and regional observatories with the aim of creating a worldwide virtual observatory called World Wide Telescope.
GGTC (*Global Grid Test-bed Collaboration*)	http://scb.ics.muni.cz/static/SC2002/Testbed.html	Múltiples organizaciones	Test-bed made up of 69 computers gathering 7.345 processors distributed throughout 14 countries. The Alliance resulted in the SuperComputing 2002 event and was used in innovative applications such as the analysis of brain activity (NeuroGrid project). GGTC won two of the three awards: the widest geographical scope award and the most heterogeneous applications award. GGTC demonstrated viability for a more ambitious project: the World Wide Grid.
Word Wide Grid	http://www,gridbus.org/ecogrid/wwg/	Múltiples organizaciones	Test-bed that extends the number of organizations and countries participating in the HPC competition of SC2003. It is currently used in the GridBus project.
CORPORATIVE GRID GLOBAL PROJECTS			
IBM IntraGrid	http://www-1.ibm.com/grid	IBM	Union among the IBM laboratorios using Grid Information Technologies.

Table 9.- Examples of Global Projects based on Grid Information Technology. Source: The authors.

PARTNER ORGANIZATIONS IN THE GLOBAL PROJECT IVOA		
ORGANIZATION	COUNTRY	URL
AstroGrid	United Kingdom	http://www.astrogrid.org
Aus-VO (*Australian Virtual Observatory*)	Australia	http://www.aus-vo.org
AVO (*Astrophysical Virtual Observatory*)	European Union	http://www.euro-vo.org
China-VO	China	http://www.china-vo.org
VO-I (*Virtual Observatory India*)	India	http://vo.iucaa.ernet.in/voi
CVO (*Canadian Virtual Observatory*)	Canada	http://services.cadc-ccda.hia.nrc.gc.ca/cvo
SVO (*Spanish Virtual Observatory*)	Spain	http://laeff.esa.es/svo/
DRACO (*Datagrid for Italian Research in Astrophysics and Coordination with the virtual Observatory*)	Italy	http://wwwas.oat.ts.astro.it/draco/
GAVO (*German Astrophysical Virtual Observatory*)	Germany	http://www.g-vo.org
VOF (*Virtual Observatory France*)	France	http://www.france-vo.org
HVO (*Hungarian Virtual Observatory*)	Hungary	http://hvo.elte.hu/en/
JVO (*Japanese Virtual Observatory*)	Japan	http://jvo.nao.ac.jp/
NVO (*National Virtual Observatory*)	USA	http://www.us-vo.org/
RVO (*Russian Virtual Observatory*)	Russia	http://www.inasan.rssi.ru/eng/rvo/
KVO (*Korean Virtual Observatory*)	South-Korea	http://kvo.kao.re.kr/

Table 10.- Partner Organizations of the International Virtual Observatory Alliance. Source: The authors and IVOA (2005).

4. Grid Information Technology for Healthcare and Life Science

The main objective of the development of e-Science in the area of health (e-Health) is to offer the scientific community a more productive environment, providing solutions to the main challenges in terms of the processing, storage and visualisation of increasingly complex and massive biomedical data (FECYT, 2005, p. 28).

One of the biggest challenges in the field of e-Health is the Electronic Clinical History (Muñoz, 2005), which it is hoped will offer health professionals all the information generated by patients throughout their lives. This implies an extraordinary volume of information, which moreover will need to be available ubiquitously (García and Muñoz, 2005). The Electronic Clinical History will need to rest on IT that is capable of handling huge quantities of data. For example, digital scanner technologies working in the health area generate databases of the order of multiterabytes (1 terabyte=10^{12} bytes), which must be shared between hospitals and scientific laboratories. Other examples include: the analysis of mammograms, which requires technologies capable of storing and comparing images to facilitate interdisciplinary collaboration, with the aim of making quick and reliable diagnoses (Ellisman and Peltier, 2004); and tele-immersion (TI) techniques (DeFanti and Stevens, 1999), which integrate audio and video conference to build models based on images and collaborative virtual reality (CVR). This also requires powerful computing resources. In TI, "tele-immersed" participants can see and interact with the other objects in the shared virtual environment (Leigh *et al*., 1999, p. 1). These techniques could be particularly useful for remote examination of patients from specialist centres, which is traditionally known as "telemedicine".

In addition, researchers in the health area now clearly need to work together. Thus, for example, when the World Health Organisation (WHO) issued a worldwide warning on 12 March 2003 about a dangerous new illness – Severe Acute Respiratory Syndrome (SARS) – laboratories in Canada, France, Germany, Hong Kong, Japan, the Netherlands, Singapore, the UK and the US, later joined by China, shared – in real time via a secure web site – images of electronic microscopy, genetic sequences, virus isolates and data from patients' samples, and undertook analyses of the samples in parallel. This allowed them to identify the coronavirus responsible for this serious disease in only one month (FECYT, 2005, p. 39).

IT in the health field not only acts as a catalyst of processes, but also modifies them, generating health and well-being (García and Muñoz, 2005, p. 23). The Electronic Clinical History therefore creates the need to align IT with the characteristics distinguishing health information. These characteristics are (García and Muñoz, 2005): (1) complexity: large volumes of non-homogeneous data exist, with unverifiable information and very complex data flows; (2) dispersion: individuals' increasing mobility means that the information can become very dispersed, making technological solutions of interoperability and accessibility necessary so that all citizens can access any information from anywhere at any time; and (3) confidentiality: secure technologies are needed that permit the proper identification of the user.

Grid Information Technology offers an infrastructure upon which to operate advanced and secure services capable of handling huge and complex volumes of data. In addition, and given its marked collaborative nature, GRIT promotes a culture based on collaboration and encourages the exchange of disperse information and knowledge. The technology is consequently ideal for application in the area of e-Health. Thus, there are e-Health applications that are already benefiting from these technologies, in the following areas: genomics and computational proteomics, e.g., Protein Data Bank, SWISS-PROT and TrEMBL (Hey and Trefethen, 2003; Fuentes *et al*., 2005), DataGridBlast (Breton, Medina and Montagnat, 2003), and CEPAR, for comparing protein structures in 3D (Baldridge and Bourne, 2003, p. 910); combinatorial chemistry, e.g., Com-e-Chem (Frey *et al*., 2003), and CHEMPORT (Baldridge and Bourne, 2003, p. 914); molecular structure and modelling for drug design, e.g., BioGrid, Asthma Grid, OpenMolGrid (Karelson, 2003), and Virtual Laboratory (Buyya *et al*., 2003); modelling and simulation of interactions, cellular and physiopathological processes from the perspective of systems biology, e.g., CELLWARE; digitalisation of X-rays and analysis of anatomical images (Breton, 2003), e.g., eDIAMOND (Brady *et al*., 2003; Boutboul *et al*., 2005, pp. 8-11), MammoGrid (Amendiola, 2003), MEDIGRID (Montagnat *et al*., 2003), and functional diagnostics of neurological activity, e.g., NeuroGrid (Buyya, *et al*., 2005); real-time planning and support of surgical processes, such as GEMSS, and CrossGrid; multidimensional research of human diseases on animal models, such as BIRN (Ellisman and Peltier, 2004); and distributed, integrated personal health history, aggregation of data for population and epidemiological studies, and e-Health portals, e.g., North Carolina BIOPORTAL. In short, Grid Information Technology has proved capable of offering solutions to the current requirements in e-Science and e-Health (Blanquer *et al*., 2004). GRIT could also make the Electronic Clinical History a reality, thereby contributing from various interconnected areas to improving the health and well-being of citizens.

6. Conclusions

In the current work we have described the efforts that are being made all around the world to find e-Science and e-Health applications based on Grid Information Technology (GRIT). Most of the applications described above are aimed at addressing the constraints on scientific research, particularly in health, when researchers analyse complex data that require huge computing and/or storage capacity. The projects discussed here also have another common denominator based on the collaborative research philosophy, which translates into a distributed architecture. This new architecture is conceived on the basis of the elimination of hierarchies in the design of the computing structure, but also the modification (reduction, flattening, interconnection) of the organisational structures involved in the research.

After reviewing the initiatives undertaken in the three geographic areas – Europe, the US, and the Asia-Pacific region – we can conclude that research effort has been enormous in recent years. This effort has been promoted and backed by scientific and technological research centres, often universities. The leading research centres in work on grids have been characterised by their combination of a series of vanguard technological capacities with the ability to interconnect resources that are complex, tacit in nature and dispersed geographically, and which contain an important intangible component. The dynamism of the projects currently running, as well as the results achieved in the recent past, allow us to predict a strong growth in the number of scientific discoveries obtained from the use of Grid technology in areas of strategic interest to human development, such as in the study of the human genome and its pathological and therapeutic implications, or in the diagnosis of complex, often degenerative, diseases, which are treatable only to a limited extent with current medicine. Among the lines of research that are likely to have most impact, we might mention advances in neuroscience based on the comparative analysis of images of brain activity. This line of research could provide the necessary boost for the long sought-after synergy between psychological and biological explanations of human attitudes and behaviour.

Nevertheless, one of the most important repercussions that scientific advances based on grid applications may have transcends science and spills over into the socio-economic domain. Making a comparative analysis between the last "wave" of technological change that we experienced with the internet in the 1990s and the evolution of Grid Information Technology today, we can find numerous analogies. First, before becoming generally available to firms and individuals, the internet was widely diffused in military circles initially, and among scientists subsequently. During the 1970s and 1980s a substantial number of scientific projects used the internet to access data and previous research, as well as to interconnect research teams, which for the first time in the history of human evolution reached global dimensions. During this period, research centres and universities developed protocols of common use and, perhaps equally important, the collaborative skills needed to extract the maximum return from complex and geographically-dispersed resources. As Ramiro Montealegre (1999) notes, scientific research institutions may prove to be the appropriate vehicle for positively influencing the different stages of technological diffusion, namely: (1) the creation of scientific-technological knowledge that adds utility to technological innovation; (2) the mobilisation of scientific, but also economic and organisational, resources, which combines efforts and adds social and economic meaning to innovation; (3) the establishment of standards that gain validity through continuous and reliable use; and (4) the inducement to innovation, promoting imitative attitudes that, by analogy, use Grid Information Technology for objectives outside the strictly scientific or health areas.

In short, we feel that the moment has come for civil society, led by firms, to assume a large part of the technological and management know-how that scientific institutions have been developing over the past ten years in relation to Grid Information Technology. Some aspects remain to be defined and assimilated before this technology diffuses massively. One of these is the regime of co-existence with, and possible substitution of, the architecture of the current internet. The second will depend on the first, and involves defining the economic-organisational utility of Grid Information Technology in the near future. The response to this second question is among the most attractive aspects for the scientific community, and could provide the springboard for the next technological revolution.

On the one hand, a response to this second question could involve the organisational specialisation of Grid Information Technology in the areas of economic-business management that offer most analogies with scientific research: i.e., those activities that consume a large quantity of resources organised in a collaborative and de-hierarchised way. On the other hand, Grid Information Technology could become the catalyst for organisational and economic change in the future, by modifying the mechanisms for distributing computing power and resources. In a hypothetical future, the possibilities offered by Grid Information Technology could lead to a "Utility" scenario, in which economic (and also scientific) agents will be able to access resources in the same way as they access energy today. This technological "revolution" could lead to an important leveraging of the human and organisational resources that both scientific research and economic growth feed on. This will unleash the forces of creative destruction, which, operating through the entrepreneur/innovator, give rise to economic cycles and change in society, as Joseph Schumpeter described in the 1930s.

Aknowledgements

This research has been supported by grant to Jaén University from the Spanish Ministry of Education (National Research Plan 2004-2007; Project SEJ2005-0016).

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