

School of Engineering & Design
Electronic & Computer Engineering

MSc in Data Communications Systems



Grid Monitoring

Theofylaktos Papapanagiotou

Dr.Paul Kyberd

March 2011

A Dissertation submitted in partial fulfillment of the
requirements for the degree of Master of Science

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Electronic & Computer Engineering

MSc in Data Communications Systems



Grid Monitoring

Student's name: Theofylaktos Papapanagiotou

Signature of student:

Declaration: I have read and I understand the MSc dissertation guidelines on plagiarism and cheating, and I certify that this submission fully complies with these guidelines.

Abstract

EGI has been replaced EGEE in as the main European Grid Initiative. Multi Level Monitoring architecture suggested central points in regional level where metrics from each information system of the grid will be aggregated. MyEGI, MyEGEE and Nagios replace SAM in availability monitoring. Performance monitoring is approached using Ganglia as the source of performance metrics, and WSRF/BDII as the carrier of that information.

Both Globus and gLite resource brokers come with their favorite information service. Grid Monitoring Architecture suggests the model by which the information should be discovered and transferred. Monitoring and Discovery Service is responsible to provide that information. Two different methods exist about the way that the information is transferred, BDII and WSRF. Both are implementing the Glue schema, support Information Providers, and export the metrics in standard formats.

Linux kernel load average is the main metric that is taken by Ganglia, and through the information providers is passed to Nagios, LDAP and the container that supports the WSRF. Ganglia distribute the metrics to all its nodes using XDR over the multicast network. Nagios store the historical data using NDOUtils to its database repository. Ganglia python client is integrated with BDII LDAP to provide real-time metrics of Gmond to information consumers. WSRF transforms through XSLT the XML taken by Gmond and passes it to the framework's Index to be discovered and aggregated.

Finally, data are represented in graphs using RRDtool through pnp4nagios plugin of Nagios system. LDAP queries using PHP provide the real-time data from BDII. DOM library of PHP used to parse data using XPath queries in WebMDS frontend of WSRF.

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Chapter 1

Introduction

1.1 Context

Performance monitoring of a grid is a key part in grid computing. Based on the reports of grid performance, decisions on capacity planning are being made. Visualization of performance status in different levels helps scientists and managers focus on the exact point of the infrastructure where a bottleneck on service exists. Current interfaces delivers performance graphs without following the standard topology schema that is presented by the grid information system.

WSRF aggregation framework and GLUE schema are examined to understand the gathering process of metrics. BDII LDAP also examined as the carrier of the information data. Ganglia's hierarchical delegation to create manageable monitoring domains is an important aspect. Performance metrics are taken using Linux kernel's load average. Performance in the aspect of how many jobs are served by each site is not examined in this project. Which of the two information services better transfer the metrics for the multi level monitoring architecture.

Build a lab to gather performance data and start working on the development of the integration parts. It is assumed that the environment is a grid site, that already have the components needed to work together. Ganglia daemons on each node, presented by the GLUE schema on site BDII, Nagios/MyEGI

monitoring frameworks. A web interface is available to present the work of the integration of Ganglia into Nagios/MyEGI.

1.2 Aims & Objectives

Different role users are going to use a portal to get information about the performance status of the grid, to export the appropriate report for their job. This project aims to develop these particular pieces of code to support the aggregation of the metrics from Nagios, to allow the web based customization of the visualization of the reports. These metrics are needed to report the availability and reliability of NGIs and particular sites of the grid.

The procedures that are going to be used in order to achieve the above aims should include at the beginning some opening and exploration of the environment where the interface is going to be placed. The usage of grid computing in the world should be well known, so a visibility of the importance and the possible uses of the software will be recognized. The appropriate access to the infrastructure should be gained, on different platforms and levels. Brunel University site and GridPP/NGS VO at the beginning, as long as the UKI ROC operations may be a good point of collaboration with researchers to reach the best possible requirements and data to analyze. The middleware used in both these VOs should be examined so with the knowledge of running projects and global usage of them may target to export better specifications. Existing operations on the grid should also be discovered. The European initiative milestones on the operations of the regional level should be considered as a route, and registration to news about the upcoming research projects that are going to use the grid should also be take place.

After that wide-opening to get the whole picture, a targeted and focused view should follow. Existing monitoring tools must be used to check the problems and search for requirements. The experience of SAM, Gridview, Gridmap, Gstat, GridICE, etc should be taken in order to merge their functionality as possible as it is. Information systems that already reside over the

infrastructure, must also be learned. Standards and specifications should be examined, on how the message bus works and delivers the data in an hierarchical manner. A contact with the CERN team working on MyEGEE and Indiana University's MyOSG team should be established, to collaborate on the core of MyOSG source. Changes submission to subversion system as long as ticket closure of the development project tool will help to get to know the core of MyEGEE and Nagios. It is possible to create and upstream a Nagios customized web interface, to create different views of Nagios resources scheme to grid topology oriented architecture. Nagios, NRPE and Ganglia installations should be deployed across the CE&SE nodes of Brunel's sites to have a working production environment to work on. Attention should be taken on the potential performance impact of these sensors deployment. UKI MyEGEE validation/testing portal will be used as a pre-production environment to check changes. PNP should be fixed in GridPP Nagios to be evaluated. Statistical access log analysis of existing tools may have results on trends of users/admins preferred views.

Various tools are going to be used to track changes and collaborate. Monitoring articles in GridPP wiki & CERN twiki should be made. Snippets upstream & status changes must be a regular operation in SVN/JIRA/Trac in CERN interfaces. Ongoing task through the dissertation project is the reading of papers and methodical updates of Mendeley citation management tool to have the bibliography organized. Possible changes suggestions to MSc on DCS course notes about grid monitoring may be made, as long as the EGI roadmap updates. Finally with the appropriate supervision and follow-up of meetings and presentations, a paper publishing might take place.

1.3 Organization

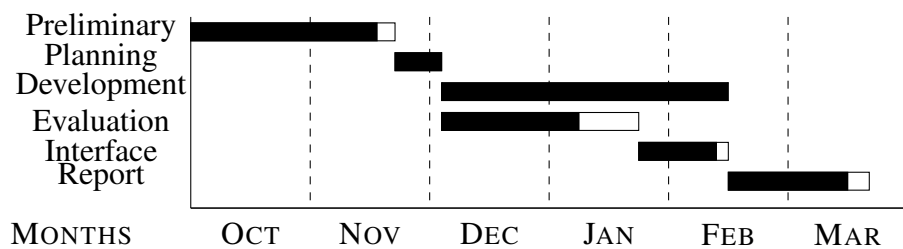
1.3.1 Tools

This project was developed in \LaTeX using Vi editor. Its releases may be found in Google Code, where Mercurial was used for source control. Citation management through Mendeley software. Papers obtained by becoming member of IEEE, ACM and USENIX. Operating Systems Laboratory of Technological Education Institute of Piraeus was used to build a testbed of grid site and tools to study existing monitoring tools.

1.3.2 Time-plan (Gantt Chart)

| Task | Start date | End date | Days |
|---|------------|----------|------|
| Preliminary | 09/29/10 | 10/24/10 | 20 |
| - Identify Concepts | 09/29/10 | 10/08/10 | 8 |
| - Gain Access | 10/08/10 | 10/24/10 | 12 |
| Planning | 11/12/10 | 12/04/10 | 17 |
| - Explore existing technologies | 11/12/10 | 11/28/10 | 12 |
| - Write Interim Report | 11/28/10 | 12/04/10 | 5 |
| Experimental-Development | 12/04/10 | 02/14/11 | 51 |
| - Evaluate performance monitoring tools | 12/04/10 | 12/25/10 | 15 |
| - Information/topology databases | 12/17/10 | 12/29/10 | 8 |
| - Develop Customized Interface | 12/29/10 | 02/14/11 | 34 |
| — Coding of information aggregation | 12/29/10 | 01/21/11 | 16 |
| — Development of the frontend | 01/21/11 | 02/10/11 | 14 |
| — Complete the interface (auth, scale, etc) | 02/10/11 | 02/14/11 | 4 |
| Report | 02/16/11 | 03/29/11 | 32 |
| - Begin Writing | 02/17/11 | 03/01/11 | 11 |
| - Submit Draft & Make Changes | 03/01/11 | 03/14/11 | 9 |
| - Prepare Final | 03/14/11 | 03/29/11 | 11 |

Table 1.1: Key activities necessary to complete the project



Chapter 2

Literature Review

2.1 Grid Computing

Grid computing [1] is the most last decade's technology innovation in high performance computing. A large number of scientists work on the operations of this huge co-operative project of EU. Monitoring & information architecture [2] has been standardized in the initial state of that project, to succeed in today scale of 150.000 cores in production. Use of grid computing nowadays takes place in academic and research environments. Also, applications in industry-based needs such as promising Power Grid control [3] are emerging.

Grid computing may be the infrastructure over which Cloud Computing may reside. Cloud computing promise that it will change how services are developed, deployed and managed. The elastic demands of education and research community is a good place where cloud computing may be developed. Many datacenters all over Europe which are currently serving grid computing infrastructure for LHC, could later share the resources to help some other big academic projects scale up as needed.

2.2 Resource Brokers

Resource Brokers [4] where developed to manage the workload on Computer elements and Resource elements. Globus is a non-service based RB, and gLite

RB which is service based. A Workload Management System (WMS) exists in gLite to do the distribution and management of the Computing and Storage oriented tasks.

Based on the middleware that resource brokers rely on, they use the equivalent information system. From resource broker's point of view, the relevant information is the data store and query. There are two main categories of information systems in middlewares. The Directory-based and the Service-based. They are used for resource mapping by the brokers when they access the resource data.

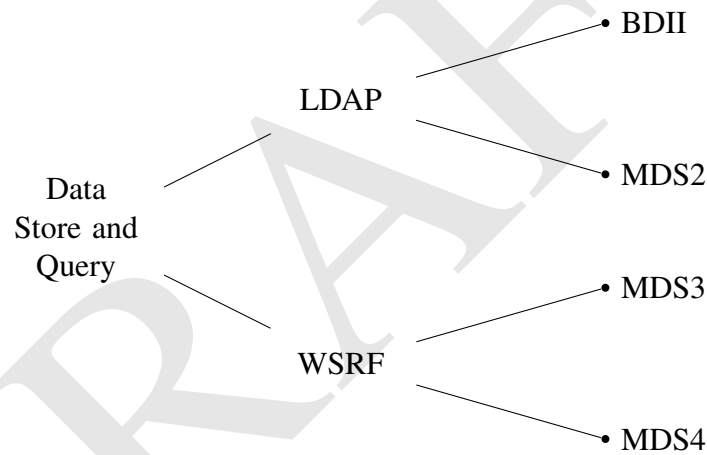


Figure 2.1: Grid Resource Brokers grouped by Information Systems[4]

2.2.1 Globus

Globus Toolkit is an open source toolkit used to build grids. It provides standards such as OGSA, OGSi, WSRF and GSI, and the implementations of OGF protocols such as MDS and GRAM.

Monitoring and Discovery Service (MDS) is part of Globus Toolkit, and provides the information for the availability and status of grid resources. As a suite of Web Services, it offers a set of components that help to the discovery and monitoring of the resources that are available to a Virtual Organization.

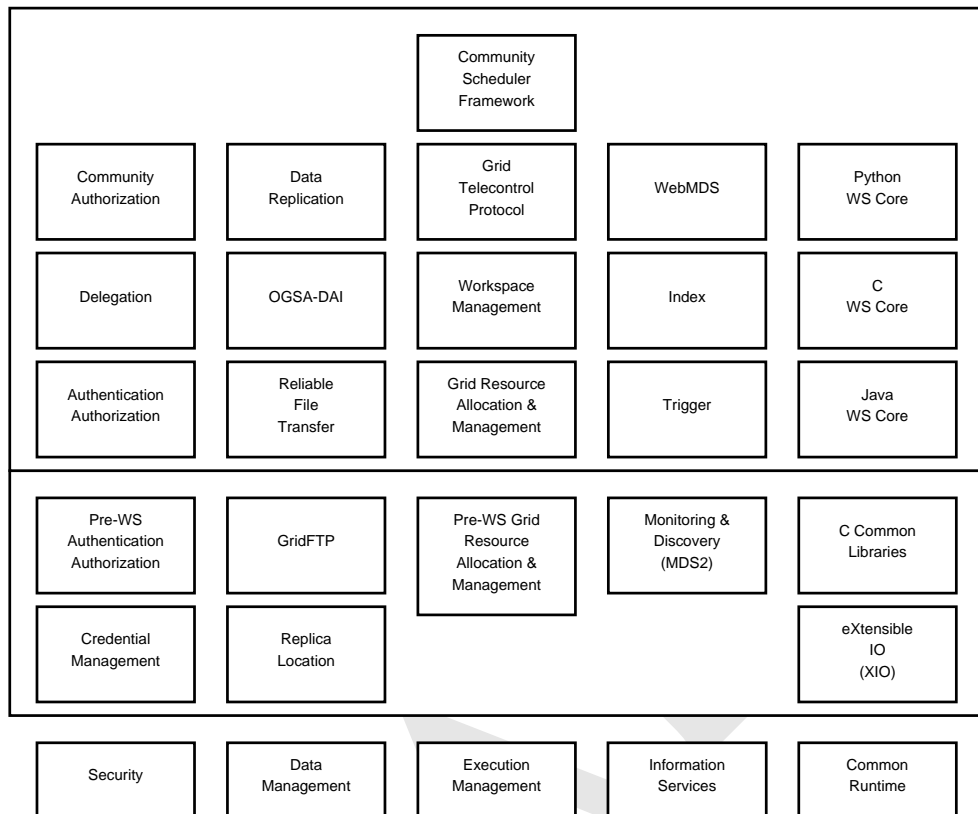


Figure 2.2: Globus Toolkit version 4 (GT4)

2.2.2 gLite

gLite is a middleware which was created to be used in the operation of the experiment LHC in CERN. The user community is grouped in Virtual Organizations, and the security model is GSI. A grid using gLite consists of User Interface, Computer Element, Storage Element, Workload Management System and Information Service.

The information service in version 3.1 of gLite is similar to MDS of Globus middleware, except that the GRIS and GIIS are provided by BDII (see Section BDII) which is an LDAP based service.

2.3 Information Services

A Grid Monitoring Architecture [5] was proposed in early 2000's. Information systems were developed to create repositories of information needed to be stored for monitoring and statistical reporting reasons. Such an organized system later was specified by the Aggregated Topology Provider (ATP) defi-

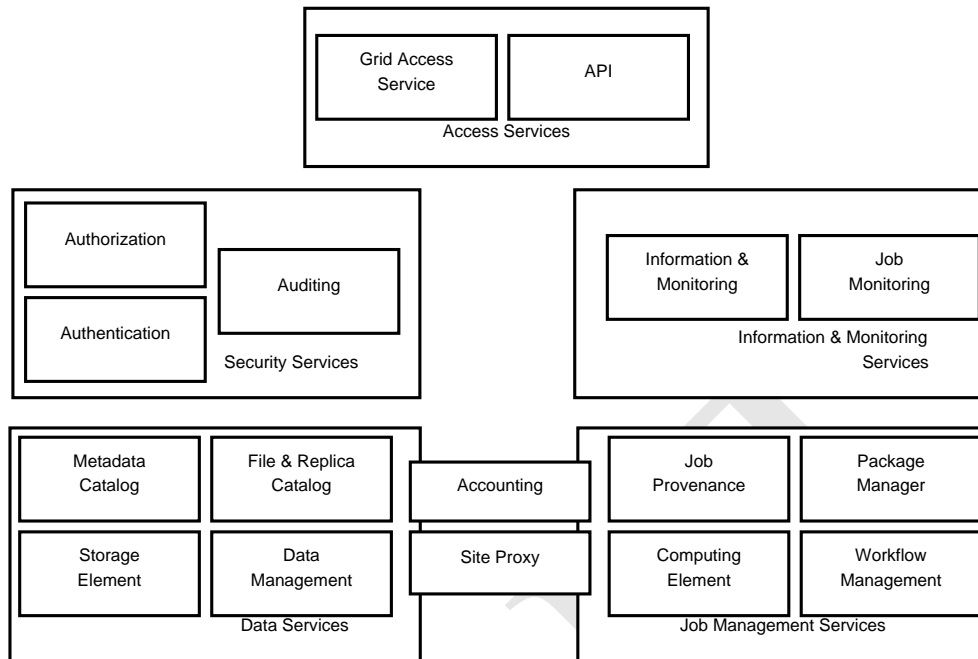


Figure 2.3: gLite architecture

dition. The largest world grids adopt that model, forming OIM in OSG (USA) and GOCDB as that information base in EGEE (Europe). Message Bus was also defined as a mean to transfer the underlying data, and well known tools came up such as Gstat, GOCDB and BDII with Glue specification. Grid performance monitoring and keeping of such an information system has also impact in the performance of the system it shelf [6], so various methods were developed to give the solution to the scaling and performance problem, such as MDS2 (GIIS & GRIS), GMA and R-GMA [7], which offers relational environment [8], has experience on production systems [9] and scales to reach huge needs such as CMS project [10, 11].

2.3.1 MDS

Monitoring and Discovery Services is about collecting, distributing, indexing and archiving information of the status of resources, services and configurations. The collected information is used to detect new services and resources, or to monitor the state of a system.

Globus Toolkit was using LDAP-based implementation for its information system since its early versions, back in 1998 [12]. MDS2 in Globus Toolkit

fully implemented referral with a combined GRIS and GIIS, using `mds-vo-name=local` to refer to the GRIS and all other strings to refer to a GIIS. It was widely accepted as a standard implementation of a grid information system [13], with good scalability and performance [14].

MDS 4 consists of the Web Services Resource Framework and a web service data browser, WebMDS. The WSRF Aggregator Framework includes:

1. MDS-Index, which provides a collection of services monitoring information and an interface to query such information.
2. MDS-Trigger, which provides a mechanism to take action on collected information.
3. MDS-Archive, is planned for future release of MDS, to provide access to archived data of monitoring information.

External software components that are used to collect information (such as Ganglia)[15] are called Information Providers.

2.3.2 Glue

As long as Information Services are used to connect different infrastructures, the schema of its structure had to be standardized. To inter-operate EU and USA grids, DataTAG developed the GLUE schema implementation. GLUE specification quickly adopted by the communities and currently its recommended LDAP DIT is specified in GLUE specification v.2.0 from GLUE Working Group of OSG.

Many objectclasses of the Glue schema define a Computer Element, a Storage Element, etc. As seen in Figure 3.3 in later chapter, performance monitoring attributes such as processor load are defined in objectclasses that extends Computer Element objectclass.

2.3.3 BDII

BDII is used by gLite as the Information Index Service of the LHC experiment. It is LDAP based and may be at top-level or site-level. The GIIS has been replaced by site BDII, which is fundamental for a site in order to be visible in the grid.

Top-level BDII contains aggregated information about the sites and the services they provide. Site BDII collects the information from its Computer Elements, Storage Elements, etc as long as every configured service that is installed on the site.

Information about the status of a service and its parameters is pushed on BDII using external processes. An information provider is also used (such as in WSRF) to describe the service attributes using the GLUE schema.

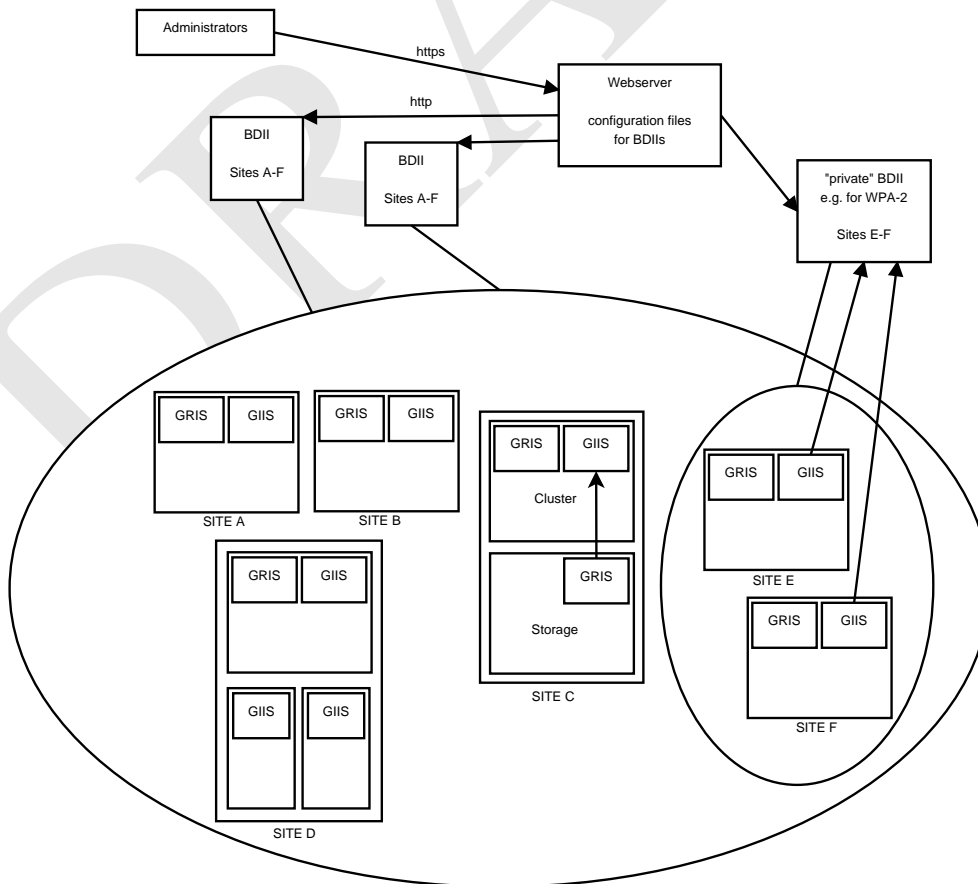


Figure 2.4: Berkeley Database Information Index

2.4 Performance Monitoring

Standards are being published about the operational models that the grid computing initiative will use. Last decade the EGEE I, II & III was adopted by European universities to fund and establish a collaborative community of researchers under a central point, the CERN oriented research project in Particle Physics. After EGEE, the European Grid Initiative were formed to lead to the explode of that community into regional initiatives. Performance and availability monitoring tools and views also follow that format, phasing out commonly used SAM [16] and having the adoption of Nagios as the monitoring of regional performance tool.

A taxonomy effort has been made [17] to present the differences of performance monitoring systems of the grid, and later a more general [18] taxonomy paper was published to give a more general visibility of these tools. GridICE was generally used to aggregate the performance metrics of ROCs in high level reports [19]. Later GridICE was left as long as the SAM left, to meet the milestone of EGI to have a regional monitoring tool (Nagios) to report the reliability of the joined sites and report the values for SLA reasons.

Grid performance can be also measured using benchmark tools in different levels of the grid architecture, using the micro-benchmarks at the Worker Node level, the Site (CE) level and the Grid VO level. Various benchmarks exist in these levels, using different libraries and algorithms, such as This project focuses on mathematically compute of the performance of a grid based on the metrics that are taken at the Worker Node level.

Different metrics and benchmarks exist, such as the measurement of the performance of CPUs in **MIPS using EPWhetstone** and the evaluation of the performance of a CPU in **FLOP/s and MB/s using BlasBench**. GridBench [20] provides a framework to collect those metrics using its own description language, **GBDL**.

GcpSensor [21] introduce a new performance metric called WMFLOPS. It uses PAPI [22] (Performance API) to access the hardware performance coun-

ters. For data distribution it uses MDS information system which provides dynamic metrics for CPU load average, one for 1, for 5 and for 15 minutes load.

2.4.1 Ganglia

Ganglia is a monitoring tool which provides a complete real time monitoring environment. It is used by both academia and industry to monitor large installations of clusters, grids. Any number of host metrics may be monitored in real time using the monitoring core, a multithreaded daemon called Gmond. It runs on every host that is in scope of monitoring. Its four main responsibilities are:

1. Monitor the changes that happen in the host state
2. Multicast over the network, the changes that has been made
3. Listen to network for changes that other ganglia nodes are multicasting and
4. Answer the status of the whole cluster to specific requests, using XML.

All the data that are gathered of the multicast channel are written to a hash table in memory. The metric data of each node that runs gmond and sends information over the multicast channel are been processed and saved. Data sent over the multicast channel is happening using external data representation (XDR). When there is a request over a TCP connection, the response is in XML.

2.4.2 Nagios

2.5 European Grid Infrastructure

Latest EGI directive to form regional operation tools pushed the use of Nagios [23] as the main tools of availability & performance (an so reliability) moni-

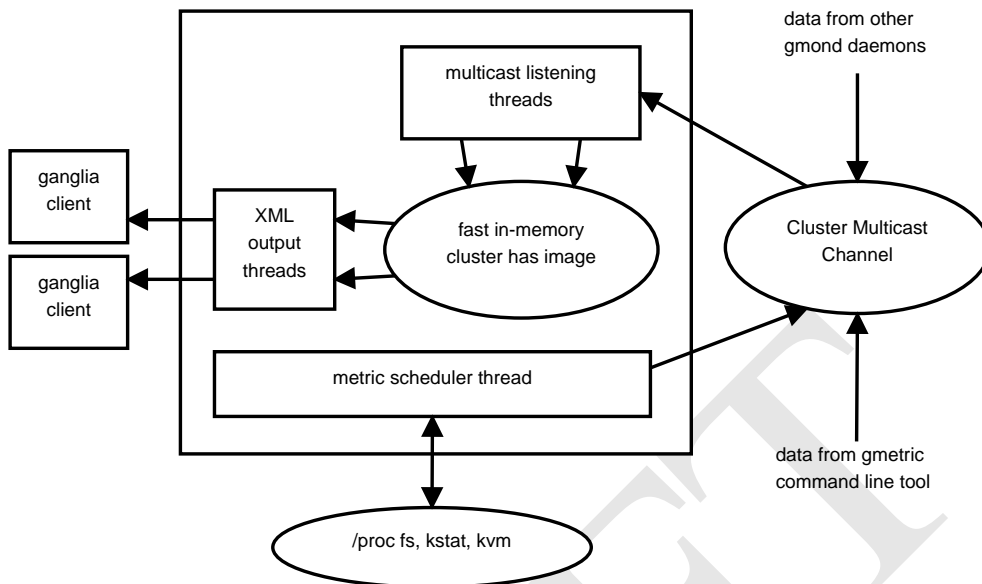


Figure 2.5: Ganglia Data Flow

toring of the grid. Each NGI/ROC (regional level) has its own interface, and hierarchically there is a Super Nagios interface to report the top level view of general system availability. Nagios offers extensions such as NRPE to remotely invoke check commands in inaccessible/private installations. Another important add-on to Nagios is the NdoUtils, which offers an SQL store of history data to the monitoring interface. Nagios Configuration Generator was introduced to help the automatic generation of the configuration based on the information system of nodes and services.

Finally, there has been proposed an integration of SAM views to a Nagios customized interface, to offer the last good known SAM interface to the old users. Nagios also integrates with GGUS, a ticketing system that european grid initiative uses. Monitoring infrastructure in EGI is fully distributed using regional Nagios servers and the corresponding regional MyEGI portals.

2.5.1 NGS and GridPP

Brunel University takes part in regional and european initiatives. 5 different Computer Elements exist, and 3 Storage Elements, consisting the UKI-LT2-Brunel site. LT2 stands for London Grid, a co-operation with other London Universities. GridPP and NGS are two collaboration groups that Brunel Uni-

versity is member of, and papers on the web interface [24] and real time visualization of the grid status were presented [25] by GridPP

In GridPP, regional monitoring tools exist to provide distributed monitoring services in UK. Regional Nagios and MyEGI/MyEGEE instances co-exist in Oxford University that offer service availability monitoring for all UK sites. Ganglia installations exist in site level deployments, and a Ganglia frontend which aggregates Tier-1 sites is offered through RAL.

Chapter 3

Design/Methods

3.1 Approach Adopted

Grid performance monitoring in this project is examined using **GMA**, an architecture that established to provide the standards for a distributed monitoring system. The technologies that will be discussed here are about the Information Infrastructure that provides the metrics to the users/applications.

The metrics are generated using **Linux kernel**'s load average functions. **Ganglia** is used to take that metrics and synchronize all cluster nodes with the relevant information, over the **multicast channel**.

Nagios is configured using a **custom script** that takes the information for the cluster nodes, and periodically queries the **Gmond** to get the metrics for the discovered nodes. The results are stored in its repository and using RRDTool and PNP4Nagios, graph reports are generated on demand.

To pass the information, two different information systems are examined, **BDII and WSRF**. Both are used in modern grid implementations and are described in **MDS specification**. BDII queries event source (Gmond) using Perl/Python LDAP libraries. The results taken, fill the directory schema which has been extended using **Glue schema** specification for Processor Load in Computing Element structure.

MDS4 introduces the use of **WSRF** in grid information system. A **Ganglia Information Provider** using **XSLT** takes the XML output from Gmond

and aggregates the metrics using **WSRF Aggregation Framework**. In front of it, a Tomcat instance serves the **WebMDS** frontend to allow **XPath** queries to the results that has been aggregated.

Finally, two sample small applications has been developed to provide a homogeneous interface that display the same information using the two different information systems.

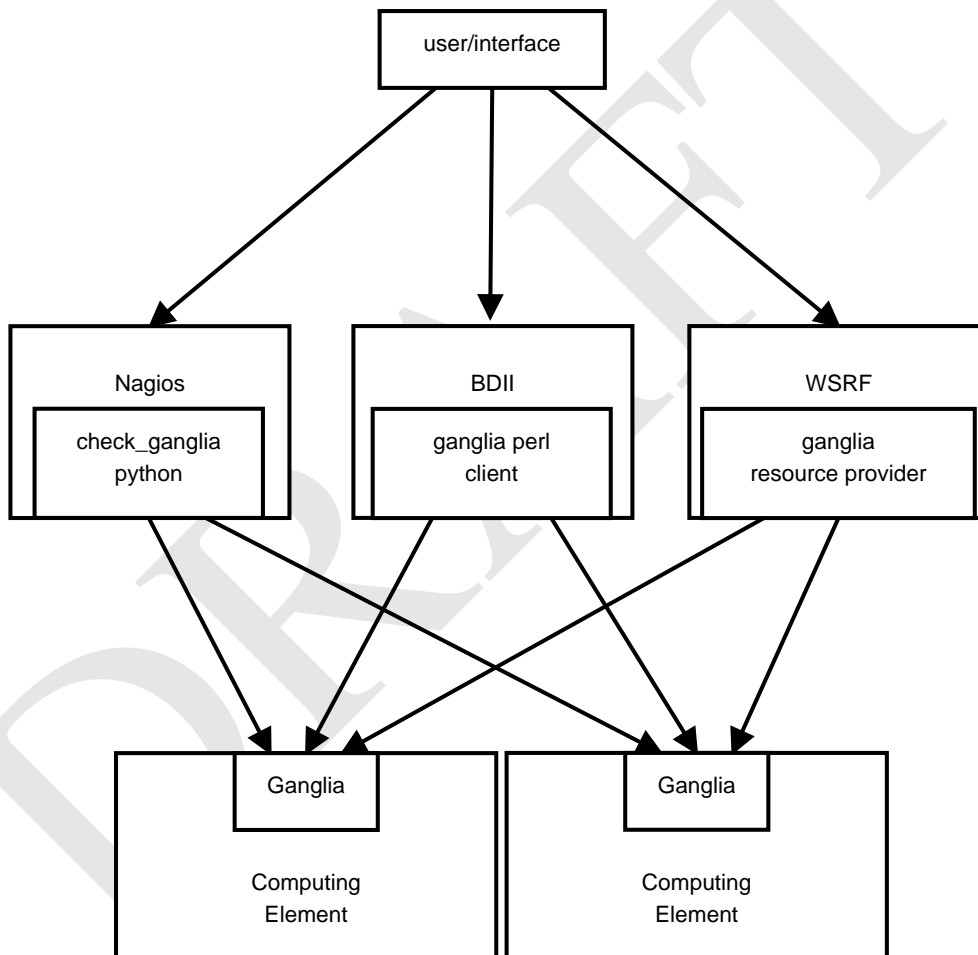


Figure 3.1: Overview of Information Systems used to monitor the grid

3.2 Design Methods

3.2.1 Grid Monitoring Architecture

By definition [3] Grid Monitoring Architecture consists of three components, as shown in Figure 3.2:

1. **Directory Service** which supports the publish and discovery of the information
2. **Producer component**: which is responsible for the availability of the performance data that takes from the event source and
3. **Consumer component**: the one that requests the performance data and receives the metrics from the producer.

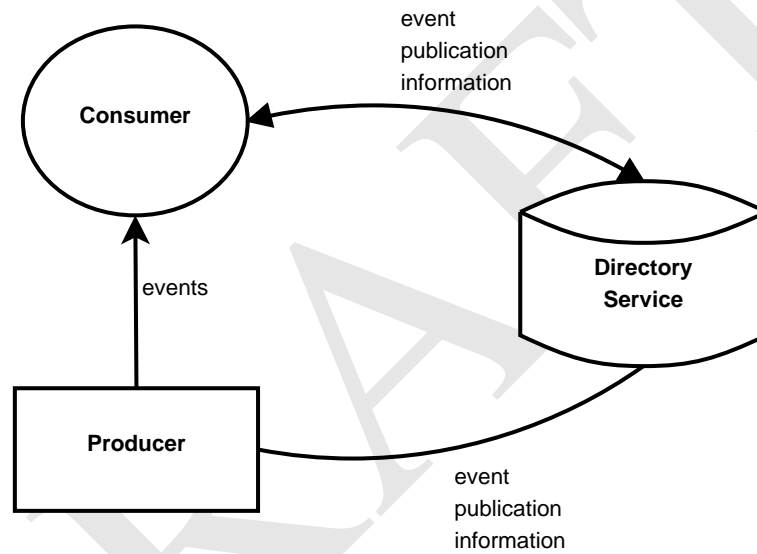


Figure 3.2: Grid Monitoring Architecture

In GMA, all metrics that are transmitted by the producer are handled as events with a timestamp, so performance data should be accurate. These events are transmitted to the consumer directly, and not through the directory service (whose role is just to advertise producers to consumers and vice versa). The GMA recommends that the structure of the data should be following a schema definition.

Grid Monitoring Architecture supports two models to handle the communication between producers and consumers:

- **Streaming publish/subscribe model**
- **Query/Response model**

The directory service is used by both producers to discover consumers and consumers to discover producers. The information of the availability of each

producer/consumer is published to the directory service, and each component may initiate a connection to another type of component that has discovered in the directory service. Even though the role of the directory service is so centric in the discovery of components between each other, the performance data messages are transferred between the producer/consumer directly and not via the Directory Service.

3.2.2 GLUE Schema

gained wide acceptance given its adoption by Globus MDS3

GLUE schema came to provide the interoperability needed between US and European Physics Grid Projects. As a standard, a common schema was introduced to describe and monitor the grid resources. Major components include:

- Computing Element (CE)
- Storage Element (SE)
- Network Element (NE)

The implementation of Glue schema may be using LDAP, XML or SQL. The MDS implementation of the Glue schema in this project includes the core Information Provider and the Ganglia Interface for the cluster information.

3.2.3 Information Infrastructure

To design the Information Infrastructure for distributed computing applications some requirements have been considered such as performance, scalability, cost and uniformity.

Because grid computing applications usually operate in large scale installations, there are performance requirements for the information infrastructure. It should allow rapid access to configuration information that is frequently used, using **caching to query periodically each host or index server for the metrics.**

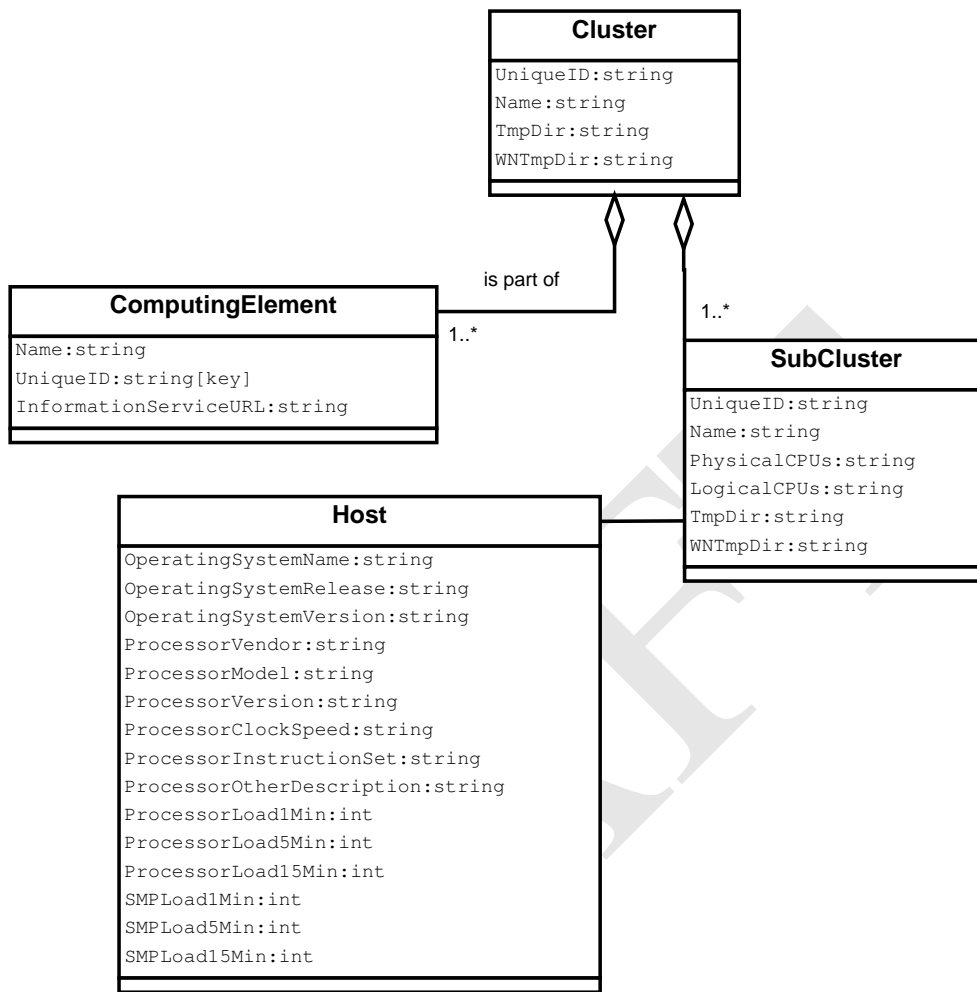


Figure 3.3: GLUE schema 2.0 extension for Host and SMP Load

The number of components in a grid infrastructure scales up to hundreds of thousands of nodes, and these components should be available for queries by many different tools. That information should be discoverable using information indexes.

Deployments, maintenance and operations in a large installation of many systems has operational costs for human resources. The information system should automatically discover and serve the availability paths for applications and grid resources/services.

Because of the large number of different heterogeneous networks of nodes and clusters, there is a need of uniformity. Uniformity helps to simplify the developers to build applications that give better configuration decisions. APIs for common operations and data models for the representation of that information. Resources are divided in groups of computing, storage, network ele-

ments, etc.

The solution proposed by GLUE standard and X.500 (Directory Service) is the key feature to scale, and get uniformity. It may be used to provide extensible distributed directory services. It is optimized for reads, its binary-tree like hierarchy and usually back-end data structure provides a framework that well organize the information that need to be delivered by an Information Infrastructure.[26]

3.3 Data-acquisition Systems

3.3.1 Metrics

CPU load is taken using the pseudo `/proc/loadavg` file which in turn is filled by Linux kernel's `CALC_LOAD` macro. This function takes 3 parameters. The load-average bucket, a y constant that is calculated using formula

$$y = \frac{2^{11}}{2^{((5\log_2(e))/60x)}}$$

for values $x = 1$, $x = 5$ and $x = 15$ (where x represent the minutes and y the exponent constant), and the number of how many processes are in the queue, in running or uninterruptible state.

3.3.2 Ganglia

The metrics about load in one, five and fifteen minutes are taken from Gmond daemon through the `proc` filesystem as seen in Figure 3.4. These values are multicasted using a UDP message on the network, only if the value has been changed from the previous one taken. There is also a time threshold that after that time the value is been sent again, even if it haven't changed, so new hosts on the network may gather the data needed for their Gmond. Each host of a cluster have the information about the metrics of itself and each other node, so it stores the whole cluster state. Using loopback interface, every Gmond

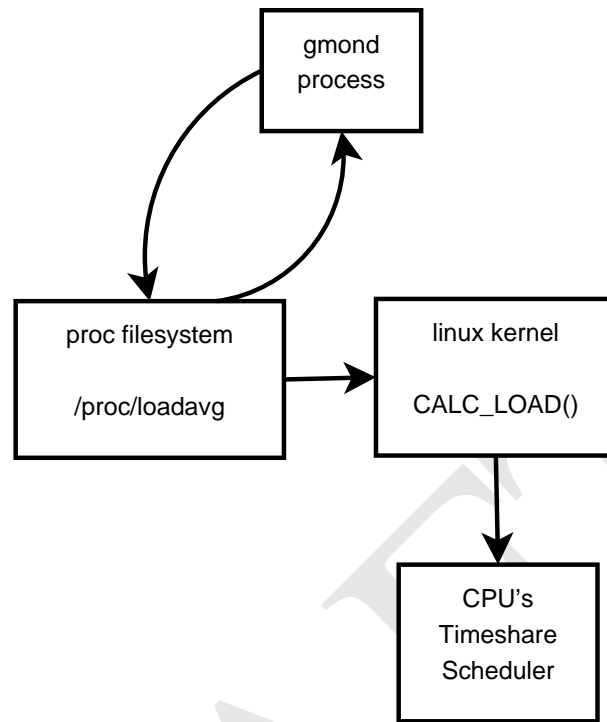


Figure 3.4: Load Average calculation

sends its metrics to itself.

If a TCP connection on the Gmond listening port 8649 is made, Gmond writes a full cluster state of metrics in XML including its DTD. There is a typical access list in the configuration called trusted hosts, and of course every node that is in the cluster that a specific node is configured to be part of, is allowed to connect to get the XML.

Installation and configuration

To install ganglia, some dependencies where needed to be installed on each node of the Computing Element. In the testbed, there where an LTSP installation existed [27] and easily deployment of ganglia succeeded. Ganglia sources compiled for Gmond on the nodes and Gmetad on the systems that Ganglia Web interface needed to be installed. Finally on worker nodes, iptables should accept connections on 8649/TCP port.

```
# yum install rrdtool perl-rrdtool rrdtool-devel apr-↵
    devel libconfuse libconfuse-devel expat expat-devel↵
```

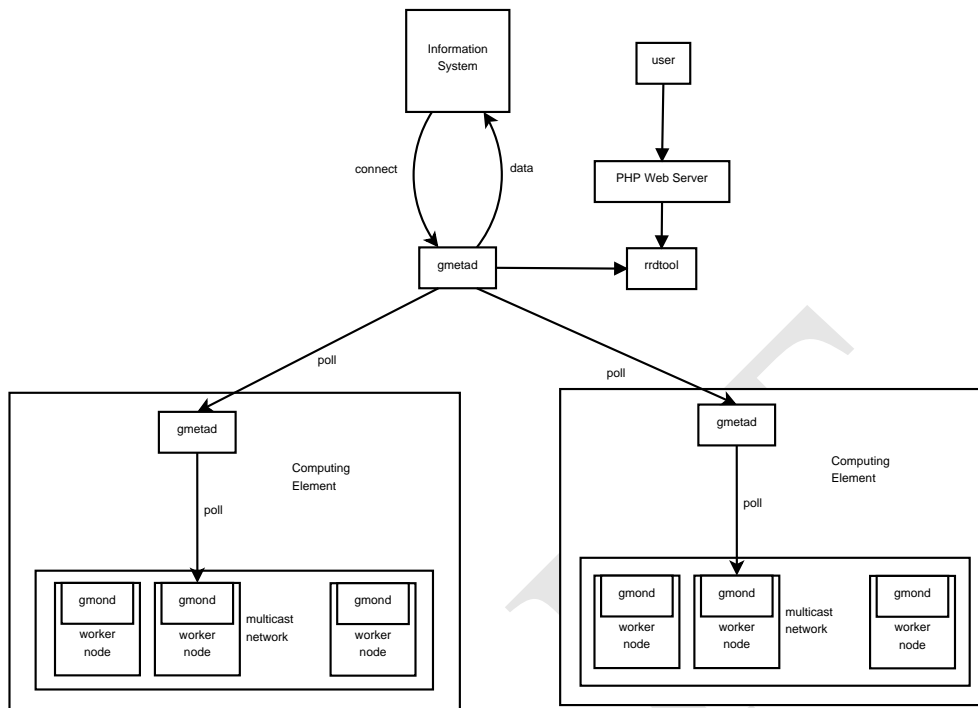


Figure 3.5: Ganglia Network Communications

```

pcrc pcre-devel
# GANGLIA_ACK_SYSCONFDIR=1 ./configure --with-gmetad
# make
# make install
# mkdir -p /var/lib/ganglia/rrds
# chown -R nobody /var/lib/ganglia

```

```

# yum install apr-devel libconfuse libconfuse-devel ↵
    expat expat-devel pcre pcre-devel
# GANGLIA_ACK_SYSCONFDIR=1 ./configure
# make
# make install
# iptables -A RH-Firewall-1-INPUT -m state --state NEW↵
    -m tcp -p tcp --dport 8649 -j ACCEPT

```

Gmond and Gmetad default configuration may be generated using the daemon itself. Gmond may be configured using multicast to communicate metrics between nodes or unicast to solve problems with jitter when deployed in

environments like amazon ec2 that do not support multicast.

3.3.3 Nagios

Nagios is the core monitoring tool that is used for grid computing monitoring as Multi Level Monitoring architecture proposes, to meet the needs of EGEE/EGI. Following SAM and Gridview, Nagios instances have been deployed in many levels of grid infrastructure, enhancing the functionality of scheduling and execution of site tests. The message bus that uses is MSG, which offers an integration between Nagios and the other monitoring tools of grid.

CERN provides MSG-Nagios-bridge, a mechanism to transfer test results between different levels of Nagios deployment (regional, project, site). MSG-Nagios-bridge both submit tests to other Nagios installations and consume results from them.

A Regional Metric Store is also used by Nagios. It is a database that provides a back-end to Nagios current and historical metrics, and connected with the frontend and the message bridge. The adapter that provides such functionality called NdoUtils, and may have a MySQL/PostgreSQL or Oracle back-end.

In the front-end, users are allowed to discover the nodes and services provided in the monitoring levels by regions, projects and sites, using CGI scripts that are part of the Nagios core distribution. Access control between levels of Nagios instances and between users and Nagios installations, is performed using the standard methods of grid, which is GOCDB as described in ATP. User authentication is done by user certificates.

To integrate Ganglia with Nagios as shown in Figure 3.6, a custom script has been created. This script queries the Gmond source for the current state of nodes of the cluster. The returned result is being transformed to a Nagios configuration file to configure the host check of the cluster nodes. The Nagios service checks for these hosts are pre configured to match what is needed.

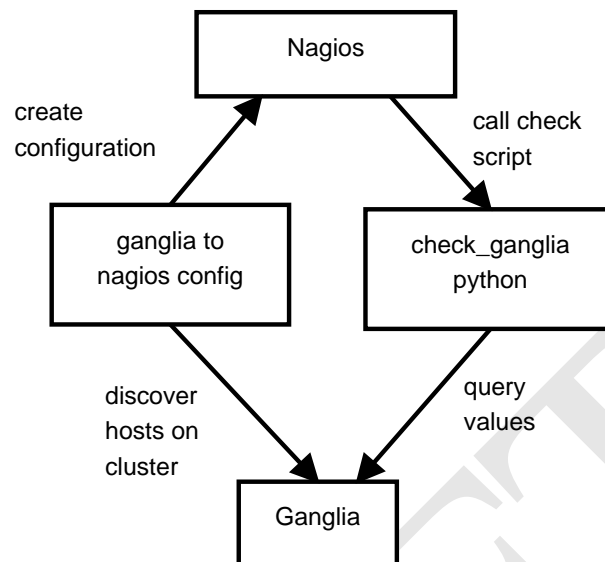


Figure 3.6: Nagios configuration and check ganglia values

Script source may be found in Listing 3.1.

Listing 3.1: Ganglia to Nagios script

```

#!/bin/bash
if [ ! $1 ]
then
    echo "Please HOST argument"
    echo "ex. ganglia_to_nagios 10.0.0.1"
    exit
fi

/usr/src/redhat/SOURCES/ganglia-python-3.3.0/ganglia.py --host $1 --live | while read host
do
    echo ";$host.oslab.teipir.gr"
define host{
    use          gmond-host
    host_name     $host.oslab.teipir.gr
    alias         $host
    address       $host.oslab.teipir.gr
    hostgroups    worker-nodes
  
```

```

}
"
done > /etc/nagios/teipir/hosts.cfg

```

When a nagios check command is executed, results are stored in a file, and Performance Data are calculated by a perl script. To scale this process, the Bulk Mode method is used to move the file to a spool directory which happened immediately with no important performance impact to the system. The NPCD (Nagios Performance C Daemon) is a daemon that is running on the Nagios host and its role is to monitor a spool directory for new files and pass the names of the files to `process_perfdata.pl`. The script in turn, processes the performance data, and this operation is fully Nagios independent so it may be scaled-out more easily. Results are finally delivered to RRDTool, and graphs are being generated. This process is presented in Figure 3.7

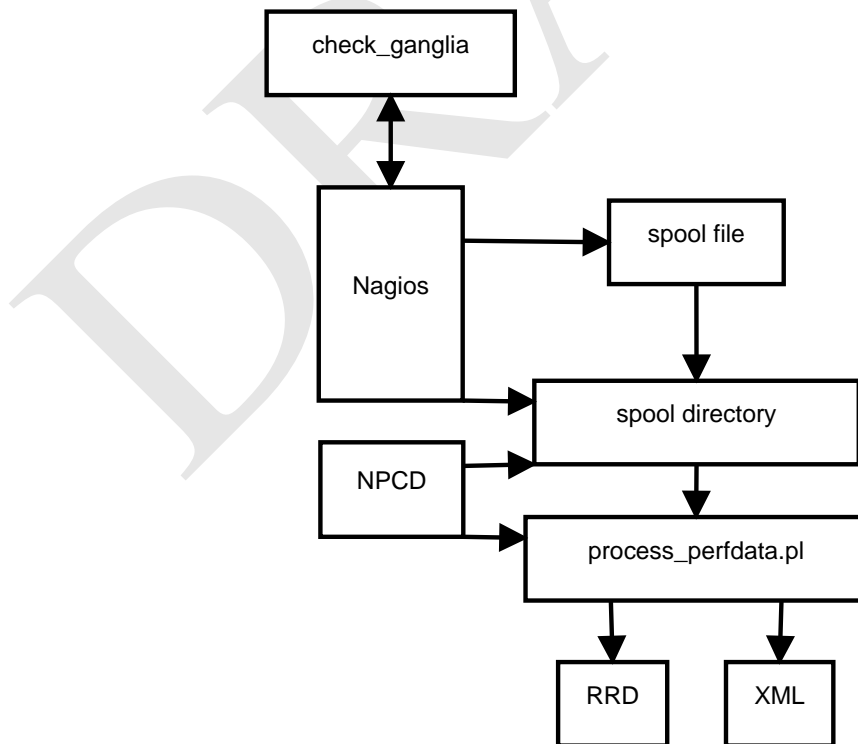


Figure 3.7: PNP 4 Nagios data flow

3.4 Range of cases examined

To deliver Ganglia metrics, two different information systems were evaluated:

- **BDII**, which is used by gLite and is based on **LDAP** and
- **WSRF**, the framework that Globus uses to aggregate and deliver information using **Web Services**.

Both Information Services are following the MDS specification and are using the Glue Schema to present the results of the metrics that are aggregated in its store.

3.4.1 LDAP based

To evaluate the LDAP based information service, a system had to have installed the gLite so it have the BDII service running. To do this, a Scientific Linux installation were used, and CERN repositories were added. The installation of gLite-UI automatically installs BDII, so using **yum command** the needed packages where installed. An `ldapsearch` returned the top elements of the BDII as shown below:

```
[root@osweb~]# ldapsearch -x -h osweb.teipir.gr -p 2170 -b "" -s base "(objectClass=*)" namingContexts
...
namingContexts: o=grid
namingContexts: o=glue
namingContexts: o=infosys
```

To test the connection to the Gmond service over TCP, and the transformation to MDS, two different ways where used. The official ganglia python client, and a perl script that is doing the same transformation:

```
# /usr/bin/ganglia --host mon.oslab.teipir.gr --format=
=MDS
dn: mds-vo-name=local, o=grid
objectclass: GlueTop
```



```

objectclass: GlueGeneralTop
GlueSchemaVersionMajor: 1
GlueSchemaVersionMinor: 1
...

```

```

# /root/ganglia_ip -h mon.oslab.teipir.gr -p 8649 -o ↵
mds
dn: GlueHostName=gr02.oslab.teipir.gr, mds=vo-name=↵
local, o=grid
objectclass: GlueHost
GlueHostName: gr02.oslab.teipir.gr
GlueHostUniqueID: RDLAB-TEIPIR-gr02.oslab.teipir.gr
objectclass: GlueHostProcessorLoad
GlueHostProcessorLoadLast1Min: 1
GlueHostProcessorLoadLast5Min: 1
GlueHostProcessorLoadLast15Min: 0
...

```

As we can see, the LDIF exported by these tools, follow the schema defined by the Glue specification, whose attributes and objectclasses extended by Glue-CE ProcessorLoad as shown in Table 3.1.

| Common Name | Attribute | Objectclass |
|--------------------------------|---------------------------------|------------------------|
| Hostname | GlueHostName | GlueHost |
| Unique ID assigned to the host | GlueHostUniqueID | GlueHost |
| Processor Load, 1 Min Average | GlueHostProcessorLoadLast1Min | GlueHostProcessorLoad |
| Processor Load, 5 Min Average | GlueHostProcessorLoadLast5Min | GlueHostProcessorLoad |
| Processor Load, 15 Min Average | GlueHostProcessorLoadLast15Min | GlueHostProcessorLoad |
| SMP Load, 1 Min Average | GlueHostSMPLoadLast1Min | GlueHostSMPLoad |
| SMP Load, 5 Min Average | GlueHostSMPLoadLast5Min | GlueHostSMPLoad |
| SMP Load, 15 Min Average | GlueHostSMPLoadLast15Min | GlueHostSMPLoad |
| Number of CPUs | GlueHostArchitectureSMPSize | GlueHostArchitecture |
| Processor Clock Speed (MHz) | GlueHostProcessorClockSpeed | GlueHostProcessor |
| Network Interface name | GlueHostNetworkAdapterName | GlueHostNetworkAdapter |
| Network Adapter IP address | GlueHostNetworkAdapterIPAddress | GlueHostNetworkAdapter |
| The amount of RAM | GlueHostMainMemoryRAMSize | GlueHostMainMemory |
| Free RAM (in KBytes) | GlueHostMainMemoryRAMAvailable | GlueHostMainMemory |

Table 3.1: GLUE schema for Host Processor Information Provider

Finally, BDII configured using **yaim** with site-info definitions as shown below:

```
# cat site-info.def
...
CE_HOST="osweb.teipir.gr"
SITE_BDII_HOST="osweb.teipir.gr"
SITE_EMAIL="theofpa@teipir.gr"
SITE_LAT=37.979166
SITE_LONG=23.674719
SITE_DESC="TEI of Piraeus"
SITE_LOC="Athens, Greece"
SITE_WEB="http://oslab.teipir.gr"
SITE_SECURITY_EMAIL=$SITE_EMAIL
SITE_SUPPORT_EMAIL=$SITE_EMAIL
SITE_OTHER_GRID="EGEE"
BDII_REGIONS="oslab.teipir.gr"
# /opt/glite/yaim/bin/yaim -c -s site-info.def -n ↵
BDII_site
```

To integrate Ganglia with MDS in early versions of Globus and BDII of gLite, the schema of OpenLDAP should be extended using the Glue-CE definitions from the DataTAG web site (MDS version 2.4). The Ganglia Information Provider that used is a ganglia client on perl, and not the python client given by the ganglia development team it shelf.

gLite have a dedicated directory for information providers, where the wrappers of each provider reside. To use the information provider with BDII, there has been created a one-line wrapper to call the perl script as shown below:

```
[root@osweb ~]# ps -ef |grep bdi[i]
```

```

edguser  24951      1  0 Feb16 ?           00:00:23 /usr/↵
    sbin/slapd -f /opt/bdii/etc/bdii-slapd.conf -h ldap↵
    ://osweb.teipir.gr:2170 -u edguser
edguser  24990      1  0 Feb16 ?           00:01:00 /usr/↵
    bin/python /opt/bdii/bin/bdii-update -c /opt/bdii/↵
    etc/bdii.conf -d
[root@osweb ~]# grep PROVIDER /opt/bdii/etc/bdii.conf
BDII_PROVIDER_DIR=/opt/glite/etc/gip/provider
[root@osweb ~]# cat /opt/glite/etc/gip/provider/glite↵
    provider-ganglia-wrapper
#!/bin/bash
/opt/bin/ganglia_ip -h 195.251.70.54 -p 8649 -o mds

```

3.4.2 Web Service based - WSRF

Globus on the other side, from version 4 and later provides the Web Service Resource Framework that offers a scalable information system with build-in aggregation framework and index service as shown in Figure 3.8. WSRF is an OASIS organization standard and follows the Glue schema and MDS specification.

To install WSRF, Globus Toolkit version 4.0.7 was used. From its binary distribution, where extracted in the target system. A PostgreSQL database was installed and a special user and DB was created to host the RFT schema and data in order to have a minimal globus environment and start the container to service WSRF. A custom start/stop script was created for that container and the file `rpprovider-config-gluece.xml` was created as shown in Listing 3.2.

Listing 3.2: Ganglia Resource Provider for WSRF Index

```

<ns1:ResourcePropertyProviderConfigArray xsi:type="↵
    ns1:ResourcePropertyProviderConfigArray" xmlns:ns1=↵
    "http://mds.globus.org/rpprovider/2005/08" ↵

```

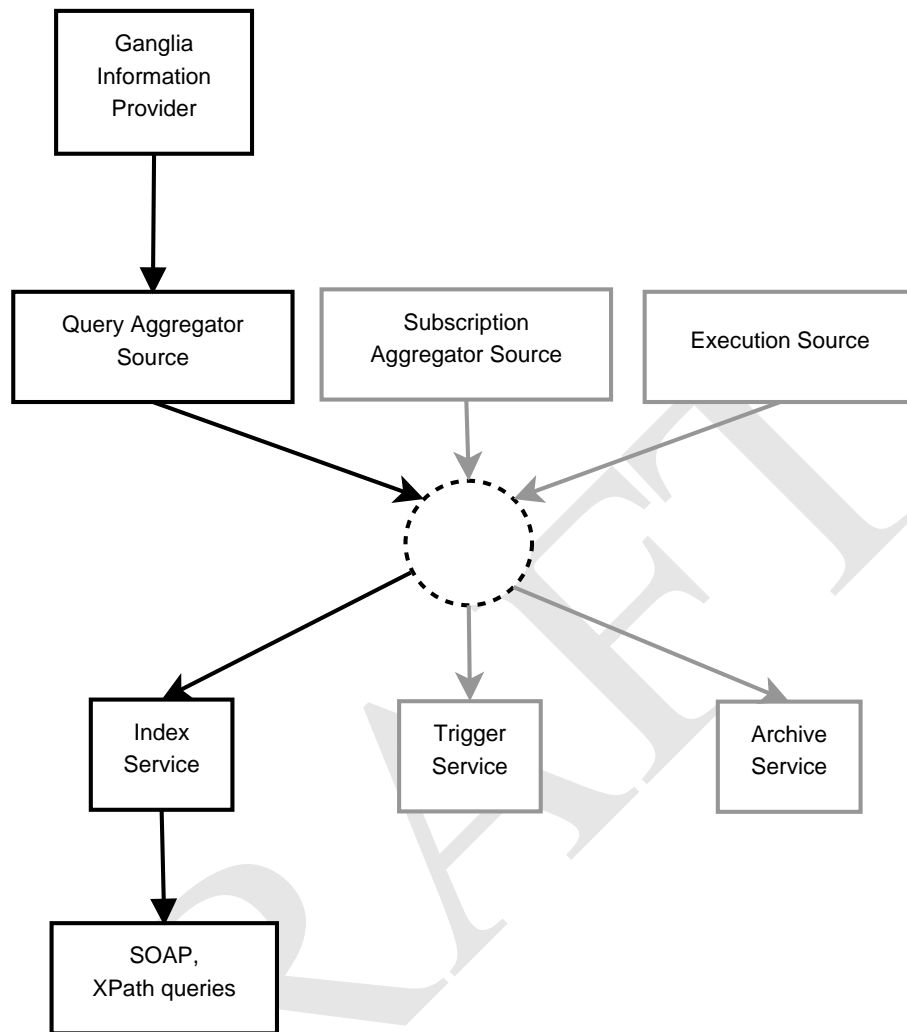


Figure 3.8: Web Service Resource Framework

```

xmlns:xsi="http://www.w3.org/2001/XMLSchema-↵
instance">
<ns1:configArray xsi:type="↵
  ns1:resourcePropertyProviderConfig">
<ns1:resourcePropertyName xsi:type="xsd:QName" ↵
  xmlns:mds="http://mds.globus.org/glue/ce/1.1">↵
  mds:GLUECE</ns1:resourcePropertyName>
<ns1:resourcePropertyImpl xsi:type="xsd:string">org.↵
  globus.mds.usefulrp.rpprovider.↵
  GLUEResourceProperty</ns1:resourcePropertyImpl>
<ns1:resourcePropertyElementProducers xsi:type="↵
  ns1:resourcePropertyElementProducerConfig">
  <ns1:className xsi:type="xsd:string">org.globus.↵

```

```

        mds.usefulrp.glue.GangliaElementProducer</↵
        ns1:className>
<ns1:arguments xsi:type="xsd:string">195.251.70.55↵
    </ns1:arguments>
<ns1:arguments xsi:type="xsd:string">8649</↵
    ns1:arguments>
<ns1:period xsi:type="xsd:int">60</ns1:period>
<ns1:transformClass xsi:type="xsd:string">org.↵
    globus.mds.usefulrp.rpprovider.transforms.↵
    GLUEComputeElementTransform</ns1:transformClass↵
    >
</ns1:resourcePropertyElementProducers>
<ns1:resourcePropertyElementProducers xsi:type="↵
    ns1:resourcePropertyElementProducerConfig">
<ns1:className xsi:type="xsd:string">org.globus.↵
    mds.usefulrp.rpprovider.producers.↵
    SchedulerInfoElementProducer</ns1:className>
<ns1:arguments xsi:type="xsd:string">libexec</↵
    globus-scheduler-provider-fork</ns1:arguments>
<ns1:transformClass xsi:type="xsd:string">org.↵
    globus.mds.usefulrp.rpprovider.transforms.↵
    GLUESchedulerElementTransform</↵
    ns1:transformClass>
<ns1:period xsi:type="xsd:int">300</ns1:period>
</ns1:resourcePropertyElementProducers>
</ns1:configArray>
</ns1:ResourcePropertyProviderConfigArray>

```

File `rpprovider-config-gluece.xml` was included by the `server-config.wsdd` of the container as shown in Listing 3.3.

```

<service name="DefaultIndexService" provider="Handler"↵
    use="literal" style="document">
<parameter name="providers"
    value="org.globus.mds.usefulrp.rpprovider.↵
        ResourcePropertyProviderCollection
org.globus.wsrf.impl.servicegroup.↵
        ServiceGroupRegistrationProvider
GetRPPProvider
GetMRPPProvider
QueryRPPProvider
DestroyProvider
SetTerminationTimeProvider
SubscribeProvider
GetCurrentMessageProvider"/>
<parameter name="rpProviderConfigFile" value="/etc/↵
    globus_wsrf_mds_index/rpprovider-config-gluece.xml↵
    "/>
<parameter name="handlerClass" value="org.globus.axis↵
    .providers.RPCProvider"/>
<parameter name="scope" value="Application"/>
<parameter name="allowedMethods" value="*/>
<parameter name="className"
    value="org.globus.mds.index.impl.DefaultIndexService↵
    "/>
<wsdlFile>share/schema/mds/index/index_service.wsdl</↵
    wsdlFile>
</service>

```

When the container was started, using a user certificate and the following commands, some XPath queries were issued to test the integration:

```

[root@osweb ~]# /opt/globus/bin/grid-proxy-init
Your identity: /C=GR/O=HellasGrid/OU=teipir.gr/CN=↵
    Theofylaktos Papapanagiotou
Enter GRID pass phrase for this identity:
Creating proxy ..... ↵
    Done
Your proxy is valid until: Thu Feb 17 11:11:59 2011
[root@osweb ~]# /opt/globus/bin/wsrp-query -s https://↵
    osweb.teipir.gr:8443/wsrp/services/↵
    DefaultIndexService "/*[local-name()='Host']"
<ns1:Host ns1:Name="gr02.oslab.teipir.gr" ns1:UniqueID=↵
    ="gr02.oslab.teipir.gr" xmlns:ns1="http://mds.↵
    globus.org/glue/ce/1.1">
<ns1:Processor ns1:CacheL1="0" ns1:CacheL1D="0" ns1:↵
    CacheL1I="0" ns1:CacheL2="0" ns1:ClockSpeed="2527"↵
    ns1:InstructionSet="x86"/>
<ns1:MainMemory ns1:RAMAvailable="75" ns1:RAMSize="↵
    495" ns1:VirtualAvailable="1129" ns1:VirtualSize="↵
    1559"/>
<ns1:OperatingSystem ns1:Name="Linux" ns1:Release="↵
    2.6.18-194.26.1.el5"/>
<ns1:Architecture ns1:SMPSize="1"/>
<ns1:FileSystem ns1:AvailableSpace="34082" ns1:Name="↵
    entire-system" ns1:ReadOnly="false" ns1:Root="/" ↵
    ns1:Size="38624"/>
<ns1:NetworkAdapter ns1:IPAddress="10.0.0.32" ns1:↵
    InboundIP="true" ns1:MTU="0" ns1:Name="gr02.oslab.↵
    teipir.gr" ns1:OutboundIP="true"/>
<ns1:ProcessorLoad ns1:Last15Min="0" ns1:Last1Min="0"↵
    ns1:Last5Min="0"/>
...

```

XPath

XPath is used to parse an XML document and get a part of it using an address scheme. For XPath, the XML document is a tree consisting of nodes, and its purpose as a language is to get the nodes that are addressed using the XPath query from that document.

Its syntax is compact, non-XML and much like the filesystem addressing, so it facilitates the use of XPath within URIs.

Example queries used in this project are:

The following is used in the PHP code that queries the WebMDS for all nodes of the XML of the WSRF containing nodes with name *Host*:

```
// *[local-name()='Host']
```

Another example is a more complex query that asks the WSRF for all nodes with name *Host* that contains a sub-node named *ProcessorLoad* and its *Last15Min* attribute has value larger than 20:

```
// glue:Host[glue:ProcessorLoad[@glue:Last15Min>20]]
```

Finally the following example may return only the *ProcessorLoad* node of the *Host* that has the attribute Name set to *xenia.oslab.teipir.gr*:

```
// glue:Host[@glue:Name='xenia.oslab.teipir.gr']/glue:↵  
ProcessorLoad
```

WebMDS

WebMDS is a web interface to query WSRF resource property information. It consists of forms and views of raw XML or organized in tables of results. This user friendly frontend comes as a part of Globus Toolkit version 4 and it

can deployed in any application server. Behind this application reside the data that the WSRF aggregation framework provides through the Index Service.

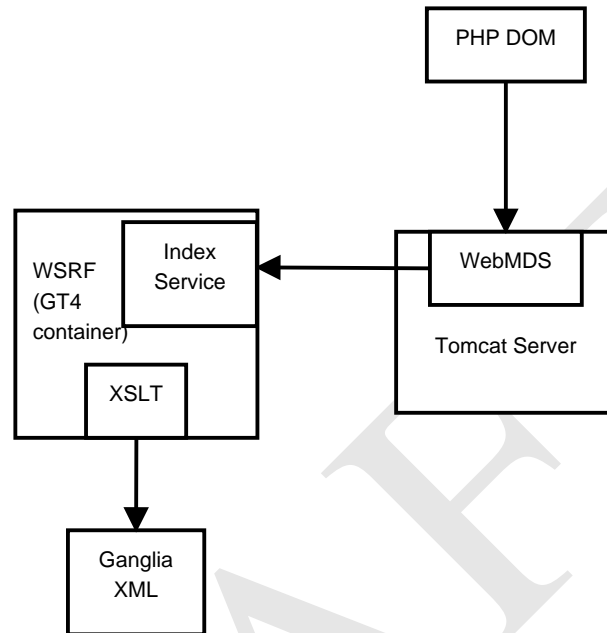


Figure 3.9: WebMDS application

Figure 3.9 display the data flow of the case where data presented using the WSRF Information System. The PHP from Brunel's web server calls WebMDS and get the result in XML which parses using DOM. WebMDS is deployed in the Tomcat container, and calls the Index Service of WSRF which is deployed in the GT4 container. WSRF connects (if cache has expired) to the Gmond process that and transforms the data received using XSLT.

For this project an Apache Tomcat server was installed in the box that globus toolkit was running, and the **webmds application** from the GT4 home was deployed. In webmds configuration file, the global option to allow user specified queries using XPath was enabled.

```

[root@osweb ~]# cat /opt/globus/lib/webmds/globalconfig.xml
<WebmdsGlobalConfig>
  <newStyleErrors>true</newStyleErrors>
  <allowUserSpecifiedQuery>true</allowUserSpecifiedQuery>
</WebmdsGlobalConfig>
  
```

</WebmdsGlobalConfig>

DRAFT

Chapter 4

Results

4.1 Events source

Results are displayed from the generation of metrics to the aggregation using various information services and the presentation using ready and custom developed interfaces.

4.1.1 Unix stuff

As described in subsection Metrics of the previous chapter, Linux provides through the **proc pseudo-filesystem** a simple file interface to the metrics taken from the scheduler of processes that are queued in the processor.

The three metrics about CPU load on 1, 5 and 15 minutes average is displayed as follows:

```
[root@gr03 ~]# cat /proc/loadavg
2.29 0.73 0.32 1/230 3584
```

which may also be displayed using the **uptime command**:

```
[root@gr03 ~]# uptime
00:01:20 up 1:41, 3 users, load average: 2.29, ↵
0.73, 0.32
```

When we examine the Linux kernel source code, there is a macro command named $CALC_{LOAD}$ which takes the options that have been discussed and returns the result of the metric. The definition of the macro can be seen in file **include/linux/sched.h**, Listing 4.1.

Listing 4.1: Linux kernel CALC_LOAD macro

```
extern unsigned long avenrun[];          /* Load ←
    averages */
extern void get_avenrun(unsigned long *loads,
                        unsigned long offset, int ←
                        shift);

#define FSHIFT      11                  /* nr of bits of ←
    precision */
#define FIXED_1     (1<<FSHIFT) /* 1.0 as fixed-point */
#define LOAD_FREQ   (5*HZ+1)         /* 5 sec intervals */
#define EXP_1       1884              /* 1/exp(5 sec/1 min) as ←
    fixed-point */
#define EXP_5       2014              /* 1/exp(5 sec/5 min) */
#define EXP_15      2037              /* 1/exp(5 sec/15 min) */

#define CALC_LOAD(load, exp, n) \
    load *= exp; \
    load += n*(FIXED_1-exp); \
    load >>= FSHIFT;

extern unsigned long total_forks;
extern int nr_threads;
DECLARE_PER_CPU(unsigned long, process_counts);
extern int nr_processes(void);
extern unsigned long nr_running(void);
```

```
extern unsigned long nr_uninterruptible(void);
extern unsigned long nr_iowait(void);
extern unsigned long nr_iowait_cpu(int cpu);
extern unsigned long this_cpu_load(void);
```

4.1.2 Ganglia

When gmond starts, it listens on port 8649/TCP by default, to accept TCP connections and throw XML report for the whole cluster. It also binds to the multicast address on port 8649/UDP to get other hosts messages for metrics changes, and also multicast its own metrics. Listing 4.2 shows the opened sockets of Gmond daemon, and Listing 4.3 display a sample xml output when connecting to 8649/TCP to transfer metrics through XML.

Listing 4.2: Gmond networking

```
[root@gr01 ~]# lsof -i 4 -a -p 'pidof gmond'
COMMAND  PID   USER  FD  TYPE DEVICE SIZE NODE NAME
gmond    11900 nobody  4u  IPv4  33699      UDP  ↔
      239.2.11.71:8649
gmond    11900 nobody  5u  IPv4  33701      TCP  ↔
      *:8649 (LISTEN)
gmond    11900 nobody  6u  IPv4  33703      UDP  gr01↔
      .oslab.teipir.gr:39991->239.2.11.71:8649
```

Listing 4.3: Gmond XML cluster report

```
<?xml version="1.0" encoding="ISO-8859-1" standalone="↔
yes"?>
<GANGLIA_XML VERSION="3.1.7" SOURCE="gmond">
  <CLUSTER NAME="RDLAB" LOCALTIME="1297198943" OWNER="↔
TEIPIR" LATLONG="unspecified" URL="unspecified">
```

```

<HOST NAME="gr02.oslab.teipir.gr" IP="10.0.0.32" ←
  REPORTED="1297198934" TN="8" TMAX="20" DMAX="0"←
  LOCATION="unspecified" GMOND_STARTED="←
1296569542">
<METRIC NAME="load_one" VAL="0.01" TYPE="float" ←
  UNITS=" " TN="50" TMAX="70" DMAX="0" SLOPE="←
both">
<EXTRA_DATA>
<EXTRA_ELEMENT NAME="GROUP" VAL="load"/>
<EXTRA_ELEMENT NAME="DESC" VAL="One minute load ←
average"/>
<EXTRA_ELEMENT NAME="TITLE" VAL="One Minute Load←
Average"/>
</EXTRA_DATA>
</METRIC>
</HOST>
</CLUSTER>
</GANGLIA_XML>

```

Worker nodes are configured to transfer metrics data using multicast. Each Gmond daemon of each Computing Element node, by Ganglia definition has to know the state of the whole Computing Element cluster. Using standard UNIX commands to listen the data transferred on the multicast network, we observe a sample transfer of `load_one` metric. As described in Subsection 3.3.2, metric data are multicasted by Gmond when there is a change in the value, or when the time threshold is reached.

Listing 4.4: XDR sample

```

[root@gr01 ~]# tcpdump -A -i eth2 dst host 239.2.11.71
22:38:26.062266 IP gr01.oslab.teipir.gr.39991 > ←
239.2.11.71.8649: UDP, length 56

```

```
E..T..@.....G.7!..@.X.....gr01.oslab.teipir.gr←
....load_one.....%.2f..
```

Using Ganglia build-in command *gstat*, a nice output of Processor Load metrics is shown for the whole cluster in Listing 4.5

Listing 4.5: Gstat output

```
[root@gr01 ~]# gstat -all
gr03.oslab.teipir.gr      2 (    0/   87) [  0.00, ←
    0.00,  0.00] [    0.0,    0.0,    0.0,  99.9,    0.1] ←
    OFF
gr01.oslab.teipir.gr      1 (    0/   75) [  0.00, ←
    0.00,  0.00] [    0.0,    0.0,    0.0,  99.9,    0.0] ←
    OFF
gr02.oslab.teipir.gr      1 (    0/   99) [  0.00, ←
    0.00,  0.00] [    0.0,    0.0,    0.1,  99.9,    0.0] ←
    OFF
```

4.2 Aggregation and transfer

Metrics taken from the event source are passed to the information service using the information/resource provider.

4.2.1 WSRF

In WSRF the *wsrfe-query* command is executed using the URL of the container where the WSRF has deployed. The container should run in a host with a host certificate signed by a certificate authority, and a certificate proxy should be initialized with a valid user certificate that is requesting the information.

```
/opt/globus/bin/wsrquery -s https://osweb.teipir.gr←
:8443/wsrf/services/DefaultIndexService "/*[local←
name()='Host']"
```

The result of the above query returns a list of all cluster nodes. An abstract result is displayed here in Listing 4.6.

Listing 4.6: WSRF query output

```
<ns1:GLUECE xmlns:ns1="http://mds.globus.org/glue/ce←
/1.1">
  <ns1:Cluster ns1:Name="OSLAB" ns1:UniqueID="OSLAB">
    <ns1:SubCluster ns1:Name="main" ns1:UniqueID="main"←
    >
      <ns1:Host ns1:Name="gr03.oslab.teipir.gr"
        ns1:UniqueID="gr03.oslab.teipir.gr"
        xmlns:ns1="http://mds.globus.org/glue/ce/1.1">
        <ns1:Processor ns1:CacheL1="0" ns1:CacheL1D="0"
          ns1:CacheL1I="0" ns1:CacheL2="0" ns1:ClockSpeed="←
          2392"
          ns1:InstructionSet="x86"/>
        <ns1:MainMemory ns1:RAMAvailable="299" ←
          ns1:RAMSize="1010"
          ns1:VirtualAvailable="2403" ns1:VirtualSize="3132←
          "/>
        <ns1:OperatingSystem ns1:Name="Linux"
          ns1:Release="2.6.18-194.26.1.el5"/>
        <ns1:Architecture ns1:SMPSize="2"/>
        <ns1:FileSystem ns1:AvailableSpace="201850"
          ns1:Name="entire-system" ns1:ReadOnly="false"
          ns1:Root="/" ns1:Size="214584"/>
        <ns1:NetworkAdapter ns1:IPAddress="10.0.0.33"
          ns1:InboundIP="true" ns1:MTU="0"
```



```

    ns1:Name="gr03.oslab.teipir.gr" ns1:OutboundIP="↵
    true"/>
    <ns1:ProcessorLoad ns1:Last15Min="45" ↵
    ns1:Last1Min="337"
    ns1:Last5Min="126"/>
  </ns1:Host>
</ns1:SubCluster>
</ns1:Cluster>
</ns1:GLUECE>

```

WebMDS and XPath

The role-based access control model of the grid security context allow queries only by authenticated and authorized users. Building a testbed with full grid security in mind would be out of this project scope, so XML result of Web Service calls is taken through WebMDS instead of WSDL discovery and SOAP messaging.

Using the following XPath query in the WebMDS form, a request to get the metrics of Host node with name *ltsp.oslab.teipir.gr* was sent.

```
//glue:Host[@glue:Name='ltsp.oslab.teipir.gr']
```

WebMDS match the query in its cache and replies only the specific node that was requested. If the cache was expired (its default value is 60 seconds) it is using the Resource Provider to fetch the XML from Gmond and transform it using XSLT to Glue schema and serve the new values as shown in Listing 4.7.

Listing 4.7: WebMDS results from XPath query

```

<WebmdsResults>
  <ns1:Host ns1:Name="ltsp.oslab.teipir.gr"
    ns1:UniqueID="ltsp.oslab.teipir.gr">

```

```

<ns1:Processor ns1:CacheL1="0" ns1:CacheL1D="0"
ns1:CacheL1I="0" ns1:CacheL2="0" ns1:ClockSpeed="↵
1600"
ns1:InstructionSet="x86_64"/>
<ns1:MainMemory ns1:RAMAvailable="17806" ↵
ns1:RAMSize="20121"
ns1:VirtualAvailable="22137" ns1:VirtualSize="24508↵
"/>
<ns1:OperatingSystem ns1:Name="Linux"
ns1:Release="2.6.32-24-server"/>
<ns1:Architecture ns1:SMPSize="8"/>
<ns1:FileSystem ns1:AvailableSpace="34243"
ns1:Name="entire-system" ns1:ReadOnly="false" ↵
ns1:Root="/"
ns1:Size="251687"/>
<ns1:NetworkAdapter ns1:IPAddress="192.168.0.101"
ns1:InboundIP="true" ns1:MTU="0" ns1:Name="ltsp.↵
oslab.teipir.gr"
ns1:OutboundIP="true"/>
<ns1:ProcessorLoad ns1:Last15Min="9" ns1:Last1Min="↵
1"
ns1:Last5Min="9"/>
</ns1:Host>
</WebmdsResults>

```

4.2.2 BDII

On the other information service, using *ldapsearch* command and specifying the base DN for the search, the host URI and the desired attributes to return, we may get the values asked from the BDII as seen on Listing 4.8

Listing 4.8: BDII LDAP search for Glue CE ProcessorLoad attributes

```
# ldapsearch -H ldap://osweb.teipir.gr:2170 -x \
-b GlueHostName=ainex.local,Mds-Vo-name=local,o=grid \
GlueHostProcessorLoadLast1Min ↔
    GlueHostProcessorLoadLast5Min \
GlueHostProcessorLoadLast15Min

# ainex.local, local, grid
dn: GlueHostName=ainex.local,Mds-Vo-name=local,o=grid
GlueHostProcessorLoadLast1Min: 27
GlueHostProcessorLoadLast15Min: 22
GlueHostProcessorLoadLast5Min: 20
```

The above information has been given by the BDII LDAP instance which used the wrapper of Ganglia Resource Provider, a customized Perl script to export MDS format as shown in Listing 4.9.

Listing 4.9: Perl Ganglia Information Provider for MDS

```
[root@mon ~]# ./ganglia_ip -h mon -p 8649 -o mds | ↔
grep -A 22 host=gr03

dn: host=gr03.oslab.teipir.gr, cl=RDLAB, \
    mds-vo-name=local, o=grid
objectclass: GlueHost
GlueHostName: gr03.oslab.teipir.gr
GlueHostUniqueID: RDLAB-TEIPIR-gr03.oslab.teipir.gr
objectclass: GlueHostProcessorLoad
GlueHostProcessorLoadLast1Min: 2.57
GlueHostProcessorLoadLast5Min: 1.48
GlueHostProcessorLoadLast15Min: 0.58
objectclass: GlueHostSMPLoad
GlueHostSMPLoadLast1Min: 2.57
```

```

GlueHostSMPLoadLast5Min: 1.48
GlueHostSMPLoadLast15Min: 0.58
objectclass: GlueHostArchitecture
GlueHostArchitectureSMPSize: 2
objectclass: GlueHostProcessor
GlueHostProcessorClockSpeed: 2392
objectclass: GlueHostNetworkAdapter
GlueHostNetworkAdapterName: gr03.oslab.teipir.gr
GlueHostNetworkAdapterIPAddress: 10.0.0.33
objectclass: GlueHostMainMemory
GlueHostMainMemoryRAMSize: 1035104
GlueHostMainMemoryRAMAvailable: 306280

```

Using the Ganglia official python client (Listing 4.10 which is distributed with the source code of Ganglia Client, rejected as an option because Perl is easier in handling regular expressions for string operations and transformation).

Listing 4.10: Python Ganglia client MDS export

```

[root@mon ~]# /opt/ganglia/bin/ganglia --format=MDS | ↵
grep -A 30 host=gr03

dn: host=gr03.oslab.teipir.gr, scl=sub2, cl=datatag↵
    CNAF, \
    mds-vo-name=local, o=grid
objectclass: GlueHost
GlueHostName: gr03.oslab.teipir.gr
GlueHostUniqueID: RDLAB-TEIPIR-gr03.oslab.teipir.gr
objectclass: GlueHostArchitecture
GlueHostArchitecturePlatformType: x86-Linux
GlueHostArchitectureSMPSize: 2
objectclass: GlueHostProcessor

```

```

GlueHostProcessorClockSpeed: 2392
objectclass: GlueHostMainMemory
GlueHostMainMemoryRAMSize: 1035104
GlueHostMainMemoryRAMAvailable: 306280
objectclass: GlueHostNetworkAdapter
GlueHostNetworkAdapterName: gr03.oslab.teipir.gr
GlueHostNetworkAdapterIPAddress: 10.0.0.33
GlueHostNetworkAdapterMTU: unknown
GlueHostNetworkAdapterOutboundIP: 1
GlueHostNetworkAdapterInboundIP: 1
objectclass: GlueHostProcessorLoad
GlueHostProcessorLoadLast1Min: 2.57
GlueHostProcessorLoadLast5Min: 1.48
GlueHostProcessorLoadLast15Min: 0.58
objectclass: GlueHostSMPLoad
GlueHostSMPLoadLast1Min: 2.57
GlueHostSMPLoadLast5Min: 1.48
GlueHostSMPLoadLast15Min: 0.58
objectclass: GlueHostStorageDevice
GlueHostStorageDeviceSize: 209555000
GlueHostStorageDeviceAvailableSpace: 197120000
GlueHostStorageDeviceType: disk

```

4.3 Presentation

Finally, to present the information there has been used two custom developed interfaces in PHP. Both programs reside in Brunel University webserver which supports the needed libraries and network connections. The source code is available under that page, and when called using BDII or WSRF, the result is exactly the same and looks like Table 4.1.

| Hostname | 1min | 5min | 15min |
|-----------------------|------|------|-------|
| ltsp.oslab.teipir.gr | 0.01 | 0.09 | 0.09 |
| xenia.oslab.teipir.gr | 0.00 | 0.06 | 0.06 |
| gr201.oslab.teipir.gr | 0.52 | 0.59 | 0.42 |
| gr130.oslab.teipir.gr | 0.00 | 0.06 | 0.16 |
| gr131.oslab.teipir.gr | 1.22 | 0.79 | 0.40 |
| gr212.oslab.teipir.gr | 0.06 | 0.09 | 0.09 |
| gr180.oslab.teipir.gr | 2.06 | 1.49 | 0.59 |
| gr181.oslab.teipir.gr | 0.71 | 0.57 | 0.32 |

Table 4.1: Sample output from both calls with DOM or LDAP

4.3.1 DOM

The one uses PHP DOM functions to call the WebMDS and get the XML as it would happened calling the WSRF Web Service with security in mind. Listing 4.11 is an abstraction of the code deployed in Brunel's webserver and returns only one value. The purpose of this listing is to present the use of functions and not the HTML stuff.

Listing 4.11: PHP DOM call to WebMDS

```
$url="http://osweb.teipir.gr:8080/webmds/webmds?info=↵
    indexinfo&xsl=&xmlSource.indexinfo.param.xpathQuery↵
    =%2F%2F*[local-name%28%29%3D%27Host%27]";
$file = file_get_contents($url);
$dom = DOMDocument::loadXML($file);
$host = $dom->getElementsByTagName('Host');
$procload = $host->item($k)->getElementsByTagName('↵
    ProcessorLoad');
echo ($procload->item($i)->getAttribute('Last1Min'))↵
    /100;
```

4.3.2 LDAP

The other PHP is using LDAP functions to connect to BDII instance and get the results from objects that instantiates the GlueHostProcessorLoad class.

Listing 4.12 displays the method to bind anonymously, form the query and get a sample result.

Listing 4.12: PHP LDAP call to BDII

```
$ds=ldap_connect("osweb.teipir.gr","2170");
if ($ds)
{
    $r=ldap_bind($ds);
    $sr=ldap_search($ds, "mds-vo-name=local,o=grid", "↵
        (&(objectClass=GlueHostProcessorLoad))");
    if ($sr)
    {
        $info = ldap_get_entries($ds, $sr) or die("↵
            could not fetch entries");
        echo ($info[0][gluehostprocessorloadlast1min↵
            ][0])/100;
    }
    ldap_close($ds);
}
```

4.3.3 Nagios

Nagios calls `check_ganglia` periodically (configured as check interval) and logs the state of each service and host check. Load averages are described as services. Listing 4.13 shows the log file of nagios service check for these values straight from Ganglia.

Listing 4.13: Nagios log with load check

```
[1297634400] CURRENT SERVICE STATE: xenia.oslab.teipir↵
    .gr;load_fifteen;OK;HARD;1;CHECKGANGLIA OK: ↵
    load_fifteen is 0.00
```

```
[1297634400] CURRENT SERVICE STATE: xenia.oslab.teipir←
    .gr;load_five;OK;HARD;1;CHECKGANGLIA OK: load_five ←
    is 0.00

[1297634400] CURRENT SERVICE STATE: xenia.oslab.teipir←
    .gr;load_one;OK;HARD;1;CHECKGANGLIA OK: load_one is←
    0.00
```

NPCD is configured in bulk mode so with some luck a file may be found in the spool directory before the interval passes to process it with perl script to RRD database. Listing 4.14 contains the performance data metrics.

Listing 4.14: NPCD temporary file in spool directory

```
[root@osweb ~]# cat /var/spool/pnp4nagios/host←
    perfddata.1297973378
DATATYPE::HOSTPERFDATA  TIMET::1297973368  HOSTNAME::←
    osweb.teipir.gr  HOSTPERFDATA::rta=0.057000ms←
    ;3000.000000;5000.000000;0.000000  pl=0%;80;100;0  ←
    HOSTCHECKCOMMAND::ncg_check_host_alive  HOSTSTATE::←
    UP  HOSTSTATETYPE::HARD
```

Finally, Nagios Web interface displays the aggregated values of host performance state in multiple views, as shown in Table 4.2.

| Host | Service | Status | Last Check | Status Information |
|-------|--------------|----------|---------------------|---------------------------------------|
| gr129 | load_fifteen | OK | 02-08-2011 20:17:23 | CHECKGANGLIA OK: load_fifteen is 0.17 |
| | load_five | OK | 02-08-2011 20:18:12 | CHECKGANGLIA OK: load_five is 0.27 |
| | load_one | OK | 02-08-2011 20:17:43 | CHECKGANGLIA OK: load_one is 0.02 |
| gr130 | load_fifteen | OK | 02-08-2011 20:14:23 | CHECKGANGLIA OK: load_fifteen is 1.77 |
| | load_five | WARNING | 02-08-2011 20:14:15 | CHECKGANGLIA OK: load_five is 4.75 |
| | load_one | CRITICAL | 02-08-2011 20:14:43 | CHECKGANGLIA OK: load_one is 11.60 |

Table 4.2: Example Nagios service status details for ganglia check

Chapter 5

Analysis

5.1 Methods Adopted

In complex distributed systems such as grids, performance bottlenecks may be located using monitoring data. From the processor usage on a single node of a computing element to the total usage of processed jobs in a large cluster, performance data help to focus on the problem that impacts the overall performance.

In order to succeed in grid monitoring, some requirements should be considered. A very large amount of data should be delivered real-time, from many heterogeneous sources on different networks or even countries. These data must be accurate and consistent. There should be synchronized timestamps on the generation of each metric, to the measurement value that should be comparable between different architectures. The time synchronization of the hosts of each cluster may be done using network time protocol, so all metrics are taken on the time that they actually report. Metrics should have error bounds to preserve accuracy, and the consistency issue is solved using coordination of that activity, so the impact of a metric to other sensors is controlled.

The flow of the monitoring process initialization is described from the GMA standard. The application-consumer queries the directory service in order to declare its interest to get metrics for a specific host/cluster. The sensors of the elements that is equivalent to the specific query generates the metrics

that will be given to the consumer from the producer, which in turn queries the directory service to find the consumer. The producer is the one that initializes the connection to the consumer in order to deliver the measurements, even if the consumer had asked the directory service for this. [28]

5.1.1 Performance Metrics

Linux kernel process scheduler provides the three numbers for the processor load during the last one, five and fifteen minutes period. There are many ways to calculate the system load in UNIX systems, updating the values on each scheduler event or periodically sampling the scheduler state.

Scheduler efficiency impact on total system's performance, and periodic sampling lead to more accurate load averages. Linux uses the second one, with the period of five seconds, five clock ticks. Each "clock tick" represented by the HZ variable which is the pulse rate of a kernel activity. This method is more performance-wise from the first one where recalculation of load occurs in every scheduler event.

There is a significant difference between processor load and processor usage of a system. Processor usage is a percent representation of the use of CPU by processes, and not used in this project. CPU load is a better metric for the system performance because it does not have a top value of 100% but is based in processes running and waiting in the scheduler queue.

Transport and sample

Gmond code uses the ganglia libmetrics library which in case of Linux operating system parses the `/proc/loadavg` pseudo-file to get Linux kernel calculated system load average as shown in Listing 5.1. When this value is taken, it is pushed to the multicast network using UDP datagram. If this value has not changed from the previous one, it is not pushed until a timeout is reached.

Listing 5.1: libmetrics code to get load average

```

timely_file proc_loadavg = { {0,0} , 5., "/proc/↵
    loadavg" };
/* ... */
g_val_t
load_one_func ( void )
{
    g_val_t val;
    val.f = strtod( update_file(&proc_loadavg), (char ↵
        **))NULL);
    return val;
}

```

5.1.2 Information Systems

WSRF

The XML that Ganglia Resource Provider took from Gmond process through TCP, using XSLT technology is transformed on WSRF to another XML document, that is following the Glue-CE schema. globus_wsrf_mds_usefulrp directory of globus configuration root, there is the file ganglia_to_glue.xslt where we can focus on the transformation rules. A snippet of interest for the case of ProcessorLoad class is seen in Listing 5.2.

Listing 5.2: WSRF XSLT for Ganglia Information Provider

```

<glue:ProcessorLoad>

<xsl:attribute name="glue:Last1Min">
    <xsl:call-template name="emitProperNumeric">
        <xsl:with-param name="numeric"
            select="floor(100 * METRIC[@NAME='load_one']/@VAL)↵
        "/>

```

```

    </xsl:call-template>
</xsl:attribute>

<xsl:attribute name="glue:Last5Min">
  <xsl:call-template name="emitProperNumeric">
    <xsl:with-param name="numeric"
      select="floor(100 * METRIC[@NAME='load_five']/@VAL←
        )"/>
  </xsl:call-template>
</xsl:attribute>

<xsl:attribute name="glue:Last15Min">
  <xsl:call-template name="emitProperNumeric">
    <xsl:with-param name="numeric"
      select="floor(100 * METRIC[@NAME='load_fifteen']/←
        @VAL)"/>
  </xsl:call-template>
</xsl:attribute>

</glue:ProcessorLoad>

```

In Listing 5.2 XPath queries noticed and a multiplication with 100 on CPU load values to get an integer is executed. This is happening in order to avoid the transfer of float values. In the frontend using DOM, a division with 100 is done to get the original CPU load average number back.

BDII

On the other hand, in BDII Processor Load values left as decimal numbers because its easy for LDAP to handle string values of numbers. The transformation from Gmond or Gmetad information provided using XML, is done by Perl XML::Parse and the output is done in MDS format. Some changes to the original Perl script written by Stratos Efstathiadis was done to match my

test-bed's LDAP schema.

5.1.3 Nagios

Nagios was installed in the testbed using YAIM tool. Some user certificates from TEIPIR and Brunel was added to access the interface through the VOMS2HTPASSWD tool.

Custom check command was introduced to configure Nagios with ganglia. Ganglia original `check_ganglia.py` client was used as shown in Listing 5.1.3.

```
define command{
    command_name    check-ganglia
    command_line    check_ganglia.py -h $HOSTNAME$ -m ↵
                    $ARG1$ -w $ARG2$ -c $ARG3$ -s 195.251.70.54 -p ↵
                    8649
}
```

Nagios service check templates was created, to match all nodes of host-group named *worker – nodes*, one for each of the three metrics that will be aggregated in Nagios. Under the configuration listed in Listing 5.1.3, options for warning and critical thresholds of Processor Load was applied, to notify the contacts that will be set to monitor these services through the rest of Nagios system.

```
define service{
    use                wn
    hostgroup_name     worker-nodes
    service_description load_one
    check_command       check-ganglia!load_one!4!5
    action_url         https://osweb.teipir.gr/nagios↵
                       /html/pnp4nagios/index.php?host=$HOSTNAME$&srv=↵
                       $SERVICEDESC$
```

}

5.2 Grid Performance and Site Reliability

Grid monitoring in general as proposed by Multi-Level Monitoring in EGEE SA1, is dealing with availability and reliability monitoring. There are threshold values for these metrics for a production site and SLA calculation make use of these metrics.

Performance monitoring when examined from this point of view, its main purpose is to count jobs that are successfully being submitted to a CE. Site reliability is calculated using that metric.

For a system engineer, performance monitoring for system administration has to do with Processor Load metrics and not with jobs failed or executed successfully. With that in mind, a system engineer may take capacity management decisions to scale-out the Computing Element, or even scale-up a single node of it.

This is the main goal of this project, to provide tools that allow the aggregation of Processor Load information to system engineers, and not job counting tools such as SAM, Gridview and MyEGEE or MyEGI. Ganglia is the event source that publish the metrics taken from Linux kernel as described, and multiple information services or even Nagios may be used to provide that information to users.

5.3 Information Services Scaling

5.3.1 LDAP

LDAP as the core technology of MDS2 has been investigated [14] and proved that scales and performs good when the data are kept in cache. The performance of the information system when it is accessed by a large number of concurrent users have degrades dramatically when data caching is not used.

Compared with WSRF, it **performs faster** [29] in small number of users, because of the LDAP base of this information service. LDAP back-end is a Berkeley DB and is implemented in C, versus Java and SOAP over HTTP and XML of WSRF. Caching in LDAP although is reported to have problems.

5.3.2 WSRF

On the other side, MDS4 (WSRF) scales better than MDS2 (LDAP) in **large number** of concurrent users. Both throughput and response in queries in large number of queries is consistent, which allows the use of MDS4 for robust operations.

WSRF also supports **many query languages**, unlike BDII which supports only LDAP queries. By default it is distributed only with support of XPath queries, but its architecture which is based in Java container and SOAP/XML standards, allow the distribution of the Information Service with other query languages as well.

Adding a Resource Provider in WSRF was much easier than adding an Information Provider in BDII, which makes MDS4 more **extensible** than MDS2. Even though in BDII a simple wrapper had to be installed in BDII GIP configuration directory, the Perl script (or the Python one provided by Ganglia) had to be changed to reach the running BDII instance of Glue schema. MDS4 and WSRF is based in XML and XSLT transformation mechanisms that allow the easy addition of other Providers of a site. It is even allowed to aggregate Index Services from other sites using the *downstream* option to register them in the local Index Service.

BDII LDAP based configuration is complex due to OID namespaces and naming authorities and is not portable with other information systems. WSRF configuration is much easier and **flexible** because of the XML-based information model, which generally considered more friendly.

Reliability is another factor where WSRF is better than LDAP. BDII after a long period of heavy activity has memory usage problems and requests may

have delay in being served, so periodically service restarts are needed, unlike WSRF Index which has been tested under heavy load and keeps serving without problems [29].

Although WSRF in many factors is dominating, during this project there has been noticed that when some nodes of the Computing Element that report its status are down, problems occur. Some deserialization exceptions appear in the container log file for a few minutes until the WSRF learn about the new state of the cluster from Gmond.

Chapter 6

Conclusions

Grid monitoring is an important factor when working with Grid Systems. Reports extracted from monitoring systems, support decisions for capacity management, and prove that a system meets requirements needed for Service Level Agreements.

Metrics for Computing Element performance monitoring usually are:

1. **Total Jobs** in running or waiting to run state.
2. Individual per working node **Processor Load**.
3. **Benchmarking** metrics such as FLOP/s.

This project focused in the calculation, aggregation and transfer to present the metrics for Processor Load of working nodes of a Computing Element. Running and waiting jobs monitoring is extremely analyzed under availability monitoring research.

Calculation using the number of processes waiting in the queue of kernel scheduler where used. This metric is explained why is more accurate from the classic percentage CPU usage.

Aggregation and transfer of metrics where examined in many different levels, from the multicasted XDR of Gmond to the resource providers of the information service that where used.

Information Service is core technology that used in Grid Computing. It has evolved in parallel with Middleware. Current version of the Monitoring

and Discovery Service standard has reached the MDS4, introducing the use of Web Services. MDS2 was based in LDAP, which is still used by some systems to discover services.

Nagios bulk aggregation features using NPCD and MSG-Nagios-Bridge also provide a method to aggregate Ganglia metrics without the use of the MDS.

Presentation where simply examined using:

1. **DOM technology** to parse XML taken from WSRF through WebMDS interface using XPath
2. simple **LDAP** communication to take the metrics from the BDII Information Service

6.1 Conclusions

Every aspect of grid monitoring keeps **scalability in mind**. Distribution of metrics in all worker nodes using Gmond is the key to keep redundant that information.

BDII Information Service is great for use in site level environment, as LDAP performs faster than WSRF in less than a hundred users.

Site monitoring needs Nagios and Ganglia for a few hundreds of nodes. Nagios web interface is enough for site-level host and service view. Ganglia web interface supports good aggregation of many clusters, to the Region-level.

WSRF caching feature, Indexer and Aggregator Framework scales better and may be used for regional and top level monitoring.

Heterogeneous environments should **rely on standards** in order to inter-operate and stay reliable. Even the Information Services mentioned above stick to the Glue schema.

A tool may seem to be great for its purpose, but after focusing on a need is may be discontinued, such as SAM. This example is taken from the availabil-

ity monitoring as its frontend were replaced by MyEGI and Nagios keeping its back-end in MRS.

6.2 Further Work

6.2.1 Aggregation

Additional investigation is required to be carried out for the aggregation of collected information. WSRF offer the Aggregator Framework, which downstream information from many EPRs and deliver it through the Index service. To scale such information in the Regional monitoring level may have issues that only in that scale will come out.

6.2.2 Benchmarking

Performance metrics which are produced using benchmarking software is good standard way of measuring and advertise the performance of Computing Elements. Such metrics are not efficient for regularly runs and frequently changes because they are cost effective performance wise. It is good although to present the performance ability of a CE, so if they could be executed every some long time periods and pushed in the information service, will offer a good metric to select one CE of another.

6.2.3 Storage element performance monitoring

Storage Element performance monitoring is an interesting area for research. Vendors that produce enterprise level storage systems also offer tools to monitor the performance of the storage system. Most used metric is I/O Operations per second and throughput in GByte per second, in every aspect of a storage system.

Storage systems are also provided by different vendors and may also deployed as custom solution. Fiber Channel solutions versus Clustered File

System cases are examined [30] as a chapter of distributed systems, storage oriented.

Hadoop is the most commonly used distributed data storage. In CMS, an experiment that is known for its huge needs in data storage, Hadoop has been adopted [31] as the distributed file system. Grid computing community have adopted the use of Total and Used GB per Storage Element (as in Computing Element), but there is still enough work on the performance monitoring.

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Electronic & Computer Engineering



Industrial Mentor's Report on a MSc Dissertation

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Dissertation Title: Grid Monitoring

I confirm / cannot confirm* that the MSc dissertation submitted by the above student truly reflects the respective contributions of the student and others, with whom the student has worked during the MSc project.

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Signed:

Name: Dr.Paul Kyberd

Date: