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Job submission and management through web services: the experience with the CREAM service

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Abstract. Modern Grid middleware is built around components providing basic functionality, such as data storage, authentication, security, job management, resource monitoring and reservation. In this paper we describe the Computing Resource Execution and Management (CREAM) service. CREAM provides a Web service-based job execution and management capability for Grid systems; in particular, it is being used within the gLite middleware. CREAM exposes a Web service interface allowing conforming clients to submit and manage computational jobs to a Local Resource Management System. We developed a special component, called ICE (Interface to CREAM Environment) to integrate CREAM in gLite. ICE transfers job submissions and cancellations from the Workload Management System, allowing users to manage CREAM jobs from the gLite User Interface. This paper describes some recent studies aimed at assessing the performance and reliability of CREAM and ICE; those tests have been performed as part of the acceptance tests for integration of CREAM and ICE in gLite. We also discuss recent work towards enhancing CREAM with a BES and JSDL compliant interface.

1. Introduction
Grid middleware distributions are often large software artifacts which provide a set of basic functionalities, each one implemented by a separate component. Such functionalities include (but are not limited to) data storage, authentication and authorization, resource monitoring, and job management. In particular, the job management component is used to submit, cancel, and monitor jobs for execution on a suitable computational resource, called a Computing Element (CE). A CE has a complex structure: it represents the interface to a usually large farm of computing hosts managed by a Local Resource Management System (LRMS), such as LSF or PBS. Moreover, a CE should also provide additional features to those of the underlying batch system, such as Grid-enabled user authentication and authorization, accounting, fault tolerance and improved performance and reliability.

Computing Resource Execution and Management (CREAM) is a system designed to efficiently manage a CE in a Grid environment. The goal of CREAM is to offer a simple, robust and lightweight service for job operations. CREAM exposes an interface based on Web Services,
which enables a high degree of interoperability with clients written in different programming
languages: currently Java and C++ clients are provided, but users can use any language with
a Web Service framework to generate their own client interfaces. CREAM is a Java application
running as an extension of a Java-Axis servlet inside the Tomcat application server [1].
CREAM is being developed within the gLite Grid infrastructure [2]. A special component
(called Interface to Cream Environment) has been created to integrate CREAM into the
gLite Workload Management System (WMS), so that gLite users can submit jobs to a CREAM
server in a transparent way. Note, however, that CREAM is a mostly self-contained service,
with few dependencies on the gLite software components. Users can thus install CREAM in
stand-alone mode, and interact directly with it through custom clients, or using the provided
C++-based command line tools.
In this paper we describe the CREAM architecture and highlight its features. We describe its
interface, and show how it has been integrated with the gLite infrastructure. Finally, we show
the results of performance tests which have been done in order to assess CREAM throughput,
compared to the throughput of the other CEs used in gLite.

2. CREAM overview
The main functionality of CREAM is job submission: users can submit jobs, described
via a classad-based Job Description Language (JDL) expression [3], to CREAM-based CEs.
CREAM JDL is the same notation used to describe job characteristics and requirements in
the gLite WMS. The JDL is a high-level, user-oriented language based on Condor classified
advertisements (classads) [4] for describing jobs to be submitted to the CREAM CE service.
CREAM supports the execution of batch (normal) and parallel (MPI) jobs. Normal jobs are
single or multithreaded applications requiring one CPU to be executed; MPI jobs are parallel
applications which usually require a larger number of CPUs to be executed, and which make
use of the MPI library for interprocess communication.

Applications executed by CREAM might need a set of input data files to process, and might
also produce a set of output data files. The set of input files is called the InputSandbox (ISB),
while the set of files produced by the application is called the OutputSandbox (OSB). CREAM
transfers the ISB to the executing node from the client node and/or from Grid storage servers
to the execution node. The ISB is staged in before the job is allowed to start. Similarly, files
belonging to the OSB are automatically transferred out of the execution node when the job
terminates.

As an example, consider the following JDL:

```
[ 
  Type = "job";
  JobType = "normal";
  Executable = "/sw/command";
  Arguments = "60";
  StdOutput = "sim.out";
  StdError = "sim.err";
  OutputSandbox = {
    "sim.err",
    "sim.out"
  };
  OutputSandboxBaseDestURI = "gsiftp://se1.pd.infn.it:5432/tmp";
  InputSandbox = {
    "file:///home/user/file1",
    "gsiftp://se1.pd.infn.it:1234/data/file2",
```
With this JDL a normal (batch) job will be submitted. Besides the specification of the executable /sw/command (which must already be available in the file system of the executing node, since it is not listed in the ISB), and of the standard output/error files, it is specified that the files file1, file2, file3, file4 will have to be staged on the executing node:

- file1 and file3 will be copied from the client User Interface (UI) file system
- file2 will be copied from the specified GridFTP server (gsiftp://se1.pd.infn.it:1234/data/file2)
- file4 will be copied from the GridFTP server specified as InputSandboxBaseURI (gsiftp://se2.cern.ch:5678/tmp)

It is also specified that the files sim.err and sim.out (specified as OutputSandbox) must be automatically uploaded into gsiftp://se1.pd.infn.it:5432/tmp when the job completes its execution.

Other typical job management operations (job cancellation, job status with different levels of verbosity and filtering, job listing, job purging) are supported. Moreover users are allowed to suspend and then restart jobs submitted to CREAM-based CEs, provided that the underlying LRMS supports this feature. Direct job submission and management with CREAM can be done with a set of command-line tools (written in C++); of course, users can produce their own client application which uses the CREAM Web Service Description Language (WSDL) interface. Job submission is also possible through the gLite Workload Management System, through the ICE (discussed later).

For what concerns security, authentication (implemented using a GSI based framework) is properly supported in all operations. Authorization on the CREAM service is also implemented, supporting both Virtual Organization (VO) based policies and policies specified in terms of individual Grid users. A Virtual Organization is a concept that supplies a context for operation of the Grid that can be used to associate users, their requests, and a set of resources. CREAM interacts with a VO Membership Service (VOMS) [5] service to manage VOs; VOMS is an attribute issuing service which allows high-level group and capability management and extraction of attributes based on the user’s identity. VOMS attributes are typically embedded in the user’s proxy certificate, enabling the client to authenticate as well as to provide VO membership and other evidence in a single operation.

3. CREAM architecture

Fig. 1 shows the typical deployment of a CREAM server. CREAM runs as a Java-Axis servlet [6] in the Tomcat application server [1]. CREAM interacts with CE Monitor (CEMON) [7], which provides an asynchronous job status change notification service, through a CREAM backend which implements the Java Naming and Directory Interface (JNDI) interface. Requests to CREAM and CEMON traverse a pipeline of additional components which take care of authorization issues. CREAM submits requests to the LRMS through Batch-system Local ASCII Helper (BLAH), an abstraction layer for the underlying LRMS. BLAH, in turn, interacts with the client-side LRMS environment, which might consist of a set of command line tools which interact with the server-side LRMS.

The CREAM service is available through a Web Service interface. The use of Web Services is one of the key features of CREAM. CREAM is intended to offer job management facilities to
the widest possible range of consumers. This includes not only other components of the same middleware, but also single users and other heterogeneous services. Thus, we need a mechanism that lets potential users to be as free as possible in using their own tools and languages to interface to CREAM. The Web Services technology offers all the interoperability characteristics that are needed to fulfill the above requirements. From the implementation point of view, CREAM is a Java application which uses Apache Tomcat as an application server; CREAM executes inside an Axis container, and exposes a SOAP interface.

Fig. 2 shows a layered view of the CREAM service. Names in italic denote interfaces, the other ones denoting actual components. The figure shows the internal structure of CREAM, which we now discuss in detail.

3.1. CREAM interfaces
CREAM exposes two different interfaces: the legacy one, and the new BES-compliant interface (the latter still under development). BES is a recent specification [8] for a standard interface to execution services provided by different Grid systems. The aim of Basic Execution Service (BES) is to favor interoperability of computing elements between different Grids: the same BES-enabled CE can be “plugged” into any compliant infrastructure; moreover, sharing of resources between different Grids is possible. BES defines basic operations for job submission and management. More specifically, the BES specification defines three Web Services port-types as follows:

**BES-Factory** This port-type allows clients to create, monitor, and control sets of jobs, and to monitor BES attributes, such as the number of jobs currently being instantiated. This port-type is intended for use by ordinary clients.

**BES-Activity** This port-type allows clients to create, monitor, and control individual activities. This port-type is intended for use by ordinary clients.

**BES-Management** This port-type allows clients to monitor the details of and control the BES itself. This port-type is intended for use by system administrators.

BES uses the Job Submission Description Language (JSDL) [9] as the notation for describing computational jobs. The legacy CREAM interface was defined before BES was available, and
also provides additional methods which are not provided by BES (notably, the possibility to renew a user proxy certificate, which is useful to avoid user proxy expiration while a job is running).

3.2. CREAM backend

The CREAM backend is a permanent storage where CREAM saves the data related to the jobs it is managing. The CREAM backend is implemented as a custom Java-based persistent storage mechanism which implements the Java Naming and Directory Interface [10] interface. CREAM also creates a directory for each user that successfully registers a job. The directory, which is located on the filesystem of the CREAM server, contains all information about the job, such as its description in form of a job JDL, the certificate used by the user to submit it, etc.

3.3. Journal Manager

The Journal Manager (JM) is a pool of threads of the CREAM main process. User job commands (job submission requests, job cancellations, etc.) are enqueued into the JM, which stores them on persistent storage to preserve them in case of system failure. The JM then serves these requests, interacting with the underlying LRMS through BLAH. The JM is used to parallelize job submission: multiple job management commands are simultaneously forwarded to the LRMS to improve the overall throughput. Commands submitted by the same user are executed sequentially in the order they were received by CREAM.

3.4. Lease Manager

When job submissions arrive through the gLite WMS, it is essential that all jobs submitted to CREAM eventually reach a terminal state (and thus eventually get purged from the CREAM server). The gLite WMS has been augmented with an additional component, Interface to Cream Environment (ICE), which is responsible for directly interacting with CREAM. ICE and CREAM use a lease-based approach to ensure that all jobs get purged by CREAM even if it loses contact with the ICE client, e.g. due to network partitioning. Basically, each job submitted through ICE has an associated lease time, which must be periodically renewed using an appropriate JobLease CREAM method. ICE is responsible for periodically renewing all leases which are about to expire. Should a job lease expire before the actual termination of a job, the Lease Manager thread will purge it and free all the CE resources used by that job.

3.5. LRMS connectors

As already introduced, CREAM can be seen as an abstraction layer on top of an LRMS (batch system), which extends the LRMS capabilities with an additional level of security, reliability, and integration with a Grid infrastructure. CREAM supports different batch systems through the idea of LRMS connectors. An LRMS connector is an interface for a generic batch system. Currently, CREAM supports all the batch systems supported by BLAH [11] through a specific instance of LRMS connector called the BLAH connector module: at the time of writing BLAH supports LSF, PBS, and Condor; Sun Grid Engine (SGE) support is currently being implemented as well. Of course, it is also possible to create other, ad-hoc connectors to interact with other types of batch systems.

3.6. Security

The Grid is a large collaborative resource-sharing environment. Users and services cross the boundaries of their respective organizations and thus resources can be accessed by entities belonging to several different institutions. In such a scenario, security issues are of particular relevance. There exists a wide range of authentication and authorization mechanisms, but Grid
security requires some extra features: access policies are defined both at the level of VOs and at
the level of single resource owners. Both these aspects must be taken into account. Moreover,
as we will see in the next sections, Grid services have to face the problem of dealing with the
delegation of certificates and the mapping of Grid credentials into local batch system credentials.

**Trust Manager** The Trust Manager is the component responsible for carrying out
authentication operations. It is external to CREAM, and is an implementation of the J2EE
security specifications.

Authentication in CREAM is based on a Public Key Infrastructure (PKI). Each user (and
Grid service) wishing to access CREAM is required to present an X.509 format certificate [12].
These certificates are issued by trusted entities, the Certificate Authorities (CA). The role of a
CA is to guarantee the identity of a user. This is achieved by issuing an electronic document
(the certificate) that contains the information about the user and is digitally signed by the CA
with its private key. An authentication manager, such as the Trust Manager, can verify the user
identity by decrypting the hash of the certificate with the CA public key. This ensures that the
certificate was issued by that specific CA. The Trust Manager can then access the user data
contained in the certificate and verify the user identity.

One interesting challenge in a Grid environment is the so-called *proxy delegation*. It may be
necessary for a job running on a CE to perform some operations on behalf of the user owning
the job. Those operations might require proper authentication and authorization support. For
example, we may consider the case where a job running on a CE has to access a Storage
Element (SE) to retrieve or upload some data. This aim is achieved in the Trust Manager
using *proxy certificates*. Proxy certificates are an extension of X.509 certificates, using RFC3820
proxy-certificates [13]. The generation of a proxy certificate is as follows. If a user wants to
delegate her credential to CREAM, she has to contact the *delegation portType*
of the service.
CREAM creates a public-private key pair and uses it to generate a Certificate Sign Request
(CSR). This is a certificate that has to be signed by the user with her private key. The signed
certificate is then sent back to CREAM. This procedure is similar to the generation of a valid
certificate by a CA and, in fact, in this context the user acts like a CA. The certificate generated
so far is then combined with the user certificate, thus forming a chain of certificates. The service
that examines the proxy certificate can then verify the identity of the user that delegated its
credentials by unfolding this chain of certificates. Every certificate in the chain is used to verify
the authenticity of the certificate at the previous level in the chain. At the last step, a CA
certificate states the identity of the user that first issues the delegated proxy.

**Authorization Framework** The aim of the authorization process is to check whether an
authenticated user has the rights to access services and resources and to perform certain tasks.
The decision is taken on the basis of policies that can be either local or decided at the VO level.
Administrators need a tool that allows them to easily configure the authorization system in order
to combine and integrate both these policies. For this reason, CREAM adopts a framework that
provides a light-weight, configurable, and easily deployable policy-engine-chaining infrastructure
for enforcing, retrieving, evaluating and combining policies locally at the individual resource
sites.

The framework provides a way to invoke a chain of policy engines and get a decision result
about the authorization of a user. The policy engines are divided in two types, depending on their
functionality. They can be plugged into the framework in order to form a chain of policy engines
as selected by the administrator in order to let him set up a complete authorization system. A
policy engine may be either a Policy Information Point (PIP) or a Policy Decision Point (PDP).
PIPs collect and verify assertions and capabilities associated with the user, checking his role,
group and VO attributes. PDPs may use the information retrieved by a PIP to decide whether
the user is allowed to perform the requested action, whether further evaluation is needed, or whether the evaluation should be interrupted and the user denied access.

In CREAM both VO and “ban/allow” based authorizations are supported. In the former scenario, implemented via the VOMS PDP, the administrator can specify authorization policies based on the VO the jobs’ owners belong to (or on particular VO attributes). In the latter case the administrator of the CREAM-based CE can explicitly list all the Grid users (identified by their X.509 Distinguished Names) authorized to access CREAM services.

For what concerns authorization on job operations, by default each user can manage (e.g. cancel, suspend, etc.) only her own jobs. However, the CREAM administrator can define specific “super-users” who are empowered to manage also jobs submitted by other users.

**Credential Mapping** The execution of user jobs in a Grid environment requires isolation mechanisms for both applications (to protect these applications from each other) and resource owners (to control the behavior of these arbitrary applications). In the absence of solutions based on the virtualization of resources (VM), CREAM implements isolation via local credential mapping, exploiting traditional Unix-level security mechanisms like a separate user account per Grid user or per job. This Unix domain isolation is implemented in the form of the glexec system [14], a sudo-style program which allows the execution of the user’s job with local credentials derived from the user’s identity and any accompanying authorization assertions. This relation between the Grid credentials and the local Unix accounts and groups is determined by the Local Credential MAPping Service (LCMAPS) [15]. glexec also uses the Local Centre Authorization Service (LCAS) [16] to verify the user proxy, to check if the user has the proper authorization to use the glexec service, and to check if the target executable has been properly “enabled” by the resource owner.

**4. WMS integration**

Users can interact directly with the CREAM services by means of a set of command line utilities which can be used to manage jobs by directly invoking CREAM operations. These command line tools are written in C++ using the gSOAP library [17].

CREAM functionality can also be used by the gLite WMS Grid component [18]. This means that jobs submitted to the gLite WMS can be forwarded for execution on CREAM-based CEs.

The WMS comprises a set of Grid middleware components responsible for the distribution and management of tasks across Grid resources, in such a way that applications are conveniently, efficiently and effectively executed.

The CREAM–WMS integration is realized with a separate module, called ICE. ICE receives job submissions and other job management requests from the WMS component: it then uses the appropriate CREAM methods to perform the requested operation. Moreover, ICE is responsible for monitoring the state of submitted jobs and for taking the appropriate actions when the relevant job status changes are detected (e.g. the trigger of a possible resubmission if a Grid failure is detected).

Fig. 3 shows a schematic view of CREAM integration with the gLite WMS. gLite users submit jobs through the gLite UI, which transfers jobs to a WMS, which then dispatches the request to the local ICE component. ICE interacts with CREAM via the legacy Web Service interface. Of course, users may also interact with CREAM directly (i.e., bypassing the gLite layer), by using the CREAM command line tools. In both cases the users must have a valid VOMS proxy credential. Other clients can concurrently access the BES interface to CREAM.

ICE obtains the state of a job in two different ways. The first one is by subscribing to a job status change notification service implemented by a separate component called CEMON (see Fig. 1). CEMON [7] is a general-purpose event notification framework. CREAM notifies the CEMON component about job state changes by using the shared, persistent CREAM backend.
ICE subscribes to CEMON notifications, so it receives all status changes whenever they occur. As a fallback mechanism, ICE can explicitly query the CREAM service to check the status of “active” jobs for which it did not receive any notification for a configurable period of time. This mechanism guarantees that ICE knows the state of jobs (possibly with a coarse granularity) even if the CEMON service becomes unavailable. Job status change information is also sent to the Logging and Bookkeeping (LB) [19] service, a distributed job tracking service.

5. Performance tests
We evaluated the performance of the CREAM service in terms of throughput (number of submitted jobs/s), comparing CREAM with the CEs currently used in the gLite infrastructure. The CEs which have been tested are CREAM, the LCG-CE and the gLite-CE. We measured the throughput for the submission of 1000 identical jobs to an idle CE, using an otherwise identical infrastructure. All 1000 jobs were inserted into the input queue of the WMS component responsible for submitting jobs to the CE—that is, the input queue of ICE for the CREAM CE, and the JobController/LogMonitor (JC+LM) input queue for the gLite-CE and LCG-CE. When the input queue was full, ICE (or JC+LM) were switched on to start the submission to the CE. The following JDL was submitted in all tests:

```
Executable = "test.sh";
StdOutput = "std.out";
InputSandbox = {"gsiftp://grid005.pd.infn.it/Preview/test.sh"}
```
OutputSandbox = "out.out";
OutputSandboxDestURI = {"gsiftp://grid005.pd.infn.it/Preview/Output/std.out"};
ShallowRetryCount = 0;
RetryCount = 0;

    with test.sh being:
    
#!/bin/sh
    echo "I am running on 'hostname'"
    echo "I am running as 'whoami'"
    sleep 600

These jobs had the ISB (the executable) downloaded from a GridFTP server, and had the output (the stdout, the hostname where the execution took place and the local user are reported) uploaded to a GridFTP server as well. Each job did a sleep for 10 minutes. Deep and shallow resubmission were disabled.

The following measures were taken:

(i) The number of successful jobs, that is, the number of jobs which successfully completed their execution (we recorded the reported failure reasons for all failed jobs); this is a Higher is Better (HB) metric.
(ii) Throughput to the CE. This is a HB metric, which denotes the number of jobs/minute which are received by the CE.
(iii) Throughput to the LRMS. This is a HB metric, which denotes the number of jobs/minute which are received by the LRMS.

In the case of submissions to CREAM using ICE, the test was repeated considering different values for the number of submitting threads in ICE. The results are given in Table 1. Note that since in the JC+Condor+LM scenario it is not straightforward to distinguish between submission to the CE vs submission to the LRMS, it was not possible to measure the submission rate to the CE as done for the ICE case.

|                | Successful jobs | Throughput for CE submission (jobs/60s) | Throughput for LRMS submission (jobs/60s) |
|----------------|-----------------|-----------------------------------------|------------------------------------------|
| ICE/CREAM, 5 threads | 999/1000        | 37.36                                   | 37.29                                    |
| ICE/CREAM, 10 threads | 994/1000        | 37.56                                   | 37.48                                    |
| ICE/CREAM, 15 threads | 995/1000        | 37.34                                   | 37.22                                    |
| ICE/CREAM, 20 threads | 994/1000        | 36.45                                   | 36.39                                    |
| ICE/CREAM, 25 threads | 994/1000        | 38.83                                   | 38.73                                    |
| LGC-CE          | 1000/1000       | N/A                                     | 13.52                                    |
| gLite-CE        | 940/1000        | N/A                                     | 2.38                                     |

We should note that the JC+Condor+LM to gLite-CE tests revealed a problem in Condor such that that it only could handle 100 jobs, even if the maximum value was correctly set to 1000 in Condor’s configuration file. At the time the tests were performed, a fix for this bug was not available yet. This partly explains the lower submission rates for the LGC-CE and gLite-CE.
6. Conclusions
In this paper we described the general architecture of CREAM, a Java-based Grid CE service. CREAM uses a Web Service interface to provide its functions via an interface based on Web Services, a lightweight implementation and a rich set of features. It is being integrated with the Grid infrastructure, in particular with the WMS subsystem, by means of a glue component called ICE. Moreover, CREAM is being extended with a BES/JSDL compliant interface.

More detailed information, including installation instructions, interface specification and usage manual for CREAM can be found on the Web page [20].

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