Synchrotron Imaging Computations on the Grid without the Computing Element

A Curri, R Pugliese, R Borghes and G Kourousias
Scientific Computing Team, IT Group, Elettra Sincrotrone Trieste, Strada Statale 14 - km 163,5 in AREA Science Park 34149 Basovizza, Trieste, ITALY

E-mail: alessio.curri@elettra.trieste.it

Abstract. Besides the heavy use of the Grid in the Synchrotron Radiation Facility (SRF) Elettra, additional special requirements from the beamlines had to be satisfied through a novel solution that we present in this work. In the traditional Grid Computing paradigm the computations are performed on the Worker Nodes of the grid element known as the Computing Element. A Grid middleware extension that our team has been working on, is that of the Instrument Element. In general it is used to Grid-enable instrumentation; and it can be seen as a neighbouring concept to that of the traditional Control Systems. As a further extension we demonstrate the Instrument Element as the steering mechanism for a series of computations. In our deployment it interfaces a Control System that manages a series of computational demanding Scientific Imaging tasks in an online manner. The Instrument Element is Grid-enabled and can be seen as an extension of the traditional Control Systems. The Instrument control in Elettra is done through a suitable Distributed Control System, a common approach in the SRF community. The applications that we present are for a beamline working in medical imaging. The solution resulted to a substantial improvement of a Computed Tomography workflow. The near-real-time requirements could not have been easily satisfied from our Grid's middleware due to the various latencies often occurred during the job submission and queuing phases. Moreover the required deployment of a set of TANGO devices could not have been done in a standard gLite WN. Besides the avoidance of certain core Grid components, the Grid Security infrastructure has been utilised in the final solution.

1. Domain, problem and requirements
The domain of the application is that of scientific computing for a large multidisciplinary physics research establishment, a Synchrotron Radiation Facility. The proposed architecture has been realised to satisfy certain computational needs in the 3rd generation SRF Elettra which also includes a 4th generation light source based on a free-electron laser, FERMI@Elettra.

Specifically the deployment was for a beamline/laboratory specialised in advanced Computed Tomography and Medical Imaging.

The Scientific Computing team of Elettra has successfully utilised the Grid Computing paradigm [7] in various occasions [1] [15]. The power of the Grid has been proved useful but it has various limitations [9] that will be discussed later in this paper. In order to overcome certain Grid-related problems we utilise a new architecture that is only-partially Grid based.

In general, the computation on the Grid is done on Worker Nodes (WN) of a Computing Element (CE). There are various “logistics” in the process that the middleware, our case gLite [3], takes care of. It has been observed that there are quite high latencies during the job submission...
phase. These latencies for certain applications are not a problem but for other they are. The proposed solution carries the computation in an atypical Grid manner while maintaining other Grid features like security and I/O to storage.

Elettra like many other Synchrotrons bases its control on a Distributed Control System (DCS) [2]. This control core manages more than 10,000 devices, including sensors, detectors, PSUs, and motors. The DCS of choice is TANGO [8]. The proposed solution assumes that a set of TANGO devices are part of the system.

In order to blend TANGO with the Grid technologies we used the Instrument Element (IE) [11] [4], a middleware extension that allows instrument integration on the Grid. The IE has been utilised in a non-standard way, so it does not control an actual instrument but a software-controlling TANGO device. This has been possible due to the extensible nature of its architecture.

In order to satisfy the specific needs of the application a suitable set of virtualisation technologies was deployed. The actual imaging algorithm and application were designed to take advantage of this setup, yielding satisfactory performance. The interaction with the application is user-friendly and is based on a modern Grid web portal, the Virtual Control Room (VCR) [10].

2. PSGen: Imaging on the Grid during the experiment

A beamline (BL) in a Synchrotron is a kind of specialised laboratory. Many of the experiments that take place in such environments have specialised and often high computing needs. Such needs may include the design of novel algorithms, software, hardware, control and user interaction. The SRF Elettra has 24 beamlines providing more than 105,000 hours of user time to visiting and in-house scientists. A mode of operation that is in demand is that of “online” processing; which takes place during the data acquisition phase of the experiment as shown in figure 1. Due to long duration of certain experiments, like >4 hour scans, this mode of operation can provide an early feedback that allows the specialist to preliminary evaluate the correctness of the experiment’s setup.

![Diagram of online and offline processing](image)

**Figure 1.** Online takes place during the experiment and ends with it, while offline starts when the dataset is complete. Where the situations permit, online is a preferred mode since it saves time.

A new software application for a specific problem was developed in such way that utilises the system described in this paper thus has the role of demonstrating its features. The requested application aimed to serve as an improvement to an established Computed Tomography (CT) [6] workflow for a Medical Imaging beamline. An established workflow implies that the beamline is already operating and functional: there are various stages of processing (including few Grid-based [5]), some sequential other parallel, and data formats and instrumentation control is already in-place. This increased the challenge since the improvements had to be a transparent part that would integrate well and would yield advantages. An example technical challenge was the on-the-fly conversion of Lempel-Ziv-Welch [17] compressed 12bit datasets of integers to a RAW 16bit
format. The conversion is not an optimal engineering solution (for large scientific datasets modern formats like HDF5 should be considered) but had been strictly requested so that the I/O formats would be exactly the same as prior to the introduction of our solution. This resulted in an undisturbed workflow where the data processing procedures, before and after the new system, remained the same.

The mode of operation was identified from the early system analysis stages that would be online. Before our solution the specific process in the beamline was operating in an offline mode. As figure 1 suggests this can provide a complete output dataset by end of the experiment. Eventually the online system that this paper is describing saves 2 hours per dataset therefore more data can be acquired for a specific experiment. The proposed architecture can be used for both online and offline applications.

The application collects X-ray absorption data during a CT scan, and then it processes them and produces the corresponding Sinogram dataset as shown in figure 2. The resulted application was PSGen, a Parallel Sinogram Generator.

![Figure 2. Non-normalised X-ray absorption and a selected sinogram line. PSGen is processing all the lines in parallel.](image)

The final system describe in this text has resulted in a rapid sub-second Absorption data processing including parallel I/O to multiple hundreds of Sinogram files; with a total I/O of approximately 5 GB per dataset; all in near-real-time.

3. The distributed control system
TANGO is an open source object oriented control system developed mainly for controlling accelerators and experiments. It can be used for almost any kind of hardware but deployment on a standard gLite WN may be difficult. The system is actively developed by a consortium of synchrotron radiation institutes: Alba, Desy, Elettra, ESRF and Soleil.

For the online processing application, two TANGO device servers have been developed: the Watchdog and the Worker. These are not part of TANGO and have been designed and developed for the proposed solution. The main task of the Watchdog is signaling the presence of a new data to the Worker device. The Worker, after receiving the signal, performs the data processing step. The system is highly configurable and provides at all stages of the processing feedback and status information.

4. Computing on the Cloud instead of the Grid
The TANGO system that has been described on the previous chapter has requirements that the typical gLite Worker Node (WN) may not have or may be impractically difficult to be satisfied. These requirements usually are OS related like user privileges and kernel tuning, and network related like having inbound connectivity. In addition to the TANGO requirements, PSGen itself requires a hardware and software setup that is not present in a general gLite CE deployment. These include custom and cutting-edge versions of libraries and dynamic memory provisioning.
An additional design decision was to provide the application with a direct, fast and low latency access to the storage which at all times can be accessed securely through the GridFTP protocol [16].

The system we designed for deploying the application coupled with the TANGO devices, is hosted in the Elettra Cloud Platform. This infrastructure is based on a virtualisation solution, XEN Hypervisor. It provides a flexible way to add, remove, upgrade, and change resources like CPUs, memory, and Network connectivity. Virtualisation was chosen at an early stage as it made resource allocation easier since CPU requirements had only been estimated and since the system would be a part of larger cluster. In the future, the application may see an increase to its computational requirements (i.e. as image sensors get larger) so scalability and upgradability is necessary [13]. The current performance satisfies the processing needs of PSGen resulting to the calculation of an approximate $15.6 \times 10^6$ 16bit unsigned integers per second.

Besides the calculation capabilities, the overall performance of the system depends on the data I/O subsystem too. The system does not use local storage at any stage. The input and output datasets are stored in a high performance Storage Area Network (SAN). The overall performance, including calculation and I/O, has been fast and stable enough for near-real-time computation as shown in figure 3.

![Figure 3](image.png)

**Figure 3.** In theory each PSGen cycle for a given dataset should be the same. The actual numbers confirm the stability and constant performance of the system, showing an insignificant variation. The initial cycles reflect cached I/O.

5. **The IE not for Instrument control**

The Instrument Element (IE) is an advanced Grid middleware extension that enables the inclusion of instrumentation to the Grid [11]. In general it is a set of technologies that permit the easy inclusion of instruments like sensors, motors and cameras to a gLite infrastructure. The main objective is the remote operation [12] and control of the instrument through a secure channel by respecting the Grid security protocols.

The IE is extensible and the scope of it may be stretched beyond its original objectives. Specifically the IE can be seen as an Integration Element by exploiting the abstraction of the concept instrument [14][15]. When the concept is generalized it may include software application too; and in our case we assume as an instrument the underlying TANGO device server that manages PSGen. Thus the full control of the PSGen application and its accompanying TANGO devices can be interfaced and provided as an IE via an Instrument Manager. At this point the IE controls a Computing entity, the PSGen application, without accessing a traditional CE. This irregular use of the IE demonstrates a case where it may even compute or more precisely: steer a computation. The IE is not involved in the data flow as this is mainly handled by TANGO and low level interfaces to the instrument, while the IE is utilized mostly as an interaction interface to the application. Alternative Web Service based technologies could be used as well, but other than the overhead of the new development, the main disadvantage would be the disconnection of the application from the rest of Grid infrastructure that it profits from (like the Storage Element (SE)).
6. Interaction through a Web portal
The Scientific Computing team of the IT Group of the Synchrotron Elettra, for the past years has been involved in R&D for technologies that aim to realise single sign-on and Web based access to various resources. One of the latest products is the VCR. The VCR was initially designed to serve as a portal for easy access to Grid resources.

![Figure 4](image-url)

Figure 4. The end-user, the beamline scientist, interacts with the application through a web browser in a simple manner.

PSGen end user interaction is through the VCR as shown in figure 4. PSGen can be accessed by the users that have access to the portal, taking into account most of the Grid-related security control, like Certificates, VOs, and the VCR-side tags (a type of flags that allow the association of a specific user or user-group with a set of applications). The PSGen user can start the application at the beginning of the experiment and receive feedback at any stage; even after logoff and re-login. The input and output datasets are stored in Storage Elements (SE) that can be browsed from the web portal. Additional work is in progress in order to allow richer GUI elements that will permit richer interaction with the remote application.

7. Conclusions
The Grid can be useful in many scenarios but there are cases that its limitations are obvious. Among those limitations are the various latencies. They usually occur during the job submission phase. These latencies are not an issue for a large family of applications but there are other cases where such delays can cause problems. The presented work was for an application with near-real-time requirements for online processing in a Tomography lab of a Synchrotron. The presented architecture and the related R&D demonstrated a hybrid approach where storage (I/O on the SE), interaction (VCR portal) and security are done on the Grid while the computation is done in a non-CE based infrastructure controlled by an IE. Such a hybrid approach is novel in the field and in the future may be extended towards other directions.

Acknowledgements
The authors would like to thank Diego Dreossi, SR X-ray CT and Medical Imaging scientist for the SYRMEP@Elettra beamline, for his valuable feedback and cooperation during all the phases of the project. Members of Elettra’s Scientific Computing team that their work has been used to realise this project include Milan Prica, Daniele Favreto and Fabio Bonaccorso. We also wish to thank the two anonymous referees for reviewing this paper and providing us with detailed feedback and constructive comments. This works has been partially supported by the DORII EU project (FP7/2007-2013).
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