Grid-based Virtual Collaborative Facility: Concurrent and Collaborative Engineering for Space Projects

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Abstract. In the past decade, Concurrent Engineering approach has been demonstrated very favourable for the assessment and conceptual design of future space missions. At the same time, a remarkable increase in distributed and collaborative computing power has been achieved by designing and prototyping technologies thanks to the Grid technology. For this reason, the European Space Agency awarded a project called Grid-based Distributed Concurrent Design to study how to allow geographically distributed facilities to interact each other in real-time over wide area networks adopting the Grid technology for the purpose of space projects, to make the structure deployment reliable, cheap and compatible with Concurrent Facilities. This project resulted in a Virtual Collaborative Facility architecture to be taken as a reference step for a distributed concurrent and collaborative platform for the Space sector. Together with this, a tailored prototype was implemented and deployed to proof the concepts and the architecture according to two common scenarios in Space Projects.

Keywords. Concurrent Engineering, distributed collaborative environment, Grid.

1 Context for Concurrent and Collaborative Engineering

Nowadays space activities are characterised by increased constraints in terms of cost and schedule combined often with a higher and higher technical and programmatic complexity.

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To answer this challenge, Space Agencies and main industrial Space Integrators have deployed Concurrent Engineering Facilities at their premises (see also [8]) to make available environments where tools from various disciplines can be exploited enabling concurrent analysis, providing quick results, increasing data sharing and coherence among engineering options. Thanks to the automated information exchange and the use of interconnected tools, the change from a sequential vision to a concurrent one for space project design allows tackling and solving problems, enabling a quick exploration of several solutions not only faster but also deeper, leading often to the possibility of taking real-time decisions.

The European Space Agency, at its ESTEC premises, has set up the Concurrent Design Facility (CDF) [1, 3] starting in 1998. This has widely demonstrated the advantages of applying the Concurrent Engineering (CE) approach to the assessment and conceptual design of future space missions and has raised an enormous interest among the European partners (academia, scientific communities, industry, other agencies) in the space sector.

At the same time, starting from mid 90's, a remarkable increase in computing power has been achieved by designing and prototyping technologies, most notably the Grid [4], to support distributing tasks and data on distributed computing centres linked with high-speed networks. With such potentials the capability to organize virtual collaboration and online interaction will become more and more concrete; data and tasks will be shared across geographically wide areas, and whole teams will interact with one another on a regular basis.

Grid technology can therefore provide the means for secure connectivity of design environments as well as integrate multiple heterogeneous systems into a powerful virtual "single" system.

2 A Grid-based Virtual Collaborative Facility

Within this framework, the European Space Agency, at beginning of 2006, awarded a project called Grid-based Distributed Concurrent Design (GDCD)[2] [3] to study how to allow geographically distributed facilities to interact each other in real-time over wide area networks adopting the Grid technology for the purpose of space projects, to make the structure deployment reliable, cheap and compatible with Concurrent Facilities. One of the purposes of this project is in fact to deploy a prototype to interconnect the above mentioned CDF to other sites run by ESA, national agencies or by industrial partners using a Grid based architecture [6].

The project successfully held its Final Presentation in September 2007, and the paper will summarise the main outcomes.

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The overall objective of a Grid-based distributed concurrent design approach is to combine the application of the CE approach, methods and tools with the emerging Grid technologies.

This combination is expected to extend the benefits of the CE approach to a wider context with the aim of improving the overall design and development process of space projects, reducing the schedule and cost. The wider context refers to both a geographically distributed architecture as well as to the application to later phases of the project life-cycle.

3 Functional Requirements for a Virtual Collaborative Facility

Analysing the needs for concurrent and distributed processes in the space sector, the following main issues arose:

- Share a common description of a space system in order to ease information flow, changes propagation, overall consistency in the form of a machine processable System Data Model;
- Common references and data pools;
- Resource sharing.

Starting from there, four conceptually different scenarios have been identified to represent the high level objectives and requirements identified (Table 1).

Table 1. Scenarios for concurrent and distributed processes in the space sector

Scenario	Objective	Requirements
1	Data share	Actors shall be able to share a common system description and to seamlessly propagate changes through it between them
2	Composed simulation	Actors shall be able to perform a complex problem solving by linking and sequentially executing simulations and analyses based on tools owned and residing at each actor premises and shared in the Virtual Organisation
2.a	Composed process	When the tools used in the chained simulation are COTS tools linked through commercial available or specifically developed interfaces
2.b	Composed analysis	When the chain is built in support to a specific problem resolution, connecting also specifically developed tools through the data/command interfaces available in the pool of tools accessible by the Virtual Organisation.
3	Parallel simulation	Actors shall be able to perform a complex problem solving (typically a stochastic analysis) by executing multiple instances of the same simulations and analyses and taking advantage of tools, licences and computing resources shared in the Virtual Organisation
4	Parallel computing	Actors shall be able to perform a complex problem solving (typically running a parallelised code) taking advantage of computing resources shared in the Virtual Organisation

The analysis of above scenarios, which are considered as representative of the Space Engineering process, helped to derive functional requirements for a Virtual Collaborative Facility.

The requirements can be resumed in the following few classes:

- Capability to provide distributed services;
- Capability to support shared data and resources;
- Capability to guarantee a secure access to data and resources;
- Capability to support complex problems solving by mean of proper use of distributed services and resources;
- Capability to provide human-to-human collaboration tools

In order to cope with above classes of requirements, a technological survey of the state-of-art has been carried on, with the goal to have some best candidates where to start from for the prototyping activities.

4 Virtual Collaborative Facility Architecture

On the basis of the outcomes of functional requirements, the design of the Virtual Collaborative Facility took place [2].

The VCF architecture is based on SOA approach and can be represented with the following Figure 1:

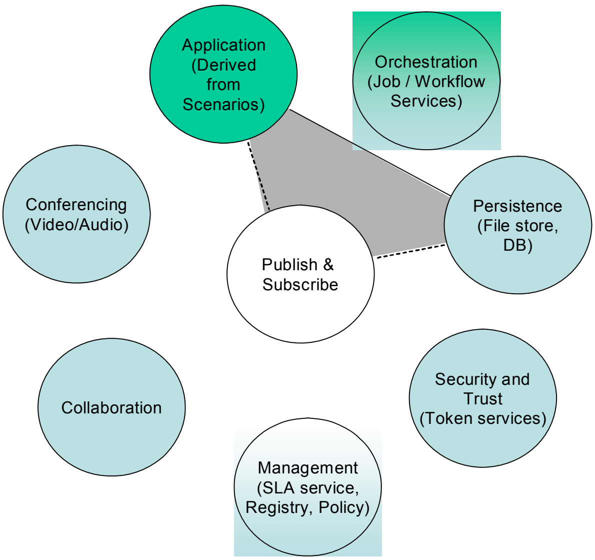

Figure 1. VCF Service Oriented Architecture

The white circle representing the *Publish & Subscribe* service derives directly from the SOA model to allow the *publish*, *find* and *bind* mechanism. All services to be accessed and all users must refer to this mechanism; in Figure 1, the triangle shows a typical interaction based on this mechanism in the case that an application needs to use a *Persistence* service. The white area on the top of the *Management* service indicates that the publishing topic needs the use of registries that pertain to the management domain.

The green circles represent application domain. A green area is on top of the *Orchestration* services meaning that a part of the tasks to be done in order to execute jobs is due to the application/user intervention, so it is much more bounded to the application context.

There are dedicated services for *Collaboration* and *Conferencing*, as they play a very important role in the Space Systems design process.

From a technological point of view, Figure 2 shows a VCF architecture based on a snapshot of most suitable technologies available at the time of the study (2006-2007):

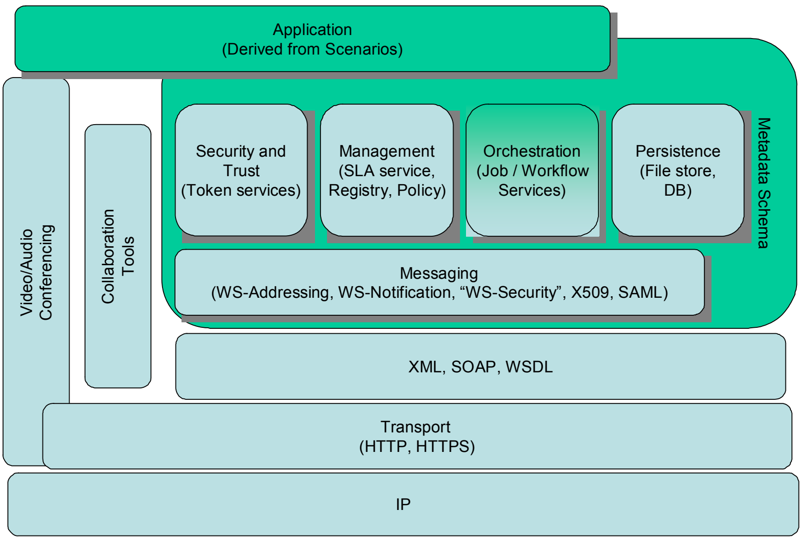

Figure 2. VCF Technological Architecture Layers

This architecture view puts in evidence two main things:

- The existence of a common background among services and applications: this is the *Metadata* background layer, which provides the context that allows the whole picture works. Based on information standards, metadata

enables seamless information exchange. Given well-integrated metadata, information can freely flow from one place to another across boundaries imposed by operating systems, programming languages, locations, and data formats. As seen both applications and services use metadata in order to do all the needed operations, discovering and finding services, classifying information and defining services relations. In particular with respect to *Orchestration*, metadata is usually considered essential for any dynamic workflow where real-time decisions are being made on which services to tie together to solve a particular problem.
- The layers that build the base of VCF architecture are all well adopted open standards and their benefits. Primarily, there is less chance of being locked in by a specific technology and/or vendor. Since the specifications are known and open, it is always possible to get another party to implement the same solution adhering to the standards being followed. Another major benefit is that it will be easier for systems from different parties or using different technologies to interoperate and communicate with one another. As a result, there will be improved data interchange and exchange.

These are the main reasons why Grid has been chosen as a viable technology for the VCF [9]:

- Grid also enables distributed, collaborative access to remote resources, where resources are not just CPU cycles and storage;
- Most (if not all) Grid implementations are Service Oriented, so fitting with VCF architeture principles, providing accessibility to resources through remote services;
- Grid offers mechanisms to enforce security providing an embedded security infrastructure, as users (and services) must be authenticated and authorised to have access to VCF resources and services;
- All Grid implementations offer workflow facilities so that users can create workflows composed of services and Grid has features/services to orchestrate and enact such workflows;
- Grid implements standards to enable interoperability e.g. allowing to easily connect custom(ised) clients to external services.

The role of Grid in the above set of technologies is embracing the whole set of services, including the management of *Metadata Schema* and *Messaging* layer. This could be seen as a “light Grid”, not strictly related to a computing- and data-oriented applications where a “heavy Grid” infrastructure is mandatory. Nonetheless, although the focus of GDCD and of the VCF is more towards a “light Grid”, the two are not mutually exclusive.

5 Virtual Collaborative Facility Prototype

The VCF prototype has been implemented as a suitable tailoring of VCF architecture. It is based on a selected Grid middleware, GRIA [5, 7], chosen after a comparative analysis of most used and advanced middleware stacks.

GRIA, compared to other Grid implementations, has the following features that are in line with VCF needs:

- It is a "light" B2B Grid middleware, and the scenarioes on the basis of the VCF concept are not (as for e-Science) based on long term (quasi)static collaborations but need a dynamic and effective management of collaboration actors who can (or better have to) enter and exit as needed during the life time of the collaboration itself;
- It follows a dynamic security management paradigm with a dynamic access control, which allows a secure management of fast, dynamic collaboration taking also into acount the possibility that actors access rights could change over time;
- It allows interoperability using standards that enable effective integration with other middleware like .NET/WSE 3.0 [9];
- It is open source, thus allowing to be customised and extended with domain/application-related "plug-ins".

The VCF prototype has then been deployed on a geographically distributed infrastructure based on several European centres acting either as service providers or clients according to the two storyboards specified to represent most common scenarios in Space Projects.

Such storyboards were:

- Sharing System Data Model: actors, at distributed facilities premises, shall be able to share a common Space System description, or part of it, and to seamlessly propagate changes through it between them adopting the ESA CDF Integrated Design Model (IDM) as System Data Model (Figure 3).

Figure 3. GDCD Storyboard #1: Sharing System Data Model

- Parallel Simulation Analyses: actors, at distributed facilities premises, shall be able to execute complex analyses by enabling the execution of multiple independent instances of the same model on remotely located machines, taking advantage of licenses owned by the different actors joining the VCF. All execution instances will share a common System Data Model, data flow shall be enabled and the code execution shall be performed (Figure 4).

Figure 4. GDCD Storyboard #2: Parallel Simulation Analyses

6 Conclusions

The following statements resume the main outcomes of GDCD project:

- Grid is a suitable technology as e-collaboration enabler for collaborative and concurrent engineering for Space Systems, where the needs are not just driven by computing- and/or data-intensive applications but mainly related to knowledge and information sharing;
- The VCF Prototype, although just a proof-of-concept providing reduced functionality w.r.t. a full fledged operational VCF, shows the possibility to perform Grid-based Collaborative and Concurrent Engineering sessions, which represents a big step forward for the current ESA CDF: it would allow involvement in all Space Systems design phases of the customer, prime, partners and manufacturers;
- The VCF Prototype shows with tangible results that VCF's use of workflow exploiting remote services (tools, simulators, etc.) can support complex computations;

- As verified during the demonstration preparation and execution phases using the VCF Prototype, the VCF will have to face more challenges to be used effectively by collaborating partners:
    - Management of different institutional security policies applicable on industrial projects (firewalls, proxies, NAT, etc.);
    - Easy-to-use or well-known client software necessary to share data between experts and avoid additional training;
    - Capability to perform integrated (video) conferencing and to allow actors to enter and leave the collaborative session at anytime, would increase session efficiency.

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