Supporting Engineering Processes Utilizing Service-Oriented Grid Technology

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1 Introduction

Speeding up knowledge-intensive core processes in engineering and increasing the quality of their results is becoming more and more decisive, since the economic pressure from national and international competitors and customers is rising. In particular, these demands exceed the organizational and infrastructural capacities of small and medium-sized enterprises (SME) by far. Hence, combining complementary core competencies across organizational boundaries is crucial for an enterprise's continuing success. Efficient and economically reasonable support of knowledge-intensive core processes in virtual organisations is therefore a predominant requirement for future IT infrastructures. The paradigm shift to service-orientation in Grid middleware opens the possibility to provide such support along the product lifecycle by employing a flexible software development approach, namely to compose applications from standard components, promising easier development and modification of Grid applications.

In this paper, a service-oriented Grid computing approach is presented which aims at supporting distributed business processes in industry (see sections 2 and 3 for industrial scenarios and the resulting requirements). The current status of implementation of the proposed approach is demonstrated by presenting an exemplary process chain from the casting industry and its support by various tools provided via a grid portal.

The paper is organized as follows. Section 2 presents several industrial engineering scenarios to explain the context of our work. Section 3 explains the requirements of a typical engineering process from the area of metal casting. The proposed approach to support this process is presented in section 4. Section 5 discusses the realization of the Grid portal. Section 6 concludes the paper and outlines areas for future research.

2 Scenarios from Industrial Engineering

In various engineering disciplines, the analysis of complex systems based on numerical simulation is a common tool in science as well as industry. The underlying processes necessary to prepare simulation, assure a simulation's quality, and to evaluate simulation's results are quite similar. Hence, process support across various disciplines can be based on a common set of functionality executed on a common platform. As a prerequisite to the design and implementation of such a platform, analyses of different disciplines have to be made. The following sections give an overview of selected engineering disciplines involved in the D-Grid community Grid project InGrid (http://www.d-grid.org, http://www.ingrid-info.de).

2.1 Casting Industry

Companies working in the casting sector are typically medium-sized businesses supplying large-scale industrial clients (automobile manufacturers, power station builders). To reduce cost, numerical simulations are performed to substite the expensive and time-consuming building of physical tools and prototypes. Ideally, the simulation of mould-filling and solidification during casting requires the coupled calculation of flow, temperature distribution and mechanical deformation. For a quantitative defect prediction, a simulation of the evolving microstructure is often necessary. Utilizing such simulations requires high computational power and skilled personnel. Grid technology enables medium-sized enterprises from the casting industry to integrate such compute-intensive simulations into their processes via the shared use of virtual IT infrastructures [1].

2.2 Sheet Metal Forming

A prototyping process in industrial practice is a lengthy course of action where physical prototypes are built, evaluated and changed until product and process models are found which suit the predefined needs [2]. Substituting physical prototypes by models ("digital mock up") to allow the analysis by numerical simulation is a way to speed up the early phases of the product lifecycle by virtual prototyping. Typical problems from industrial practice are driven by the need to reduce time and cost in design as well as in manufacturing. Hence, the focus in virtual prototyping in sheet metal forming is put on the minimization of material and manufacturing costs (e.g. size and weight of the product, number of stages in the manufacturing process, maintenance cost due to tool wear).

2.3 Groundwater Management

In the field of groundwater modelling, increasingly large areas are being simulated and are often represented by complex 3D Finite Element models. Numerical simulation of these models requires their calibration, i.e. minimizing the deviation between simulation results and actually measured values (e.g. the flow head in an observation point). A successfully calibrated model allows minimization of operational costs and/or to determine optimal locations of pumping stations while still satisfying constraints like a minimum allowed groundwater level (s.a. [3]) or a maximum allowed contamination of drinking water.

3 Requirements

As an example of typical processes during product and process design in engineering, a process chain from metal casting involving a variety of participants and functionality was analyzed and modelled as an event-driven process chain (EPC, s. e.g. [4]). In Fig. 1, this model is presented to provide a comprehensive view on a process' participants and on the data and control flow between participants and involved software systems. The process can be divided into five phases: In the **first phase**, the real-life metal forming process has to be mapped to a process model, incorporating the specific details of the process (e.g. geometry, materials etc). For this task, not only the domain expert with the appropriate know-how on the real-life process has to be involved. Moreover, a computational engineer having knowledge of the simulation software package and the preprocessing tools is needed. When the initial model creation is completed, the **second phase** is entered. The model needs to be calibrated, i.e. model parameters will be adjusted and simulation runs are made to verify that the model reflects the reality. Again, the domain expert and computational engineer are required in close cooperation to calibrate the previously generated model. Since the calibration process is particularly difficult, the model is continuously checked if it suits the needs. Hence, the output of single simulation runs is permanently reviewed by all participants. The calibration process iterates as long as the model is not yet adequately calibrated. During the **third phase**, preliminary jobs (e.g. transferring the calibrated models to the compute nodes, setting algorithm parameters etc.) for preparing the optimization run are performed. The optimization sub-process in the **fourth phase** is entered next. The optimization algorithm now generates a number of model parameter sets which need to be simulated and evaluated. As long as the stop condition of the optimization algorithm is not yet reached, this subprocess iterates until the model is sufficiently optimized. The **fifth phase** describes the post-processing which incorporates the collaborative viewing between the domain expert and computational engineers. If the resulting model is not sufficient, the optimization cycle is re-entered.

From a detailed analysis of the different domains presented in the previous section as well as in the elaborated scenario from metal casting, the following requirements can be derived: **Support of collaborative processes** in engineering, within the customer-supplier network becomes more and more important since competencies and resources on either side (customer as well as supplier) are not sufficient to solve the given problems in product and manufacturing process design within the given time, cost and quality restrictions. **Access to functional and computational resources** in the course of an engineering process is needed to fulfil all the requirements. For example, systems from computational engineering (computer-aided design and engineering, CAD/CAE, finite element-based analysis codes, FEA) are needed in product design as well as systems for managing product data along the whole product lifecycle (PDM/PLM). Hence, access to those different types of functionality in one environment must be provided in all relevant processes.

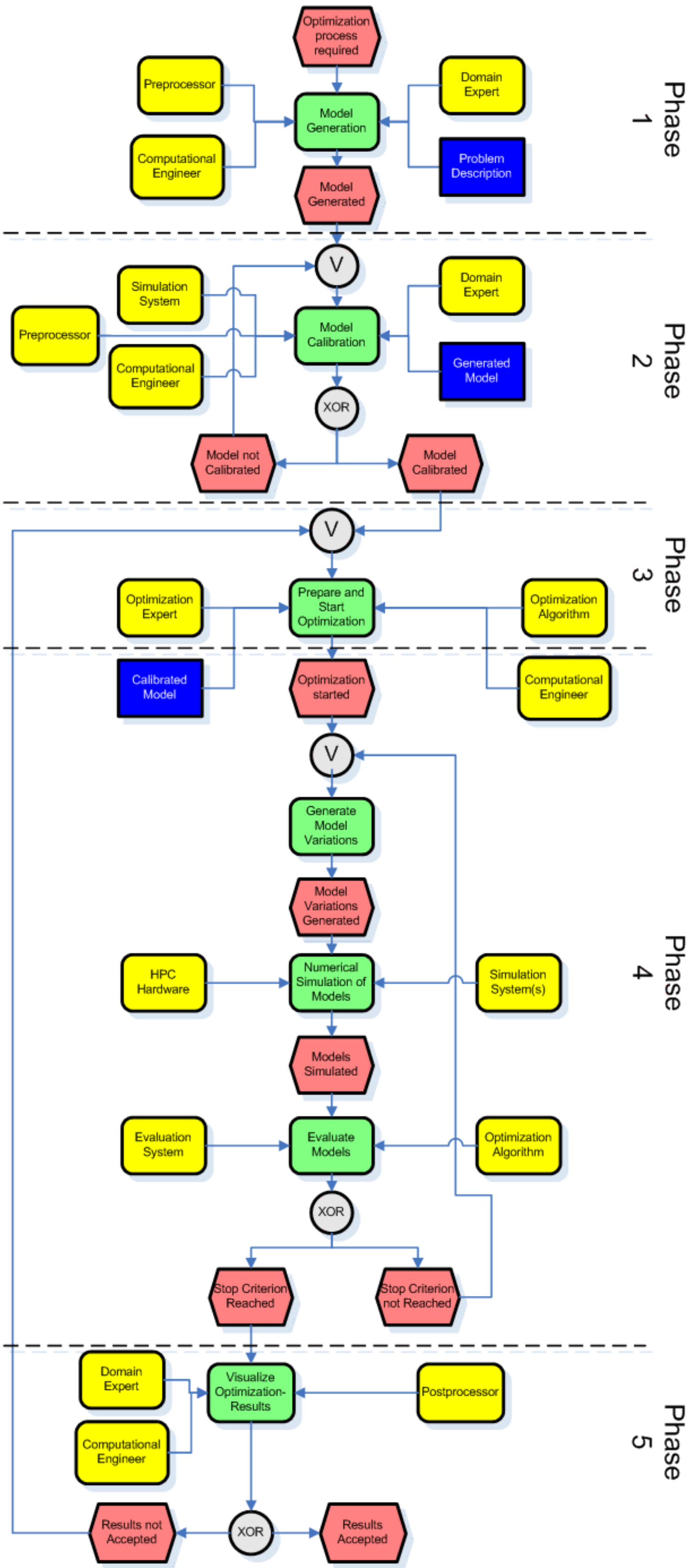

Figure 1: An exemplary process model (as an EPC) in metal casting.

Seamless integration into the IT-infrastructure of the participating institutions or enterprises in engineering processes is necessary to allow access to all the resources required by the aforementioned sophisticated functionality. For example, small to medium sized enterprises (SME) in the automotive supplier industry have neither the IT infrastructure nor the skilled personnel to operate resources (hardware, software) for complex numerical analyses of their products and their manufacturing processes. Integrating these capabilities into an enterprise’s own existing IT infrastructure must not make high demands on the infrastructure and the personnel. **Secure communication and job execution** is crucial since data and information exchanged in the course of the engineering processes represent the intellectual capital of the participating enterprises. Even information about resource usage (e.g. to allow accounting and billing in a commercial scenario) must be stored securely. **Management of various commercial licensing models** is also inevitable since a wide variety of software systems must be utilized along a typical process in engineering,. These systems may range from small tools written by the participating engineers up to large scale CAD/CAE systems or enterprise resource planning systems (ERP). Besides the typical problems from enterprise application integration, the problem of handling the licenses of commercial codes in a distributed and cross-organizational scenario must be considered.

4 Solution Approach

4.1 Overview

The proposed approach is based on utilizing service-oriented Grid technology [5,6,7] to support complex engineering processes from top level modelling, workflow design and execution to actual Grid service code. In Fig. 2, the different levels of abstraction between processes and actual code are depicted with respect to the corresponding models and implementation platforms (were applicable). A mapping exists between each consecutive level, enabling a consistent and systematic procedure down to the code of components supporting specific activities in the processes. These activities comprise a diversity of functions: e.g. sophisticated search processes in product data, numerical simulation of complex manufacturing processes, distributed simulation-based optimization etc. Once such a specific functionality is available as a Grid service, any process – modelled a priori or emerging ad hoc – can be supported by these flexibly combined components.

4.2 System Architecture

According to the requirements derived in sect. 3 and the aforementioned approach to bridge the gap between processes and code, in Fig. 3 an overview of the architecture of the Grid-based solution approach is given. Engineers participating in a process like the one described previously can log into the portal server using a standard web browser either via HTTP or the secure HTTPS protocol. The portal server consists of a standard Apache Tomcat server which hosts the GridSphere portal environment.

<table>
<tr><th>Level of abstraction</th><th>Model</th><th>Implementation, Platform, Tool</th></tr>
<tr><td>Knowledge-intensive Business Process</td><td>Business Process model (EPC, BPMN)
Knowledge model (enriched BPMN model)</td><td>BP modelling tools</td></tr>
<tr><td>Workflow</td><td rowspan="2">Workflow model
(BPEL, BPEL4People, BPEL-SPE)
Data model (UML)</td><td>BPEL editor</td></tr>
<tr><td>Orchestrated Grid Services</td><td>Grid-enabled Workflow Engine</td></tr>
<tr><td>Grid Service</td><td>Generated Java code</td><td rowspan="2">GT4, Grid Portal, JSR 168-compliant Portlets, Grid-Sphere</td></tr>
<tr><td>Functionality</td><td>Wrapped legacy applications (Java, C, C++, Fortran code)</td></tr>
<tr><td>Resources</td><td>Distributed HPC</td><td>Portal servers, application servers, database servers</td></tr>
</table>

Figure 2: Levels of abstraction, models, implementation platforms and tools relevant for engineering process support

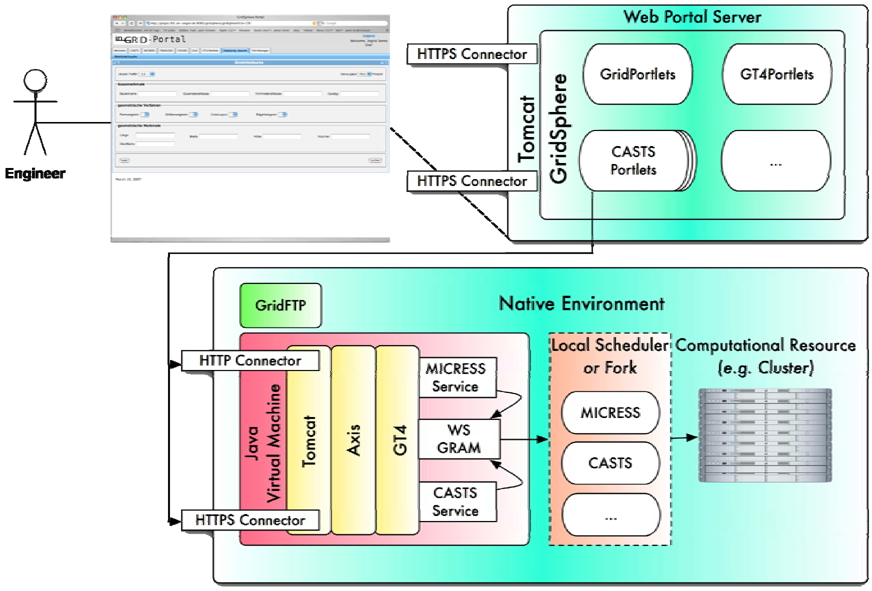

Figure 3: Overview of the components of a Grid-based architecture to support engineering processes by a portal.

GridSphere's basic functionality is used for certificate handling, so the user can authenticate to the Grid nodes by using X.509 proxy certificates. Within GridSphere, custom, JSR168-compliant portlets have been created to automatically initiate single simulation runs as well as complex optimization workflows. Simulation or optimization models may be uploaded to the portal and are transferred to the appropriate compute nodes via GridFTP. Numerical simulations are then started by a web service call (i.e. a SOAP message, in this case transferred either by HTTP or HTTPS). The SOAP message is then processed by the Apache Axis framework and passed to the appropriate GT4 service. The GT4 certificate delegation facilities are used to authenticate the user against the web service, and a local WS-GRAM (Web Service Grid Resource Allocation and Management) call for starting the simulation in the native environment is initiated. The local WS-GRAM call is done for the following reasons:

- The native software is run with the user permissions of the certificate owner (determined by looking up the certificate in a map-file). Thus, it is ensured that basic security concepts provided by the operating system (e.g. file permissions, user space processes etc.) are used.
- WS-GRAM already offers a variety of interfaces to local scheduling systems (e.g. PBS/Torque, SGE etc.). Therefore, the service code does not have to be changed if the service is deployed on different cluster systems with different schedulers or even on single node workstations (in this case, the WS-GRAM fork interface is used).
- State information about the running process is exposed by WS-GRAM. This information can easily be evaluated by the calling service code to react on it (e.g. job failures, finished jobs or running jobs).

Results are archived by the service code and collected by the web portal automatically via GridFTP. An engineer is now able to either view some of the results online or download the entire result set.

5 Grid-Based Process Support in Metal Casting

The process as described in section 3 was partially supported by a prototypical implementation of a service-oriented, Grid-based environment as proposed in section 4. Core element of the support – from a user's perspective – is a Grid portal providing the interface to the various services and tools necessary to perform the individual steps of the process. In particular, parts of a process requiring user interaction (e.g. constructing the geometry of a casting mould using a CAD system) cannot be automated. Instead, providing a user with a set of adequate tools (e.g. via the portal) is a way to support also these parts of processes efficiently.

In general, a portal may be one way of accessing resources and functionality provided by a Grid infrastructure among others. Depending on the requirements on the client side (e.g. sophisticated graphical user interface, human interaction) it may be inevitable to provide a rich client extending a portal's capabilities. In this example, a Grid-enabled BPEL editor (see [9]) used to modify workflows related e.g. to simulation and optimization of the casting process is an example of a rich client which is started from within the portal.

In Fig. 4, a snapshot of the current version of the portal developed within the InGrid community Grid project is shown. Major parts of the process described in Fig. 1 can be supported by the individual portlets: "CASTS" provides access to the simulation code CASTS used to simulate metal casting processes and the interface to a simulation-based optimization algorithm with its specific parameters, "Grid" is the interface to distributed resources, certificates etc., "File Manager" allows easy transfer of files from and to nodes of the Grid (e.g. to support communication about simulation results by diagrams, plots, reports etc.), and "Similarity Search" to support finding similar parts in a product database (see [8] for further details on this functionality). Additionally, access to several other simulation tools from InGrid partners will be integrated within the "MICRESS", "FENFLOSS" and "COVISE" portlets.

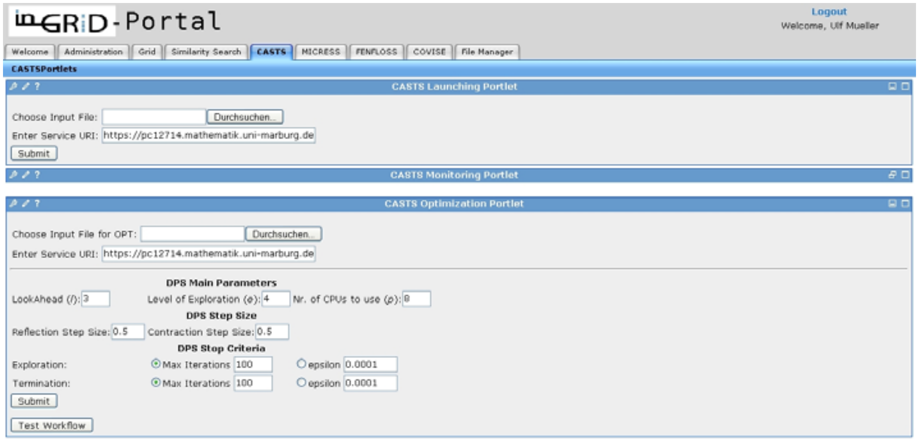

Figure 4: Snapshot of the InGrid portal to support engineering processes e.g. in metal casting by similarity search, simulation and simulation-based optimization.

Providing certain functionality within such a portal as a Grid service is a complex and error prone task which can be alleviated by tools supporting model-driven code generation. Parts of the services used in this prototype were generated semi-automatically [9, 10, 11].

6 Related Work

Numerous environments either exist or are currently under development aiming at the support of complex engineering tasks in design. Combining process support and use of semantics in chemical engineering is the aim of the Process Data Warehouse approach (PDW, s. [12]). While this project is not yet focused on distributed use of resources or of the developed environment to support engineering processes, other projects like GEODISE [13] or P-GRADE [14] were designed and implemented aiming at the integration of workflow management and computational resources for simulation and optimization in engineering during design tasks. A Grid-enabled problem solving environment for engineering design where distributed parties are able to collaborate has been introduced by Goodyer et al. [15]. The system makes use of the gViz Library [16] which allows collaborative visualization on the Grid and provides the user to start Grid jobs on Globus Toolkit based hosts. The main focus is put on collaborative application steering and result visualization of given simulation problems.

While the aforementioned projects focus on selected aspects from supporting complex and knowledge-intensive workflows in engineering, InGrid tries to provide a comprehensive framework based on concepts from grid computing, workflow management, knowledge-based systems, resource management integrated with issues like license management and security inevitable for the deployment of such systems in commercial scenarios in industry.

7 Conclusions

A design for a Grid-based environment to support complex processes in engineering was presented in this paper. Various engineering disciplines were briefly described and one specific process from metal casting was modelled as an example for typical processes in engineering dealing with simulation and optimization. From the analysis of the different domains and processes, several requirements for the design and implementation of process support systems were derived. According to these requirements, a set of services for simulation and optimization of casting processes were implemented and provided to the user via a portal.

Mapping interactive parts of the process (e.g. modifying a design using a CAD system) to actual services is not always straightforward. Hence, one topic for future work is a systematic approach (from modelling to design and implementation of specific tools and/or services) to support this type of process steps efficiently in a service-oriented environment. Another area of future research is the seamless integration of security mechanisms offered by Globus Security Infrastructure (like WS-SecureConversation) and Virtual Organization Management features into the workflow enactment engine and our workflow designing tool. Finally, further research in the improvement and interoperation of collaboration features is needed.

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References

1. J. Jakumeit, T. Barth, J. Reichwald, M. Grauer, F. Thilo, T. Friese, M. Smith, B. Freisleben. "A Grid-Based Parallel Optimization Algorithm Applied to a Problem in Metal Casting Industry". In: Filipic, B., Silc, J. (eds.) "Bioinspired Methods and their Applications", Jozef Stefan Institute Press. pp. 131-146. 2006.
2. M. Grauer, T. Barth, M. Gerdes. „A Concept and First Experiences in Simulation-Based Optimization of a Single-Stage Sheet Metal Forming Processes". In: Intelligence in a Small Materials World - Proceedings of the Fourth International Conference on Intelligent Processing and Manufacturing of Materials (IPMM), DEStech Publications Inc., S. 277-285, 2005.
3. F. Thilo, U. Junghans, M. Grauer, S. Kaden, J. Hillebrandt. „Reducing Groundwater Management Costs by Parallel Simulation-based optimization". In: Proceedings Computing and Control in the Water Industry (CCWI 2005), Exeter, pp. 135-140.
4. Scheer, A.W.: ARIS -business process frameworks. Springer, Berlin, 1999.
5. S. Weerawarana, F. Curbera, F. Leymann, T. Storey, D. Ferguson. Web Services Platform Architecture. Prentice Hall. 2005.
6. T. Erl. Service-Oriented Architecture. Prentice-Hall. 2006.
7. B. Sotomayor, L. Childers. Globus Toolkit 4. Morgan Kaufman. 2005.
8. C. Lütke Entrup, T. Barth, W. Schäfer. „Towards a Process Model for Identifying Knowledge-Related Structures in Product Data". In: U. Reimer, D. Karagiannis (eds.). Practical Aspects of Knowledge Management. LNCAI Vol. 4333. Springer. pp. 189-200. 2006.
9. T. Friese, M. Smith, B. Freisleben, J. Reichwald, T. Barth, M. Grauer. "Collaborative Grid Process Creation Support in an Engineering Domain".

In: Y. Roberts et al. (eds.): HiPC '06. LNCS 4297. Springer. pp. 263–276. 2006.

10. T. Friese, M. Smith, B. Freisleben. "GDT: A Toolkit for Grid Service Development". In: Proc. of the 3rd International Conference on Grid Service Engineering and Management, pp. 131-148, 2006.
11. M. Smith, T. Friese, B. Freisleben. „Model Driven Development of Service-Oriented Grid Applications". In: Proc. of the International Conference on Internet and Web Applications & Services, Guadeloupe, pp. 139-146, IEEE Press, 2006.
12. S.C. Brandt, M. Schlüter, M. Jarke. „A Process Data Warehouse for Tracing and Reuse of Engineering Design Processes". Int. J. of Intelligent Information Tech., 2(4): 18-36, 2006.
13. G. Xue, W. Song, S. Cox, A. Keane. "Numerical Optimization as Grid Services for Engineering Design". Journal of Grid Computing, 2(3):223–238, 2004.
14. G. Sipos, P. Kacsuk. "Collaborative Workflow editing in the P-GRADE". Proceedings of the Micro-CAD, 2005.
15. C. Goodyer, M. Berzins, P. Jimack, L. Scales. "A Grid-enabled Problem Solving Environment for Parallel Computational Engineering Design". Advances in Engineering Software, 37:439–449, 2006.
16. K. Brodlie, D. Duce, J. Gallop, M. Sagar, J. Walton, J. Wood. "Visualization in Grid Computing Environments". Proceedings of IEEE Visualization, pp. 155–162, 2004.