2
Related Work

In this chapter we present a few major works that motivated us to conduct this research towards the conception of the CEE Conceptual model, presented formally in Chapter 3. In what follows we justify the choice of the selected technologies used in CEE answering the following questions:

Why use Workflow Management Systems (WfMS) and Grid Computing (GC) infrastructure.

Why use Virtual Reality Visualization technology.

Why use a Service Oriented Architecture (SOA) for the implementation of CEE.

2.1.
Workflow Management Systems and Grid Computing

Since the last decade, several industries have been improving their operations through the adoption of Workflow Management Systems (WfMS). Those systems allowed them to improve the management of activities and the flow of information in the organization through the restructuring of their business processes known as Business Process Management (BPM) [BPMI]. Initially the WfMS were associated to the automation of business processes, during which, documents, information and/or tasks are passed from one participant (human being or machine) to another for the accomplishment of an action, in agreement with a set of defined rules. Such systems have enabled productivity enhancements in tasks such as processing of customers purchase orders, invoice processing, authority-for-expenditure management, etc.

For the oil & gas industry, especially in production operations, there are innumerous advantages for adopting Workflow Management Systems. The automation of engineering processes not only requires fewer workers to manage the same assets but also allows knowledge to be transferred between workforce generations in the form of well documented, previously tested and standardized workflows. Thus new employees will be able to accomplish the same work with less experience and knowledge. Moreover the increasing complexity of production operations requires the management of larger data sets, more precise decision making, and creates opportunities for optimization through more sophisticated control mechanisms. Therefore, Engineering Workflows constitute an adequate tool to embrace all these challenges.

Recently, several industries have begun focusing on Scientific and Engineering Workflows (ScWfMS) that differ in many ways from Business Workflows. Scientific Workflows gained wide acceptance in the field of bioinformatics in the early 2000s [VEG07]. While Business Workflows tend to deal with discrete transactions, Scientific and Engineering Workflows tend to deal with large data quantities, multiple data sources in multiple formats, and multiple interconnected tools. New software tools and architecture can be created to standardize Engineering Workflows by bringing together data from heterogeneous systems and consolidating separate engineering capabilities within a single platform.

2.1.1. Data Driven Multiphysics Simulation Framework (DDMSF)

In Reservoir Engineering, the need to perform extensive reservoir studies for either uncertainty assessment or optimal exploitation plans brings up demands of computing power and data management in a more extended way. Klie et al. [KBG+06] proposed and integrated framework called DDMSF, Data Driven Multiphysics Simulation Framework (Figure 2.1). DDMSF is composed of a suite of high performance numerical tools and a grid-enabled middleware system for scalable and data-driven computations for multiphysics simulation. DDMSF also includes a decision-making software system used for running integrated multiphase flow applications during subsurface characterization and oil reservoir management.

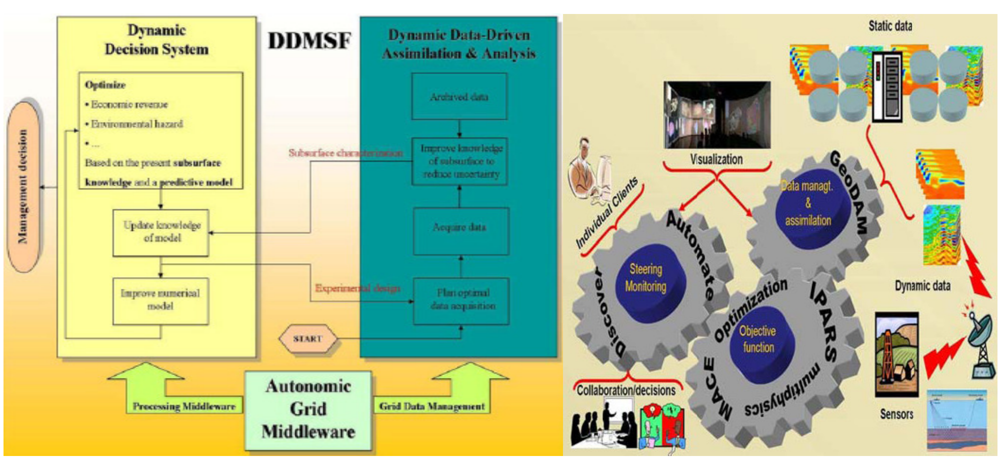


Figure 2.1: DDMSF and its components. Architecture (left) and interaction scenario (right).

The proposed suite of tools and systems consists of

- *IPARS* – a scalable and integrated multi-physics/multi-block reservoir simulator (encompassing flow, geomechanics, petrophysics and seismic);
- *Seine/MACE* (multiblock adaptive computational engine), *SPSA* (simultaneous perturbation stochastic approximation) and the *VFSA* (very fast simulated annealing), very efficient stochastic optimization algorithms (global, local and hybrid approaches) executing on distributed computing systems on the grid;
- *GeoDAM* – a geosystem data access and management software component for storing, querying, and retrieving distributed data archives of historical, experimental (e.g., data from field sensors) and simulated data;
- Discover - a decentralized grid middleware service that provide secure and coordinated access to the resources and information required by the simulations;
- External services that provide data, such as current oil market prices, relevant to the optimization of oil production or the economic profit.

The aforementioned components offer enormous potential for performing data-driven studies and efficient execution of complex, large-scale reservoir models in a collaborative environment. In Figure 2.1 the right side illustrates the interaction scenario of all these components for the optimal reservoir management carried on with DDMSF.

Dynamic data-driven approaches are increasingly becoming more feasible because of the confluence of several technologies. First, advanced sensor technologies have improved the ability to capture data faster and at higher resolution. Second, Grid Computing (GC) is making possible to realize large-scale, complex numerical models [FKN+01, FKN+02a, FKN+02b]. GC infrastructure aims to dynamically and seamlessly link powerful and remote resources to support the execution of large scale and disparate processes characterizing a particular problem. In order to harness wide-area network of resources into a distributed system, many researchers have been focused on developing grid middleware frameworks, protocols, programming and runtime environments. These efforts have led to the development of middleware tools and infrastructures such as Globus [FK99], Condor-G [FTF+01], Storage Resource Broker [RWM+02] and others.

Among all DDMSF components, the Discover Computational Collaboratory [MP03] strongly inspired the solution proposed here. Its overall objective is to realize a CPSE that enables geographically distributed scientists and engineers to collaboratively monitor, interact with, and control high performance applications in a truly pervasive manner, transforming high-performance simulations into modalities for research and instruction. Key features of Discover include a collaborative portal for interaction and control, mechanisms for web-based runtime visualization, scalable interaction and collaboration servers that reliably provide uniform access to remote distributed applications, and also security, authentication and access control mechanisms that guarantee authorized access to applications.

2.1.2. Wind Tunnel

Paventhan et al. [PTC+06] proposed the creation of a Scientific Workflow for wind tunnel applications. They observed that scientific and engineering experiments often produce large volumes of data that should ideally be processed and visualized in near real-time. The difficulty to achieve this goal is that the overall turnaround time from data acquisition, movement to a data processor and visualization of he results is frequently inhibited by factors such as manual data movement, system interoperability issues, manual resource discovery for job scheduling and disparate physical locality between the experiment and the scientist or engineer workstation. They argued that customized application specific workflows can reduce the time taken to accomplish a job by automating data flow driven activities, supplementing or replacing manual user-driven tasks.

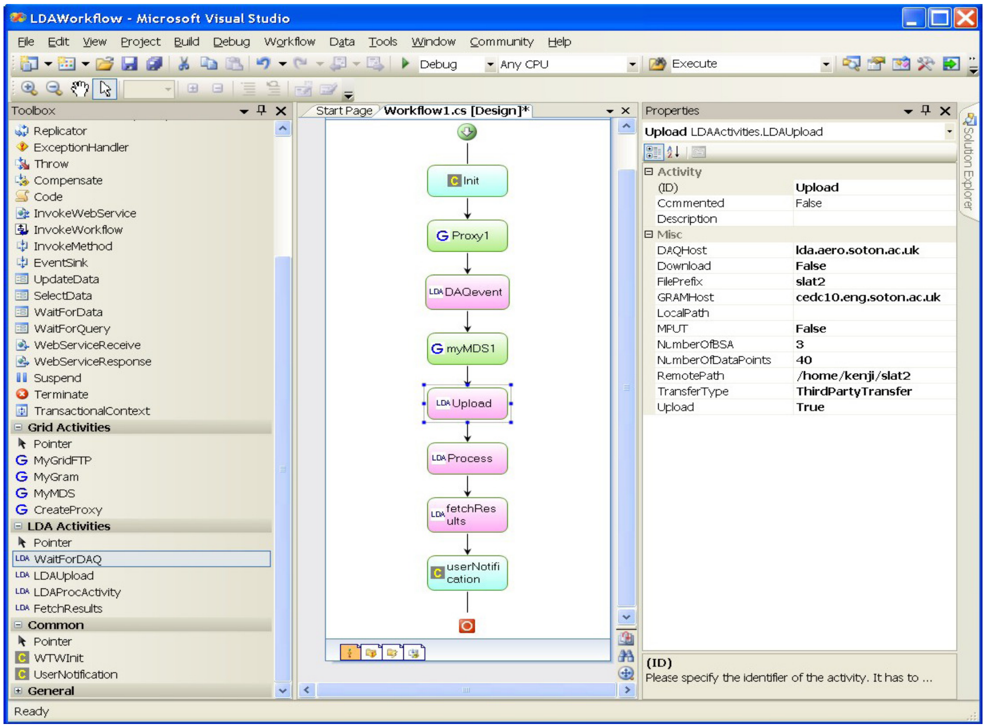


Figure 2.2: Sequential workflow using customized wind tunnel grid activities.

Two different approaches based on Windows Workflow Foundation (WWF), an extensible framework for developing workflow solutions were implemented. The WWF is a component of Microsoft WINFX [WINFX07]. It has a predefined set of activities (if-else, while, parallel, invoke WebService and so on), and allows the creation of user-defined custom activities. The first approach consisted of the extension of WINFX workflow activities to deliver a set of application-specific wind tunnel activities allowing the users to compose sequential workflows and seamlessly access Globus Grid services using a .NET-based Commodity Grid Toolkit created by the authors, MyCoG.NET [PT05]. Figure 2.2 shows a sequential workflow designed using customized wind tunnel grid workflow activities. The DAQevent is a customized event driven activity, that upon completion of the data acquisition, verifies the raw data files for completeness and in case of success enables workflow transition to next activity. The MyGridFTP, MyGRAM and MyMDS activities use MyCoG.NET Commodity Toolkit to access Globus resources. These Grid service access activities are further customized for individual experiments, as is the case of Upload and FetchResults which are activities derived from MyGridFTP, for respectively automatic uploading of raw data files from Data Acquisition host to GRAM-server (Grid Resource Allocation Management) and transfer of the results from GRAM-server to WWF server and to the user's desktop.

In the second approach, they presented a database-centric architecture for wind tunnel experimental workflow that hosts both data and processing. The strategy is to run the data parallel code on a database cluster that hosts both experimental data and user algorithms. The customized database activity set will allow the user to compose workflows based on this approach. With the rapidly evolving capabilities of Database Management Systems (DBMS) such as high-level language stored procedures (Java, C#, etc.), native support for XML, XML Web Services and Transactional Messaging are changing the role of DBMS in Scientific Workflows.

2.1.3. Vistrails

Vistrails [CFS+06] is a visualization management system developed at the University of Utah. It provides a Scientific Workflow infrastructure which can be combined with existing visualization systems and libraries. A key feature that sets Vistrails apart from other Visualization Systems as well as Scientific Workflow Systems is the support for data exploration. It separates the notion of dataflow specification from its instances. A dataflow instance consists of a sequence of operations used to generate a specific visualization.

Data provenance, i.e., the capacity of maintaining information of how a given data product was generated [SPG05], has many uses, from purely informational to enabling the representation of the data product. By maintaining a detailed data provenance infrastructure of the exploration process, in a structured way, with a flexible XML schema to represent different kinds of dataflows, the system allows the visualization experiments to be queried and mined. Users can query a set of saved dataflows to locate a suitable one for the current task; query saved dataflow instance to locate anomalies documented in annotations of previously generated visualizations; locate data products and visualizations based on the operations applied in a dataflow; cluster dataflows based on different criteria; etc. With Vistrails, users have the ability to steer their own simulations.

Data provenance is a very important feature for any CPSE because scientists and engineers often create several variations of a workflow in a trial-and-error process when solving a particular problem. Data exploration through visualization requires scientists and engineers to go through several steps. In essence, they need to assemble complex workflows that consist of dataset selection, specification of series of operations that need to be applied to the data, and creation of appropriate visual representations, before they can finally view and analyze the results. Usually, insight comes from comparing the results of multiple visualizations that are created during the data exploration process. Unfortunately, today this exploratory process is far from interactive and contains many error-prone and time-consuming tasks.

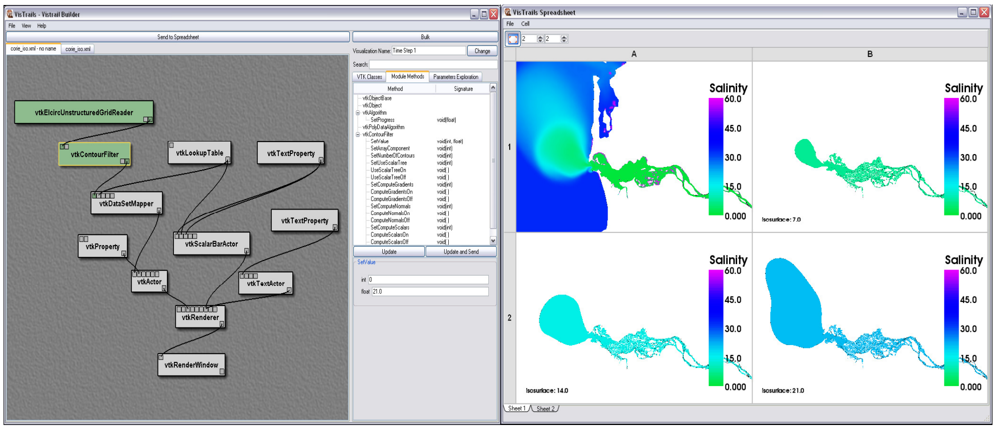


Figure 2.3: The Vistrails Builder (left) and Vistrails Spreadsheet (right)

Vistrails manage both the data and metadata associated with visualization products. Users create and edit data flows using the Vistrails Builder user interface. The dataflow specifications are saved in the Vistrails Repository. Users may also interact with saved dataflows by invoking them through the Vistrails Server, through a web-based interface, or by importing them into the Vistrails Visualization Spreadsheet. Each cell in the spreadsheet represents a view that corresponds to a dataflow instance; users can modify the parameters of a dataflow as well as synchronize parameters across cells (Figure 2.3). Dataflow execution is controlled by the Vistrails Cache Manager, which keeps track of operations that are invoked and their respective parameters. Vistrails Cache Manager infrastructure was implemented using Kepler [LAB+06, Kepler 07].

2.1.4.
Discussion

Scientific Workflows and Grid Computing enable the development of complex engineering simulations. The ability to compose, design and execute rapid prototyping of experiments, provided by ScWfMS together with the grid philosophy of "on-demand" availability of computational resources are valuable features for LSEP.

The capacity of sharing resources across organizational boundaries provided by a grid computing infrastructure gives a lot of flexibility for LSEP, allowing the execution of engineering simulations “transparently everywhere”.

2.2. Virtual Reality Visualization Technology

Visualization is an important component for many PSEs. For example, Parker et al. [PMH+98] describe SCIRun [SCIRun], a PSE that allows users to interactively compose, execute, and control a large-scale computer simulation by visually "steering" a dataflow network model. SCIRun supports parallel computing and output visualization, but originally has no mechanisms for experiment managing and archiving, optimization, real-time collaboration, or modifying the simulation models themselves.

Paraview [Paraview] is a kind of PSE for visualization that allows the interactive creation and manipulation of complex visualizations. Paraview is also based on the notion of dataflow, and provides visual interfaces to produce visualizations by assembling pipelines out of modules that are connected in a network. However, both SCIRun and Paraview have important limitations which hamper their ability to support the data exploration process. First, there is no separation between the definition of a dataflow and its instances. In order to execute a given dataflow with different parameters (e.g., different input files), users need to manually set these parameters through a GUI — clearly this process does not scale to more than a few visualizations. Second, modifications to parameters or to the definition of a dataflow are destructive — no change history is maintained. This places the burden on the scientist to first construct the visualization and then to remember the values and the exact dataflow configuration that led to a particular image.

Despite their limitations, SCIRun and Paraview show the importance of combining visualization with PSE. As we pointed out before in Chapter 1, the importance of three-dimensional modeling and visualization has led engineering companies to increasingly adopt the use of VRCs in order to favor visual communication in technical work sessions and decision-making meetings. In this kind of environment, collaboration is greatly improved, as compared to the use of desktop displays, mainly due to fact that people share the same physical space, with their attention dedicated to large-size representation of their models, facilitating the communication of concepts and reducing misunderstandings.

2.2.1. Immersive Well Path Planning

In the Upstream segment of the oil & gas industry, the determination of optimal well locations is a challenging problem for Reservoir engineers since it depends on geological and fluid properties as well as on economic parameters [KBW+04].

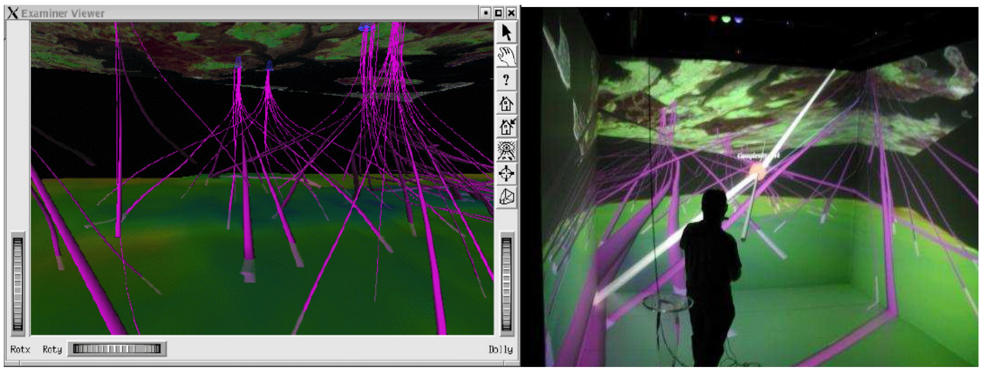


Figure 2.4 : IDP Desktop interface and an IDP user interacting with the virtual world.

Gruchalla [Gru04] investigated the benefits of immersive VR for well-path editing. He reported speed and accuracy improvements of immersive systems over desktop system, based in a study with 16 participants who planned the paths of four oil wells. Each participant planned two well paths on a desktop workstation with a stereoscopic display and two well paths in a CAVE-like [CS+92] Immersive Virtual Environment (IVE) (Figure 2.4). Fifteen of the participants completed well path editing tasks faster in the IVE than in the desktop environment. The increased speed in the IVE was complimented by a statistically significant increase in correct solutions. The results suggest that an IVE allows for faster and more accurate problem solving in a complex interactive three dimensional domain. The Immersive Drilling Planner is a long-term project to explore the impact of immersive visualization for drilling, in an effort to reduce drilling costs, risks, and time spent [DVRC].

2.2.2. VRGeo Demonstrator

The VRGeo Consortium [VRGeo] is an oil and gas international consortium for developing visualization technology for Geosciences and Engineering applications in Virtual Environments (VEs), conducted by Fraunhofer Gesellschaft (FhG, Germany)[1].

VRGeo has been presenting many significant contributions for the use of VR technology, specially in the area of Collaborative Work in Virtual Environments. Simon et al [SS+05] presented a qualitative and quantitative study comparing usability and interaction performance for multi-viewpoint images, where a large screen projection-based stereoscopic display system is shared by a small group of people, each of them with its own viewpoint (Figure 2.5).

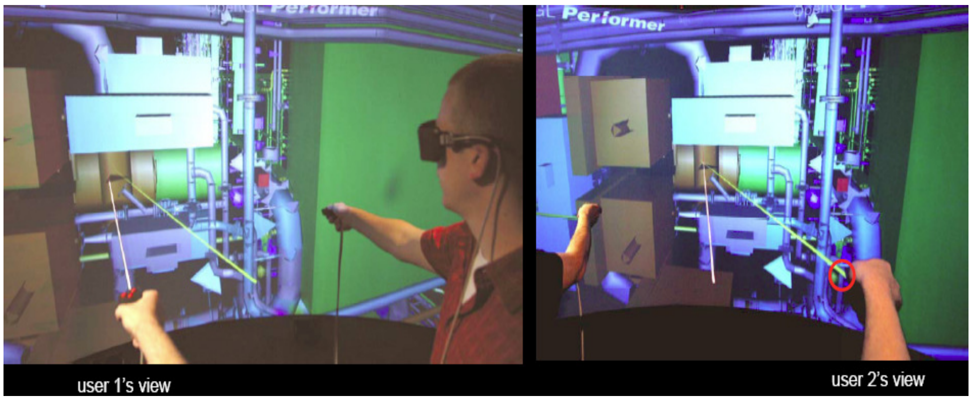
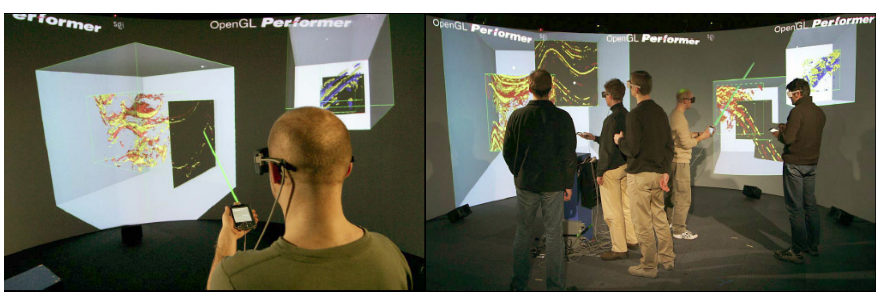


Figure 2.5 : Multi-viewpoint image rendering.

Another interesting work was the VRGeo Demonstrator Project for Co-located Collaboration interactive analysis of complex geological surfaces and volumes in an immersive VR system [Simon05]. In their paper they showed a new interaction paradigm allowing multiple users to share a virtual space in a conventional single-view stereoscopic projection-based display system, with each of the users handling the same interface and having a full first-person experience in the environment. Multi-viewpoint images allow the use of spatial interaction techniques for multiple users in a conventional projection-based display (Figure 2.6).



[1] The author of this thesis worked as a guest research scientist from 2003 to 2004 in this group.

Figure 2.6 : Multiple users interacting with multiple workspaces.

2.2.3. Geological-Mapping and Displacement Analysis (GMDA)

In the Geology field, Kreylos et al [KBB+06] presented an approach for turning immersive visualization software into scientific tool. They created immersive visualization measurement and analysis tools that allow scientists to use real word skills and methods inside Virtual Environments. They emphasized that VR visualization alone is not sufficient to enable an effective work environment. They have also conducted some informal studies to determine the impact of using VR methods on some geosciences tasks such as Geological-Mapping (identification of structures; facets, folded layers of rock and geomorphic features) and Displacement Analysis (measure the deformation of the Earth's surface and of natural or man-made structures due of geological events such as landslides, floods or earthquakes). Although not being a quantitative study, due to the small numbers of participants, they observed that VR visualization enabled scientists to make more accurate observations in less time, and to be more confident about their observations.

Another very important result, that has caught our attention, was the usage of their system as a debugging tool for Finite Element Method (FEM) simulations. Through the coupling of their VR visualization system and a FEM simulator they could solve a convergence failure in their simulation of a Plate Subduction analysis in the Aleutian chain region. For such a problem scientists use Computational Fluid Dynamics (CFD) to investigate the fact of tectonic plates entering the Earth's mantle in the vicinity of subduction zones. After having failed to find the cause of the problem using conventional tools, only by exploring their data in the VR application they could find the reason. There were several regions where one component of the simulation input exhibited severe aliasing that resulted in numerical convergence and stability problems as can be seen in the Figure 2.7-right.

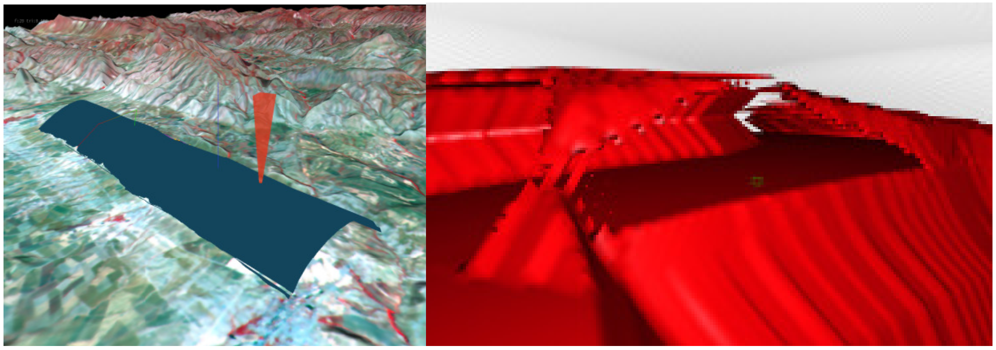


Figure 2.7 : A 3D fold surface calculated from the virtually mapped data (left). Isosurface showing aliasing in the simulation viscosity field (right).

2.2.4. Discussion

Data exploration through visualization requires scientists and engineers to go through several steps. In essence, they need to assemble complex workflows that consist of dataset selection, specification of series of operations that need to be applied to the data, and creation of appropriate visual representations, before they can finally view and analyze the results. Usually, insight comes from comparing the results of multiple visualizations that are created during the data exploration process. The ability to provide an interactive Data Exploration tool using VR visualization is a very valuable component for any CPSE constructed for LSEP.

2.3. Service-Oriented Architecture

Nowadays, businesses are dealing with two fundamental issues:

- Reduce costs and maximize the utilization of existing technology;
- The ability to change quickly.

Most enterprises today contain a range of different systems, applications and architectures of different ages and technologies. Integrating products from multiple vendors and across different platforms constitutes a real nightmare. To remain competitive, businesses must adapt quickly to internal factors such as acquisitions and restructuring, or external factors like competitive forces and customer requirements. They must have a more flexible and responsive environment, capable of dealing with the ever changing business requirements.

Service Oriented Architecture (SOA) [HKG+05, Ort05] is an alternative to alleviate the problems of heterogeneity, interoperability and changing requirements. SOA provides a platform for building application services with the following characteristics: loose coupling, location transparency and protocol independence. Based on SOA, a service consumer does not even have to care about a particular service it is communicating with, because the underlying infrastructure, or service “bus”, will make an appropriate choice on behalf of the consumer. The infrastructure hides as many technicalities as possible from a requestor. Wrapping a well defined service invocation interface around a functional module hides implementation details from other service requestors. Thus, particularly, technical specificities from different implementation technologies do not affect SOA participants. It is also possible to reconsider and substitute a service implementation for another one with an improved implementation, or with better quality of service characteristics.

2.3.1. Real-Time Architecture Project (RTAP)

The vision of intelligent or digital oilfields is roughly an interplay of several technologies that provides resources for gathering raw data (well or facilities operations) through electronic meters or gauges, transmitting this information via satellite, microwave or fiber optics to remote servers and data historians, and transforming it into knowledge for decision making (Figure 2.8).

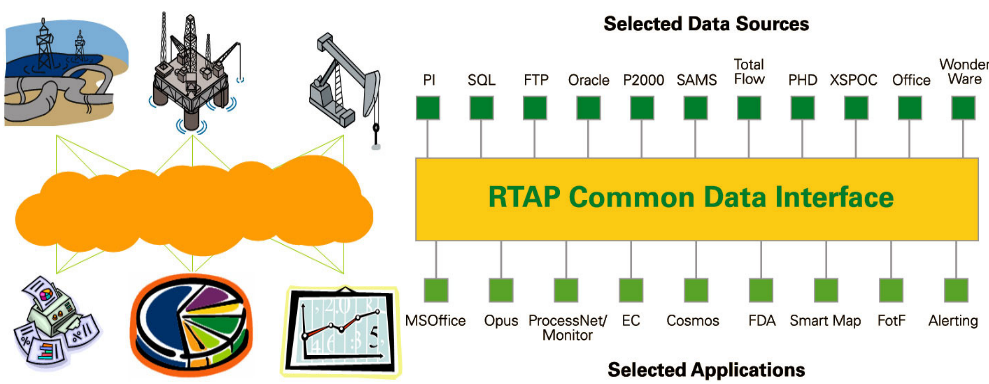


Figure 2.8 : Automated monitoring system (left). RTAP web services layer (right).

Real-Time Architecture Project (RTAP) is an initiative of the British Petroleum company (BP) to provide a common approach for all its assets to access real-time production operations data [GFF+05]. RTAP utilizes Web Service technologies, which create highly flexible interfaces based on established and emerging Internet standards. It integrates a wide range of tools such as Production Reporting, Real-time Visualization, and Active Alerting with new or existing data sources of many kinds. BP has already implemented this solution in many locations and in a number of business units, providing many common applications with access to a dozen commercial and proprietary data sources (Figure 2.8).

The ultimate goal of RTAP is to implement a common, standards-based architecture for data access and integration, replacing the large number of custom, proprietary interfaces currently in use. Since RTAP launching some years ago, significant progress has been made toward this goal, with the intent of expanding the current implementation to a next generation SOA in the near future.

2.3.2.
Integrated Asset Management framework (IAM)

Another SOA application that influenced this research is the Integrated Asset Management framework (IAM). IAM provides to its users a front-end modeling environment for specifying and executing a variety of workflows from reservoir simulations to economic evaluation [SBO+06]. The IAM framework is intended to facilitate seamless interaction of diverse and independently developed applications that accomplish various sub-tasks in the overall workflow. For instance, with IAM a user can pipe the output of a reservoir simulator running on one machine to a forecasting and optimization toolkit running on another node and in turn piping its output to a third piece of software that can convert the information into a set of reports in a specified format (Figure 2.9).

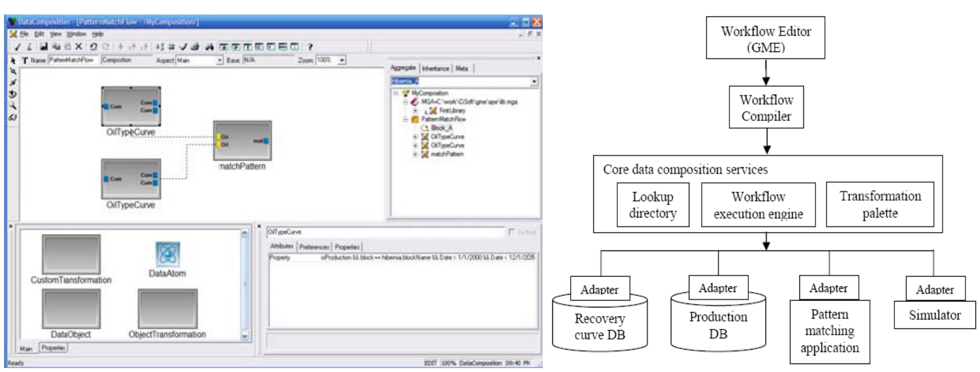


Figure 2.9: IAM graphical modeling tool (left) and its architecture (right).

IAM adopted a service-oriented approach where every component, regardless of its functionality, resource requirements, language of implementation, etc., provides a well-defined service interface that can be used by any other component in the framework. The service abstraction provides a uniform way to mask a variety of underlying data sources (real-time production data, historical data, model parameters, reports, etc.) and functionalities (simulators, optimizers, sensors, actuators, etc.). Workflows can be composed by coupling service interfaces in the desired order, through a graphical modeling or textual front-end and the actual service calls can be generated automatically.

Data composition is one of the key components of the IAM framework. It refers to a general process of applying a variety of intermediate transformations to data as it flows from one service to another as part of a larger workflow. Automating data flow among multiple information consumers will greatly expedite many workflows by eliminating the typically laborious tasks involved in manual preparation of data for input to various tools. In order to enable a Data composition perspective they created the following components and services:

- ***Data sources.*** The production data and the recovery curve catalog are the sources of ‘raw’ data that could be stored in a standard database. Access to the database could be through a web service that provides a query interface for data retrieval and update;
- ***Aggregation service.*** A software module aggregates time-based raw data (from production as well as simulation), and generates type curves along the desired dimensions - e.g., cumulative oil production vs. reservoir pressure;
- ***Pattern matching service.*** This software module accepts a set of reference curves from the catalog and a type curve derived from the production data, and performs pattern matching to estimate the best fit.

Figure 2.9-left illustrates the use of their graphical modeling tool for building a highly simplified real-time reservoir management workflow. In this workflow, a catalog of type curves is available from a series of a priori reservoir simulation runs. The curves in the catalog correspond to a set of differing models of the reservoir. As real world production data from the reservoir becomes available, it is periodically compared to the type curves in the catalog to estimate the best fit. The type curve(s) that best matches the production data at a given time could then be used as input to other disjoint workflows such as oil production forecasting.

2.3.3. Discussion

We argue that SOA offer to Large Scale Engineering Projects a number of compelling benefits for allowing the development of a flexible and stable architecture. Through the use of its three main concepts - loose coupling, location transparency and protocol independence – a Problem Solving Environment developed for a LSEP using an SOA will be able to:

- respond efficiently to changes in the business and competitive landscape,
- reuse of legacy system while enhancing integration;
- reduce overall technology development costs by:
  - leveraging functions already built into legacy system services;
  - reusing services developed for other process;
  - simplifying maintenance and support through elimination of redundant and siloed applications.

2.4. CEE Main Ideas

The work of the Data Driven Multiphysics Simulation Framework (DDMSF) and the former OE characteristics discussed in chapter 1, pointed out to the necessity of integrating a myriad of different applications to solve common OE problems (Figure 2.1). This motivated us to the pursuit of an Enterprise Application Integration (EAI) for CEE. Recently, EAI has been greatly simplified by the adoption of an SOA integrated with an Enterprise Service Bus [HKG+05]. In Chapter 4 we provide more detailed information about the usage of ESB in the CEE SOA architecture.

Wind Tunnel provides a series of workflow activities allowing the users to compose sequential workflows and seamlessly access Grid services (Figure 2.2). The Wind Tunnel approach also inspired the development of our CEE by combining the ScWfMS with the execution of engineering applications in a Grid infrastructure computing environment through the use of Grid Resource Allocation & Management (GRAM) job submission.

The Vistrails approach inspired our CEE strategy, but some of the differences of the CEE are the use of a BPEL (Business Process Execution

Language) ScWfMS, the focus on immersive and realistic visualization and the absence of data provenance support.

The VRGeo Demonstrator's collaboration capabilities showed the benefits of collaboration in a Virtual Environment for interpreting geological data (Figure 2.6) or investigating platform 3D CAD models (Figure 2.5). This is a very important feature for our CEE which has the Offshore Engineering field as its main target (see Chapter 1).

As shown by GMDA, the usage of a VR Visualization system to debug engineering simulations is a very powerful tool for Large Scale Engineering Projects. Their observation that VR visualization enabled scientists to make more accurate observations in less time and with more confidence has also motivated to include a VR Visualization system as an important component of the CEE architecture. The fact that VR visualization alone is not sufficient to enable an effective work environment has stimulated us to create additional tools for the VR Visualization component of CEE (CEE-VRV). Some of those tools are Annotations and Measurements and are discussed further in the Collaborative Tools section in Chapter 3.

The IAM project has inspired very much the CEE architecture. The adoption of an SOA with services encapsulated as components motivated us to use a Service Component Architecture [SCA] in the development of the CEE.

To finalize this chapter we present a comparison of the features provided by CEE and the features presented by the related solutions. It can be seen from this comparison that CEE has a wider spectra addressing the most important requirements of Large Scale Engineering Projects.

	CEE	DDMSF	Wind Tunnel	Vistrails	GMDA	IAM
ScWfMS						
Scripting Language	✔	✖	✔	✔	–	✔
Visual Tool for Composition	✔	✖	✔	✔	–	✔
Data Provenance	✖	✖	✖	✔	–	✔
Grid Computing Infrastructure						
Job Submission	✔	✔	✔	✔	–	✔
Job Monitoring	✔	✔	✔	✔	–	✔
Collaboration						
Collaborative Portal	✔	✔	✖	✖	–	✖
Videoconference	✔	✖	✖	✖	–	✖
Visualization						
Virtual Reality	✔	✖	–	–	✔	–
Collaborative Visualization	✔	✖	✖	✖	–	–
Visualization Tools (3D Annotations, Measurements, Virtual Tours)	✔	✖	–	–	✔	–
Scientific Visualization	✔	✔	–	✔	✔	–
Computational Steering	✖	✖	–	✔	✖	–
Data Access Service						
Data Stage In/Out	✖	✔	✔	✔	✖	✔
Querying and Retrieval Mechanisms	✖	✔	✔	✖	✖	✖

✖	Does not provide
✔	Provide
–	Not Applicable

Table 2.1 Feature comparisons between CEE and related solutions