A Componentized Approach to Grid Enabling Seismic Wave Modeling Application

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Abstract. Seismic modeling is an integral part of the seismic data processing for oil and gas exploration, as it provides us the seismic response for a given earth model. Grid enabled seismic wave modeling can facilitate users in the area of geophysics to calculate synthetic seismograms using federated HPC resources and complex solution algorithms without knowing their complexities. The present paper is about componentization of the wave equation based seismic modeling algorithm and its implement using Imperial College e-Science Networked Infrastructure (ICENI) Grid Middleware.

1 Introduction

Oil and gas companies are constantly challenged to assess promising locations for exploration and to improve production processes. The cost and availability of computational power has always been a limiting factor in the application of advanced seismic processing methods to refine subsurface images. Today, seismic data processing is as much based on complex algorithms, computation, data analysis, and collaboration. Though the computer power, data storage, and communication continue to improve exponentially, computational resources are failing to keep up with what geophysicists demand of them. The "Computational Grid" offers a potential means of surmounting these obstacles to progress [1], however they also present many challenges to their effective exploitation by non-trivial applications. Grid based programming requires a high-level programming model that performs in a resource/ platform independent fashion.

ICENI uses a component-programming model to describe Grid applications. This is clearly beneficial because it promotes code reuse and reduces the task of Grid application development to that of application composition [7]. Each component in an application represents an abstract or running software resource service that can communicate to other components in the application through the ICENI middleware.

2 Wave Equation Based Seismic Modeling

The basic problem in the theoretical seismology is to determine the wave response of a given model to the excitation of an impulse source by solving the wave equations under some simplifications. In the scalar approximation, the acoustic wave equation may be solved to evaluate the waveform. The acoustic wave equation in a 3D heterogeneous medium given by

$$\frac{1}{K}\frac{\partial^2 p}{\partial t^2} = \frac{\partial}{\partial x}\left[\frac{1}{\rho}\frac{\partial p}{\partial x}\right] + \frac{\partial}{\partial y}\left[\frac{1}{\rho}\frac{\partial p}{\partial y}\right] + \frac{\partial}{\partial z}\left[\frac{1}{\rho}\frac{\partial p}{\partial z}\right] \tag{1}$$

where, p is the negative pressure wavefield, ρ is the density and K is the incompressibility. But instead of solving this second order hyperbolic wave equation, numerically one can use an equivalent first order system [5], which can be derived from equations of motion. If *u, v* and *w* are the components of the velocity vector in the *x*-, y- and *z*- directions respectively, then

$$\rho\frac{\partial u}{\partial t} = \frac{\partial p}{\partial x}, \qquad \rho\frac{\partial v}{\partial t} = \frac{\partial p}{\partial y}, \qquad \rho\frac{\partial w}{\partial t} = \frac{\partial p}{\partial z} \tag{2}$$

Using equations (1), and (2), we can also write a first order system of hyperbolic equations

$$\frac{\partial \mathbf{P}}{\partial t} = \mathbf{A}\frac{\partial \mathbf{P}}{\partial x} + \mathbf{B}\frac{\partial \mathbf{P}}{\partial y} + \mathbf{C}\frac{\partial \mathbf{P}}{\partial z} \tag{3}$$

where

$$\mathbf{P} = \begin{bmatrix} p \\ u \\ v \\ w \end{bmatrix}, \quad \mathbf{A} = \begin{bmatrix} 0 & \lambda & 0 & 0 \\ \rho^{-1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \quad \mathbf{B} = \begin{bmatrix} 0 & 0 & \lambda & 0 \\ 0 & 0 & 0 & 0 \\ \rho^{-1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \quad \mathbf{C} = \begin{bmatrix} 0 & 0 & 0 & \lambda \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \rho^{-1} & 0 & 0 & 0 \end{bmatrix}$$

In contrast to equation (3), equation (1) requires the calculations of derivatives with respect to physical parameters. Equations (1) and (3) are usually solved by explicit finite-difference methods. The selection of the method depends on the formulation of the wave equation whether equation (1) or (3), convergence criterion, number of computations, accuracy etc. This requires a good understanding of finite difference methods for partial differential equations.

3 The ICENI Middleware

ICENI [3], [4] is an end-to-end Grid middleware system developed at London e-Science Centre. ICENI is based on an implementation independent API that interfaces to a service oriented architecture (SOA). As such, computational resources and software capabilities are exposed as services that can be discovered by the user.

ICENI is rich in metadata which is preserved at all levels within the system. This includes: metadata about how each component in a particular application works, as provided by the component developer; performance characteristics, stored from previous runs of the component within the ICENI environment; and metadata (both static and dynamic) provided by the Grid resources which are available for use by components in an application. Together these aspects enable a user to construct an application from components, to submit this workflow specification to a scheduling system capable of exploiting the application meta-data to optimize the placement of the components to reduce overall execution time.

4 Componentization Approach for Seismic Modeling

Seismic Modeling can be divided into the following four basic modules and each module will have independent components, which can be selected by the user to compose an application to execute in a Grid environment.

1. Input data files and problem parameters. This allows the user to provide input velocity, density files and their related parameters such as the size of the domain, records length, source, receiver locations etc.

2. Mathematical model and algorithms. This allows the user to select mathematical models such as the parabolic/hyperbolic form of the wave equation. Based on the form of the partial differential equation, the user will have a choice for selecting the solution method e.g. finite difference or finite element. After selecting a solution method, the user can have a choice for selection of a specific solution scheme [5].

3. Parallel system parameter selection. Although the intricacies of the running system will be hidden from the user, if some user wants to define the parallel system and partitioning of the domain etc, parallel system parameter selection can allow the user to select various partition algorithms [6]. The Grid middleware should be responsible for hiding the complexity of Grid usage and through performance modeling can indicate the best parallel parameters for the particular problem size on that computational resource.

4. Results and visualization. This allows the user to define how he wants to receive and visualize the data e.g. data storage location, format and visualization tools.

We have developed various binary components for each of the above four basic modules where the user has a choice to select according to the needs for data available for the processing. For example, in the case of a salt dome model, a user will prefer to select a hyperbolic formulation of the wave equation and will have a choice to select the finite difference scheme as McCormick for better resolution

5 Seismic Modeling as an ICENI Application

In order to develop various components of the seismic modeling application, we have used the ICENI binary *ComponentBuilder* that allows us to expose native code as a component within a Grid environment. Further, this permits us to specify the ports of the components according to the meaning, behavior and implementation in a graphical way. Once the components have been developed, we use the ICENI Netbeans based client to browse and monitor available services in ICENI. This client also provides an intuitive way for application to be composed, whereby components can be dragged-and-dropped onto a composition pane, before being connected together to visually describe the workflow of the application. The composed application can then be submitted and launched through ICENI in order to schedule and execute the component.

Most of the components used in the Seismic Modeling application were developed independently from ICENI and work as separate binary applications. The binary applications can be accessed through the use of the ICENI *Binary Component* – a way of wrapping up an existing application to use within the ICENI framework.

Every Binary Component is associated with the binary executable that the component represents, a JDML file that describes how the application is to be executed and the arguments that it may take. The Binary Component is capable of taking input and output data from other components in ICENI. This allows a set of arguments to be passed to the binary executable (through the *stdin* ports), and/or the output of the application to be passed back to ICENI.

6 Conclusion

We have shown that the wave equation based seismic modeling application has been implemented successfully within the ICENI Grid environment. Since ICENI is an integrated Grid environment for component applications, we have componentized the seismic modeling application into various independent binary modules. Finally, they have been wrapped up by using the ICENI binary ComponentBuilder to make them available as services to compose the seismic modeling application and execute within a Grid environment.

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