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Web-FEM: An internet-based finite-element analysis framework with 3D graphics and parallel computing environment

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Abstract

This paper presents an Internet-based finite-element analysis framework, named Web-FEM, which allows users to access finite-element analysis service from remote sites over the Internet by using an Internet-connected machine only. The implementation utilizes modern computer graphics, parallel processing, and information technology to provide features such as platform-independence, 3D graphical interface, system performance, multiple-user management, and fault tolerance in comparison with other Internet-based analytical systems. These features make its usage like using a traditional finite-element package installed and run on a local machine, and its performance like using a high performance computing facility. The object model design and the implementation of this system are presented in detail.

Keywords: Finite element; Internet; 3D graphics; High performance computing; Object-oriented systems

1. Introduction

During the 1990s, object-oriented programming philosophy was investigated for the implementation of the finite-element method. The research concerning this topic includes Miller [1], Mackie [2,3], Baugh and Rehak [4], Zimmermann et al. [5], Yu and Adeli [6], Lu [7] and Archer et al. [8]. The research showed several advantages, such as data abstraction and code reuse, of using object-oriented design in finite-element implementation. Some researchers further tried to integrate parallel processing with object-oriented finite-element program design. The research on this subject includes Mukunda [9], Modak and Sotelino [10,11], Dere and Sotelino [12], McKenna [13], and Chen and Archer [14,15]. All these studies were implemented by extending sequential object-oriented design. Chen and Archer present a general-purpose parallel program based on the general finite-element procedure. All the other systems rely on a parallel algorithm, such as Static Condensation, Dynamic Reduction, Nonlinear Domain Decomposition, or Group Implicit algorithm, to achieve great efficiency for a specific type of problem. Using parallel processing techniques greatly enhances the performance of these systems. The encapsulation and polymorphism features of object-oriented programming also make parallel processing easier to manage, extend and understand in these systems.

In recent years, the way software systems work has been revolutionized due to the continuing development and popularity of high-speed Internet. Some researchers have adopted the concept that analysis software and computing resources can be provided to public users by using the Internet, like many other services, such as search engines, which we can access online. Peng and Law [16] present a software framework for collaborative structural analysis over the Internet. A core framework at the server allows users to access and attach their own developments to the core by using a web-browser. The framework provides a "plug-and-play" environment where researchers and developers

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can define their own implementations to work with the core program, by utilizing pre-defined Internet-enabled communication interfaces. Nuggehally et al. [17] present an Internet-based computing platform for the boundary element method. Yang et al. [18] present a generic web-based platform for conducting model-based numerical simulations of seismic ground response online. These two platforms distribute pre- and post-processing components to the user computer, and only retain core computational functions on the server machine. Peng and Law [19] present an Internet-enabled framework that facilitates building an FEM program as distributed web-services. These implementations successfully fulfilled, analytical services can be accessible over the Internet using web forms on browsers to receive users' inputs and present the results.

Although providing analytical services to users over the Internet is not a new concept, some crucial requirements, such as 3-dimensional (3D) visualization of data and system performance, for making Internet-based analytical services popular and successful still have not been addressed. This paper presents an Internet-based analytical service framework, named Web-FEM (Web-based framework for the finite-element method), to address these issues to further popularize the web-service concept for engineering computing. The system goal is to make the usage of the proposed system like accessing a traditional finite-element package, and the performance of the proposed system like using a high performance computing facility. The basic idea is to separate the functionalities packed in a traditional software package into two components, and distribute them between client and server. The component on the client computer handles the presenting of data and interacting with the user. The component on the server machine handles the core computation of the application. In order to integrate these two components to work as a single system, another component on the server machine is required to coordinate these two components over the Internet. The object model design and implementation of this prototype system utilizes and integrates modern computer graphics, parallel processing, and information technology to provide features which produce a concurrently accessible parallel computing environment on the server side, and a platform-independent 3D graphical user interface on the client-side. This new Internet-based framework is expected to provide users a more practical analytical service than current Internet-based analytical systems and more convenience in accessibility, usage, and maintenance, and better computing resource planning than traditional software packages. This paper is an updated and revised version of the conference paper [20].

2. System requirements analysis

From a system development viewpoint, there are some requirements which are keys to successfully utilizing Internet-based concepts. The system design must consider all these requirements to successfully realize the web-service concept for finite-element application.

To achieve web-service, the client-side user interface must be able to communicate and interact with the finite-element analysis system on the server side over the Internet. Therefore, Internet communication ability and a communication protocol between client and server are basic requirements. Furthermore, a basic concept of web-service is that the service should be accessible by a user using any platform. Therefore, another basic requirement is the client-side user interface must be platform-independent.

As noted in the above literature review, the current Internet-based implementations of analytical services all use web forms on web-browsers as the user interface to achieve the above basic requirements. However, the presentation of numerical model and analysis result data is limited to using text and numbers due to insufficient graphical display ability available on a standard web-browser, whereas the traditional finite-element analysis software installed in a private machine and used by a user locally can provide a custom graphical user interface, which is either integrated with the analysis program or co-exists in the same machine, to interact with the user. For modern finite-element analysis applications, providing a 3D graphical interface (pre- and post-processor) to present numerical data for efficient model examination and result evaluation is a basic requirement. Therefore, the lack of graphical display ability, especially in 3D displays, can prevent the current Internet-based analytical systems from being popular.

On the other hand, an Internet-based system is an openly shared system for public users. Several users may access the system simultaneously. Letting multiple tasks share the computing resources and run concurrently is not a fair solution. Thus, a job scheduling/queuing mechanism must be provided on the server side for handling concurrent access. In addition, the server-side system must have a fault tolerance mechanism to prevent queuing tasks from being hung up by failures, such as an unusual disconnection or a system crash. Therefore, a client machine must be able to reconnect to its submitted job when the original connection gets lost, and the job queue must be able to be recovered when the server system has recovered from a crash. Furthermore, the network security is also an issue for all Internet-based applications, and needs to be well handled.

Further consider the computational characteristic of finite-element analysis, which is a highly computation-oriented application in comparison with other Internet-based applications. The computation for a single finite-element analysis task can be quite time-consuming and resource-demanding. This is an issue because a time-consuming task makes following tasks stack up and the users must wait in queue for a long time. In addition, the storage of huge amounts of input/output data is also an issue. If an openly shared system cannot provide enough efficiency and resources in computing and data storage, it is difficult to provide as a web-service.