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A sharable format for multidisciplinary finite element analysis data

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ABSTRACT

The sharing of finite element analysis (FEA) data during the design process is a key requirement for success in collaborative design environments. However, compared to other fields like computer-aided design (CAD), sharing FEA data using a standardized neutral format remains relatively inefficient because the format must accommodate a wide range of data types produced from multidisciplinary analysis applications. In this paper, we propose a new format improving the exchangeability of FEA data in a collaborative design environment. Our approach is designed to address a wide variety of industry concerns as it achieves substantial data compression by storing only essential FE information and is efficient for visualizing heterogeneous analytic results by using a modified scene graph data structure. To maximize the efficiency of managing multidisciplinary data, our format also allows the use of hierarchical management within a single structure. We implemented a system based on our format, which is able to efficiently use the proposed sharable data translated from various systems. Several examples from commercial FEA systems are provided to demonstrate the effectiveness of the format.

1. Introduction

Companies are transcending the traditional design paradigm of in-house production. Instead, collaborative design is practiced in distributed development environments to improve product quality, reduce development costs and shorten the time-to-market. This is a new approach where multidisciplinary stakeholders participate in decision-making and share design information across domain boundaries in a distributed environment [1]. In these collaborative design networks, exchanging product data is the one of the main requirements for success. Thus, extensive research efforts and development work have recently been carried out to meet this need, especially in the field of computer-aided design (CAD) [2,3].

However, the exchange of finite element analysis (FEA) data produced in computer-aided engineering (CAE) processes remains relatively inefficient. This is because that a wide variety of analysis systems are used for virtual product verification, while only a few CAD systems are used in the design process. For instance, aircraft dimensioning and verification are performed on static strength, fatigue strength, damage tolerance, composite materials analysis, thermal analysis, and other criteria [4]. As a consequence, the variety of FEA data formats is of the same order of magnitude as the number of analysis systems. This leads to an unacceptably high level of information redundancy. Moreover, the large file sizes of FEA data make it difficult to exchange data. In the case of a fluid simulation, the native analysis data can occupy dozens of gigabytes even though the analysis is of only one small solid part. In these CAE applications, only limited analytical information with 2D captured images and numeric data are shared with the other stakeholders. The original analysis data can be replicated in several places in each local repository of the simulation machines. As a consequence of this lack of exchanging full analytic information, CAD engineers and managers sometimes make incorrect design changes causing additional and unintended iterations of redesign.

In this paper, we propose a sharable format, Practical post-Analysis Model (*PAM*), which allows the efficient sharing of FEA data in a collaborative design process. To make the format shareable, we focused on the following three functions: (1) capability to hierarchically store various FEA data raised from multidisciplinary domains; (2) lightweight data carrying essential analytic information with compressed meshes; and (3) interoperability between CAD and CAE domains using design–analysis mapping information. An implementation of a management system based on the proposed format is also presented. Section 2 covers the background and limitations of the analysis data exchange. In Section 3, the data structure of the proposed format is presented. Section 4 details the implementation of the data structure and the system modules. Finally, in the conclusion, our work and future opportunities for extending our research are presented in Section 5.

2. Background

Since data exchange is central to the implementation of a collaborative environment, much previous research efforts have

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focused on standardizing data and data exchange methodologies. The development of new management solutions, such as Product Data Management (PDM) and Product Lifecycle Management (PLM), which emphasize the tracking and control of product data, has added further impetus to these investigations. While this research originally only examined CAD model integration or the standardization of common documents, the entire product development dataset has now become a target for standardization. The following literature review covers current progress in the standardization of heterogeneous data, especially for FEA data exchange in the CAE field.

A standardized neutral data format is one solution that can be adopted to reduce interoperability problems. A neutral format reduces the number of bidirectional translators needed to communicate N different systems from $O(N^2)$ to $O(N)$, and this has many advantages for users. For this reason, an industry-wide agreement exists that a neutral standard format holds the best solution for interoperability problems [5–7]. One of these standards, the Standard for Exchange for Product model data (STEP), has been the most used technique in this area [8]. In CAD, for example, many methodologies for the exchange of design information such as geometry [9,10] and design intent [11] have been suggested using the STEP standard. Recently, STEP has surpassed its role as a standard coming from one domain, and has evolved into a widely used standard able to comprehensively represent information about a product's development throughout its in-service lifetime [12]. In the STEP standard, there are Application Protocols (APs) that define the application specific views of integrated resources in a clearly defined context. Some examples of APs include AP202, *Associative Drafting* and AP203, *Configuration Controlled Design*. A particularly important AP is AP209, which specifies formats for the data associated with FEA software and is suitable for dealing with analytical information [13,14]. It takes into account the geometric data of the parts or assemblies, the associated Finite Element Models (FEMs), the material properties, and the results of the FEA processing. A number of CAE studies have examined the feasibility of exchanging analysis data using AP 209 [15–17]. However, although AP209 provides a standard for the format of data architectures and containers, it does not cater for data analysis itself. Therefore, additional work is required to apply this standard to specific applications. Also, it accommodates all the types of data from both CAD and CAE as a standard protocol, and this characteristic easily increases the size of the data.

As the amount of design information increases, the size of exchanging data across the developmental domains also increases in the same order. Research on lightening CAD data has been extensively conducted in order to make the data suitable for exchange. For example, the *JT* [18], *X3D* [19], *HSF* [20] and *XGL* [21] formats were developed for efficient exchange and visualization of the large size CAD models. Each format was developed based on specific lightening technologies including mesh compression, streaming, data approximation and reference-instantiation, but they have the same prior objective of efficient exchange by lightening the CAD data size [22]. Compared to CAD, lightening the FEA data still remains as a challenging issue in practice. To meet the need for a lightweight format to exchange the analysis information, some commercial formats such as *CEI Ensight* [23], and *GLView VTFx* [24] formats have been developed, but these formats offer only a limited interface across the various developmental domains in terms of data exchange. Song et al. [25] presented a lightweight CAE middleware called *CAE2VR* and suggested a method for sharing heterogeneous FEA data in a virtual reality environment. Cho et al. [26] also suggested a methodology and a data representation scheme to reduce the size of large FEA data in order to enhance the exchangeability of analysis information in collaborative environments. These research efforts, however, have not provided a generic methodology to hierarchically accommodate the multidisciplinary analysis data within a single lightweight data structure.

Table 1
Specifications of a sharable format for multidisciplinary CAE use.

Specifications	Requirement coverages
Lightweight data	(1), (2), (5), (8)
Capability to store multidisciplinary analysis data hierarchically	(1), (3), (6)
Efficient visualization and verification of finite element results	(2), (5), (8)
Interoperability between CAE and CAD models	(4), (7), (8)

As analysis information has strong interconnections with design, design exchange through the integration of CAD and CAE has also been raised as another method for improving design collaboration and is currently being extensively researched [27–30]. As the development paradigm shifts from a CAD-centric to a CAE-centric process, the integration paradigm is also shifting from a CAE-embedded design model to a CAD-embedded analysis model or an intermediate-approach model. For the intermediate approach, Lee [27] suggested a CAD–CAE integrated approach using multi-resolution feature modeling techniques to provide a unified and synchronous modeling environment. Gujarathi et al. [31] also presented an integration approach between the CAD and CAE using a neutral data structure, called the Common Data Model(*CDM*). While the CAD–CAE integration techniques are conceptually powerful, it is difficult to apply them widely in realistic cases due to the difficulty of simultaneously accommodating large amounts of information from the CAD data and CAE models. Indeed, in the real practice only the associativity information between the CAD and CAE models may be adequate to enhance the interoperability in terms of exchanging developmental ideas [32].

3. Data structure of the sharable format

Although some formats have been provided to enhance the exchangeability of the FEA data, it is still relatively inefficient to share the various CAE and related data within a single format, as was mentioned in the previous section. Thus, we propose a novel concept of a neutral format for efficiently sharing FE results and associated analysis data when working in a collaborative environment. In order to design a practical and sharable format for multidisciplinary FEA data, we first identified the requirements raised by the industry based on our experience and previous work [4,33,5,28]. The most crucial requirements are summarized as follows:

(1) Improved access to appropriate data sources.
(2) Higher throughput for analysts and designers to allow faster design verification.
(3) Repeatable and consistent simulation methods, transforming simulation from an ad hoc procedure into a methodical process.
(4) Fewer simulation errors and design or engineering changes.
(5) Enhanced visibility and usability of simulation results.
(6) Traceability and consistency of input data and results.
(7) Enhanced collaboration between design and simulation, both within the enterprise and throughout the supply chain; and
(8) Faster and more reliable engineering decisions.

Table 1 presents these requirements as formalized data format specifications that were used in the development of the new sharable format.

In the following sections, we enumerate these specifications and discuss the technologies and concepts necessary to implement each specification with the overarching goal of creating a sharable data format.