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A Numerical Framework to Simplify CAD Models for Reliable Estimates of Physical Quantities

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Abstract. The paper proposes a general numerical framework to simplify a CAD model into a volume mesh model under reliable control of certain prescribed physical quantity that the designer is interested in. Different from previous work, the proposed approach does not assume that the candidate features have been detected and can directly generate the simplified volume mesh model. In addition, it can efficiently estimate the quantitative impact of each individual feature via solving a linear equation of small dimension less than 10. This is achieved by reformulating the problem as estimating the solution differences caused by different stiffness matrices, using the *combined approximation* approach. Performance of this approach is demonstrated via numerical 2D examples.

AMS subject classifications: 65M10, 78A48

Key words: Defeaturing error, simplification framework, physically-reliable, CAD/ CAE integration, combined approximation.

1 Introduction

The paper proposes a general numerical framework to simplify a CAD model into a volume mesh model under reliable control of certain prescribed physical quantity that the designer is interested in. It discusses the overall process to conduct this task without

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explicitly detecting features. In addition, to achieve this, a novel *defeaturing error estimator* is proposed that quantitatively assesses the impact of removing details to the target quantity of interest, via efficiently solving a linear equation of very small dimension.

In fact, automatically generating a suitable simplified CAD or volume mesh model by removing small details from a complex CAD model is an important step in seamless CAD/CAE integration [27,32]. The process is essential to reduce the original design's geometric complexity, to facilitate downstream tasks including meshing and field solution computations and to increase their reliability [30, 40]. Due to the lack of the appropriate approach to control the physical properties during simplification, the process is typically done manually, estimated accounting for over 50% of all engineering analysis time at Sandia [3], for example and stated to be an open issue in various recent research surveys [27, 28, 32] and studied in different research communities [14, 15, 31].

One of the main technical challenges to resolve this issue of *physically-reliable simplification* is to quantitatively estimate the impact of removing geometric details on certain engineering analysis problems–the *defeaturing error*. Several research groups have recently devoted significant efforts to resolve this issue and have produced very promising results, e.g., for the problem of heat conduction [11, 21, 23, 36], linear elasticity [12, 20, 23], plate bending [37] and other specific nonlinear problems [21–23, 41]. Li et al. recently also studied the case in which multiple features interact [24]. These approaches typically derive analytical expressions for the defeaturing error and provide insightful theoretical understanding on the impact of an individual feature on engineering analysis with basic numerical tests. In addition, previous researches also studied the problem of small details in engineering analysis from different aspects [4, 17, 26, 39, 42–44].

However, applying these error estimators to reach the ultimate goal of generating physically-reliable simplified CAD or volume mesh model still requires further research efforts. Specifically, the previous approaches are generally built on a set of detected features, which itself is however a complex issue: features may interact and many geometric details may not be easy to represent or detect as specific features [10, 34]. Additionally, generating a defeatured model involves complex geometric operations and may not always be reliable [19, 38]. Actually, the details involved in physically-reliable simplification and the features involved in previous studies on feature detection are very different—the latter are features for manufacturing purposes while the former are used to produce a simplified volume mesh model. Detecting features before simplification, which actually adds further geometric operations and computational expense, is actually not completely necessary. In order to easily describe feature importance and to be consistent with previous studies [20–24], we still use the term "defeaturing error" to refer to the importance of a feature.

Note also that excellent work has also been conducted by Foucault et al. based on various mechanical criteria or geometric operations to guide the simplification process [**?**, 8]. In addition, Ferrandes et al. [6] proposed an overall framework to guide the simplification process, where the defeaturing induced engineering error is estimated within a local region around it. All these approaches, however, are also dependent on a first detection