Available online at www.sciencedirect.com

ScienceDirect

Computer-Aided Design 40 (2008) 760–777

COMPUTER-AIDED DESIGN

www.elsevier.com/locate/cad

Standardized data exchange of CAD models with design intent

Junhwan Kim[a], Michael J. Pratt[b,*], Raj G. Iyer[c], Ram D. Sriram[a]

[a] National Institute of Standards & Technology (NIST), Gaithersberg, MD, USA
[b] LMR Systems, 21 High Street, Carlton, Bedford, MK43 7LA, UK
[c] TACOM, US Army, Warren, MI, USA

Received 3 September 2006; accepted 11 June 2007

Abstract

Modern CAD systems generate feature-based product shape models with parameterization and constraints. Until recently, standards for CAD data exchange among different CAD systems were restricted to the exchange of pure shape information. These standards ignored the construction history, parameters, constraints, features and other elements of 'design intent' present in the model to be transferred. This paper suggests an implementational foundation for CAD data exchange with the preservation of design intent, based on the use of newly published parts of the International Standard ISO 10303 (STEP). Case studies are presented which employ a hypothetical STEP application protocol (AP) using Parts 55, 108 and 111 of ISO 10303. A prototype translator based on this AP has been implemented and tested. The paper reports on the experience gained in 'intelligent' data exchange.

Keywords: Data exchange; Design intent; CAD models; STEP; Construction history; Parameterization; Constraints

1. Introduction

The exchange of CAD (Computer Aided Design) models between different CAD systems and to downstream applications has become an important industrial requirement. Until recently, national and international CAD data exchange standards, including ISO 10303 (STEP) [1–3], have been limited to transferring geometry. These standards have been incapable of handling the additional design intent information generated by modern CAD systems [4]. Most STEP translators can currently only transfer 'dumb' shape models representing the final result of some constructional process, with all information about that process being lost in the exchange. The essential elements of the lost information include

1. *Construction history*: the procedure used to construct the shape model;
2. *Parameters*: variables associated with dimensional or other values in the model, providing an indication of what it is permissible to change;
3. *Constraints*: relationships between parameter values or between geometric or topological elements of the model, specifying invariant characteristics in the model under editing operations, usually in the interests of maintaining product functionality during modification;
4. *Features*: local shape configurations in the model that have their own semantics.

Development versions of three recently published parts of ISO 10303 were used in the work to be described:

— ISO 10303-55, 'Procedural and hybrid representation' [5] provides for the transfer of construction history information.
— ISO 10303-108, 'Parameterization and constraints for explicit geometric product models' [6] makes possible the capture and transfer of parameter and constraint information, and the representation of 2D sketches.
— ISO 10303-111, 'Elements for the procedural modelling of solid shapes' [7] provides representations for what are commonly known as 'design features'.

These documents are STEP Integrated Resources (IRs). The implementable parts of STEP are called Application Protocols (APs), and are based on specializations of selected integrated resources, as appropriate for the particular application area addressed [2,3]. In the current absence of a STEP AP

* Corresponding author. Tel.: +44 0 1234 721720; fax: +44 0 1234 721720.
E-mail address: mike@lmr.clara.co.uk (M.J. Pratt).

0010-4485/$ - see front matter © 2008 Published by Elsevier Ltd
doi:10.1016/j.cad.2007.06.014

referencing the three documents mentioned above, the experiments reported here used a hypothetical AP constructed from those and other IRs directly, without specialization.

It should be noted that, while this paper is concerned solely with shape models, the basic constraint definitions in Part 108 are very general, allowing specializations that can be used to model constraints of any type applying to any kind of model.

The transfer of design intent information using Parts 55, 108 and 111 of STEP allows the intuitive editing of a model in a receiving system after it has been transferred, as though it had originally been created there. The transferred model is 'intelligent', by contrast with the 'dumb' models resulting from earlier STEP exchanges [8]. In industry, much non-productive time is currently spent by CAD system users in trying to reconstruct the lost design intent in exchanged dumb models.

This paper provides theoretical foundations for model exchange with design intent between modern CAD systems, and uses them to assess the new STEP capabilities. The paper also reports on experience in the development and use of a prototype translator using those new capabilities. The methodology used in the translator development is discussed under several sub-headings:

— *Classification:* A parametric construction history model contains many classes of information. The definition and use of a classification scheme allows us to categorize the types of information present in the model repository of the sending system. The available categories vary between systems. Classification is discussed in Section 3.
— *Structuring:* We introduce the notion of a 'unit of construction'. This will usually correspond to a design feature in the CAD system sense, but in mapping between the sending system, the ISO 10303 exchange file and the receiving system, it may be necessary to include or exclude elements of supporting information for the construction of that feature, depending on how it is defined in those three places. The intention is to match the number of degrees of parametric freedom across both the pre- and post-processing phases of the exchange, and thus to break the overall transfer down into manageable units while avoiding information loss. Structuring is discussed in Section 4.
— *Interoperability:* This concerns the resolution of semantic differences between similar constructs in different CAD systems. It also covers the problem of incompatible numerical tolerances in CAD systems. The achievement of semantic and numerical interoperability will ensure the maximum preservation of model integrity and design intent in the exchange of CAD models. Interoperability is discussed in Section 5.

2. Literature review

Most early work on data exchange of 3D CAD models, whether using formal (IGES, STEP) or *de facto* (DXF, SAT) standards, focused on the final geometry of the model. For example, the STEP application protocol AP203 [9] allows the transfer of boundary representation (B-rep) and closely related types of models, including assemblies of such models. The difference between AP203-based translation and the approach described in this paper is that we can now effectively transfer parameterized families of models, defined in terms of features, dimensions, constraints, and construction history information — in short, the types of geometric model generated by modern CAD systems. This enables the preservation of the design intent in the original model.

An early suggestion for a method of exchanging CAD models in terms of their construction history was made by Hoffmann and Juan [10]. Their EREP (editable representation) was a specification for the representation of sequential feature-based design processes. It supported parameterization and constraints, and was the subject of a trial implementation. Another project aimed at moving beyond the exchange of pure geometric models was the PDES Inc. project ENGEN ('Enabling Next GENeration design') [11]. This used representations based on the STEP methodology [2,3]. It concentrated mainly on the exchange of geometric constraints and demonstrated the exchange of constrained 2D profile data. Bettig and Shah [12] proposed a standard set of geometric constraints for parametric modeling and data exchange. They defined explicit constraints for the relationships between all the geometric entity data types specified in ISO 10303-42, the STEP geometry/topology resource [13]. However, the STEP resource ISO 10303-108 [5,14] focuses on a smaller selection of widely implemented geometric constraints, and provides 'freeform' constraint capabilities that can be used for more specialized cases.

The work described in the present paper is aimed at preserving, as far as is possible, all aspects of design intent including relationships implied by the constructional operations used. The approach described by Rappoport [15], based on the concept of 'feature rewrites', appears to concentrate more on consistency of pure geometry between the original and the received models. One example given by Rappoport [15] concerns the replacement of an extrusion feature created by extruding up to a specified surface by an extrusion having a specified length, with an identical geometric result. This may be satisfactory from the geometric point of view, but it loses the 'design intent' characteristic that was present in the original system, where modification of the specified surface will automatically lead to a consistent modification of the extrusion.

Another approach to the exchange of procedural models, demonstrated at KAIST in Korea, uses the capture and transfer of the journal file created by CAD systems, which contains a record of every action of the system user [16–18]. The KAIST team has defined a non-STEP neutral format for the representation of a common command set, and in [18] has described the use of a 2-level ontology for CAD model exchange, in which the upper-level ontology plays a similar role to the STEP feature definitions used in the present work. A new STEP resource, ISO 10303-112, that allows the exchange of construction history representations of 2D profiles or sketches, has also been developed at KAIST.

ISO 10303-111 ('Elements for the procedural representation of solid shapes') [7,19], provides representations of operations