CAD Services—An Industry Standard Interface for Mechanical CAD Interoperability

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1   ABSTRACT

Most organizations seek to design and develop new products in increasingly shorter time periods. At the same time, increased performance demands require a team-based multidisciplinary design process that may span several organizations. One approach to meet these demands is to use "Geometry Centric" design. In this approach, design engineers team their efforts through one united representation of the design that is usually captured in a CAD system. Standards-based interfaces are critical to provide uniform, simple, distributed services that enable the "Geometry Centric" design approach. This paper describes an industry-wide effort, under the Object Management Group's (OMG) Manufacturing Domain Task Force, to define interfaces that enable the interoperability of CAD, Computer Aided Manufacturing (CAM) and Computer Aided Engineering (CAE) tools. This critical link to enable "Geometry Centric" design is called: Cad Services V1.0. This paper discusses the features of this standard and proposed application.

2   BACKGROUND

Design and engineering of complex systems is increasingly becoming distributed and collaborative. The complexity of modern products also dictates that a single designer or design team can no longer manage the complete product development effort. Driven by such issues, companies are increasingly staffing only their core competencies in-house and depending on other vendors and therefore other tools, to provide the complementary design knowledge and design effort needed for a complete product. Design and engineering tools are no longer merely exchanging geometric data, but interact with other tools to acquire knowledge including analysis, simulation, constraints, and rules. Furthermore, these knowledge exchanges increasingly cross organization boundaries, product line and tool set. The need for interoperability and rapid integration between systems, more than ever, reveals the need for an industry-wide solution for integration and computational frameworks.

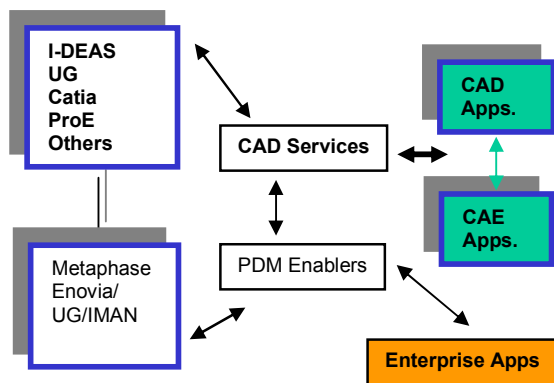Despite these needs, a recent study, ref. 1, conducted for the U.S. auto-industry conservatively, estimates that $1B per year is wasted due to reentering or translating data between CAD systems and downstream applications (such as Computer Aided Engineering—CAE).

There is recognition that well-defined and stable interfaces are essential for achieving rapid interoperability between tools. Integrating dissimilar systems from multiple disciplines, CAD, CAM, CAE, KBE and PDM to name a few, is now one of the primary challenges for integrating product development systems. Industry standards in the areas of distributed computing and domain-specific interfaces are, for now, the only viable solution to enable that kind of interoperability.

3   OVERVIEW

The CAD Services V1.0 interface standard described in this paper is an effort to provide uniform, simple, distributed services that enable a "Geometry Centric" design approach. This new standard would provide uniform interfaces to design geometry and topology features that can be easily and accurately shared among design team members. These high-level interfaces can respond to engineering queries without the need for data translation or low-level data structures. These interfaces can, therefore, shield the design engineer from the full complexity of a CAD system.

Standards benefit both the end-user and vendors community. A primary goal for both user and vendor is to reduce software development, maintenance, and support costs. Vendors can benefit by addressing customer needs in a standards based environment. This should improve the usability of their product while not reducing their core competitive advantages. Users community will benefit from the improved functionality of their software tools and lower integration costs. A customer developing applications for multiple systems must write and maintain one-to-one interfaces for each system. A software vendor may have to address software support and maintenance for multiple platforms, languages and requirements. A standards based interface will ease both of these situations (as seen in figure 1).

Figure 1. Systems link through industry standard services.

CAD Services interfaces map to business requirements in accordance with the Object Management Group's vision of interoperability. This initiative has developed a standard CAD interface that complies with and uses standard CORBA Services and other adopted domain standards.

4   OMG AND CORBA

4.1   Object Management Group (OMG)

OMG is a consortium of vendors, developers and end users with the goal of creating and promoting a standardized object-oriented architectural framework for distributed applications based on distributed object technologies. The OMG objective is to promote and support the development of standard interfaces to object-oriented software components that enable reusability, portability and interoperability in a heterogeneous environment.

4.2   Object Management Architecture

The Object Management Architecture (*OMA*) defines the conceptual infrastructure upon which object-oriented applications and objects are based. The Reference Model identifies and characterizes the components, interfaces, and protocols that compose the OMA. This includes the Object Request Broker (ORB) component that enables clients and objects to communicate in a distributed environment, and four categories of object interfaces:

♦ *Object Services* are interfaces for general services that are likely to be used in any program based on distributed objects.
♦ *Common Facilities* are interfaces for horizontal end-user-oriented facilities applicable to most application domains.
♦ *Domain Interfaces* are application domain-specific interfaces.
♦ *Application Interfaces* are non-standardized application-specific interfaces.

The *Common Object Request Broker Architecture* (*CORBA*) defines the programming interface to the Object Management Architecture. Through a series of RFPs, OMG is populating the OMA with detailed specifications for each component and interface category in the Reference Model.

The wide-scale industry adoption of OMG's OMA provides application developers and users with the means to build interoperable software systems distributed across all major hardware, operating system, and programming language environments. One of these industry wide efforts is under the umbrella of the Manufacturing Domain Task Force (MfgDTF).

4.3   Manufacturing Domain Task Force

The MfgDTF's mission is to foster the emergence of cost effective, timely, commercially available and interoperable manufacturing domain software components through CORBA technology. Its goals include:

♦ Recommend technology for adoption that enables the interoperability and modularity of CORBA based manufacturing domain software components.
♦ Encourage the development and use of CORBA based manufacturing domain software components, thereby growing the object technology market.
♦ Leverage existing OMG specifications. Recommend liaison with other appropriate organizations in support of the preceding goals.

Most of MfgDTF work is done in workgroups, each covering a specific manufacturing domain. The Product and Process Engineering workgroup (PPE) is one of the most active workgroups. This Work Group was chartered by the MfgDTF to develop standardized interfaces for software systems supporting design and analysis of products and the processes and facilities used to make them. The scope of this effort encompasses engineering throughout the product and process lifecycle. CAD Services is one of the active initiatives under the PPE workgroup.

5   CAD SERVICES V 1.0

CAD Services is a CORBA interface standard that was jointly developed by a team of CAD users and vendors. This Object-Oriented interface was designed to allow geometry and topology sharing between members of a design team. The adopted standard has the following features:

1. Geometry and topology queries for both manifold and non-manifold geometries.
2. Parametric regeneration of solid models.
3. Tagging geometric entities with application specific information.
4. Geometry creation.
5. Integration with PDM Enablers V 2.0 standard.

This Cad Services standard provides uniform access the native geometry kernels in Catia, Unigraphics, ProE and a number of other CAD systems. Commercial implementations will be available within the next year. At least one vendor plans to provide an open-source implementation, ref. 2.

6   CAD SERVICES INTERFACE MODEL

CAD Services interfaces are divided into eight different modules with a significant inter-dependency between modules (as illustrated in the figure 2). The first of these modules is the *CadConnection* module that provides standard interfaces to connect with the CAD Services server. *CadConnection* interfaces provide access to *CadMain* module interfaces. *CadMain* interfaces include Model interfaces that provide support for assemblies. The *CadFoundation* module provides primary interfaces that are inherited by geometric entities. It also provides a general Attributable interface that can be used to "tag" geometric entities with application specific information through the use of DynAny local data structures. Basic geometric (tessellation) data structures and interfaces can be found in the *CadGeometry* module. The CadGeometryExtens module provides additional geometric entities that are subtypes of those in CadGeometry. Boundary representations (BREPs) can be found in the *CadBrep* module. *CadBrep* contains interfaces for solid models that are represented through Bodies, Faces, Edges and others. These solid models expose parametric features that allow shape regeneration through interfaces in the *CadFeature* module. Finally, *CadUtility* provides a series of basic data structures used throughout the standard. One of these structures is a *CadError* exception. This exception can be raised by almost all of the CAD Services interfaces. This general exception is needed due to the wide dissimilarity of CAD system implementations and the variability of native CAD API support.

6.1   CadConnection Module

The CadConnection module provides high-level connectivity to the *Model* interface in the *CadMain* module. To reach and connect to the Model, a typical client will interact with both the CadServer and the CadSystem interfaces within the CadConnection Module. *CadServer* is a lightweight interface used primarily to connect with the *CadSystem* interface. It provides two read-only attributes that contain information on the native CAD system and properties needed to activate the underlying native CAD system.

The read-only attributes essentially provide a template that is "filled-in" by the client and passed into a "connect" request that (if correctly applied) returns a reference to the CadSystem interface. This connection
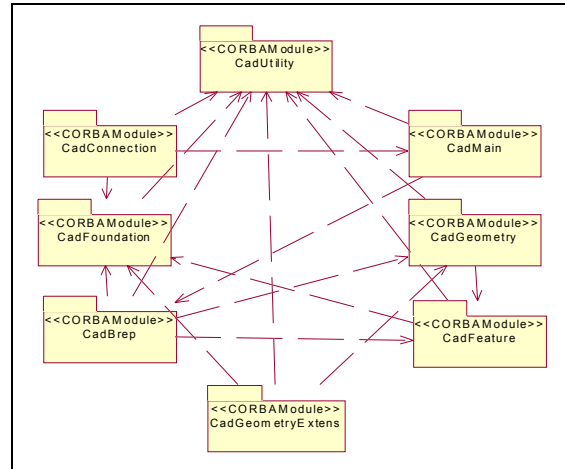

Figure 2. CAD Services V 1.0 module structure.

operation has various security provisions so that user authentication can be performed. The CadSystem interface allows clients to return a list of available Models, access to these Model interface, creation of Models and an optional access to a Graphical User Interface (GUI).

The structure of this module closely follows the approach to be followed in the proposed new PDM Enablers V. 2.0 standard, ref. 5. This commonality allows vendors and implementers to use common authentication policies between the two systems.

6.2   CadMain Module

CadMain interfaces include the *Model* interface that provides the primary access to a wide variety of geometric entities. Specifically, the Model interface supports access to parts and assemblies through operations that identify, if this model contains other Models (ModelInstances). For example, the *CadSystem::available_models()* operation might return a sequence of strings that identifies an assembly file that contains various parts within that assembly. A *CadSystem::open_model* operation on this assembly file would also load the various parts contained within the *Model* and make them available to the client through a *Model::model_children()* operation. The Model interface also provides access to any geometric entities within the model (e.g. Surfaces, faces, etc.). It also provides an operation that creates an EntityFactory that can be used to construct geometric entities within a Model.

6.3   CadFoundation Module

CadFoundation defines general elements and behavior that are shared by all CAD geometry entities. These behaviors are inherited by all geometric entities in the Model through the Entity and the Attributable interfaces. The Attributable interface provides the ability to "tag" a geometric entity is a broad range of

possible data structures through the DnyAny data structure. The DnyAny data structure is very flexible and provides a mechanism for Engineering Applications (as well as others) to "tag" or label the geometric entity with application specific information (e.g. cost, maximum load, other data). The Entity interface provides a series of basic properties that define certain characteristics of the Entity (for example, dimensionality). The CadFoundation module also provides interfaces that support grouping of CAD entities through *Layer* (entities with shared color) or application specific groupings, *EntityGroup.*

6.4   CadGeometry Module

The CadGeometry module contains basic geometric data structures and interfaces that are used throughout the CAD Services interfaces. The two primary interfaces in this module are Surface and Curve. They inherit common functionality through the *CadFoundation::Entity* interface. A common use for either of these interfaces is to establish the exact three-dimensional location of the surface or curve through a point query projection. These operations receive a sequence of three-dimensional point locations and return a sequence of points closest to the particular curve or surface.

6.5   CadBrep Module

The CadBrep module contains Boundary REPresentations (BREPs). BREPs are solid models such as Bodies, Faces, Edges and others. These solid models may expose parametric features that allow shape regeneration through interfaces in the CadFeature module.

6.6   CadFeature Module

The CadFeature Module provides interfaces (through inheritance with CadFoundation::Entity) that enable modification of native CAD entities. These interfaces enable suppression of various design features and a parameter set of expressions or values that define the geometry of the CAD entities. For example, a solid model of a box might have an associated parameter set that uniquely defines the width, length and height of the box. A client application might alter any of these parameters to regenerate the geometry, but would be unable to specify new parameters.

6.7   CadUtility Module

The CadUtilty module is a collection of general-purpose data definitions used throughout the specification. This includes data structures for NURBS surfaces and curves, presentation information and basic geometry types (for example, points, rays, and vectors). No interface definitions are in this module.

6.8   Performance

The primary requirement for CAD Services interfaces is to ensure high-performance data access. Each CAD Services call may involve extensive network connections; therefore, the aggregation of data calls is essential. In other words, data access to geometry and topology information has to be developed using interfaces that provide substantial "chunks" of data as opposed to a series of calls that access data in fine granularity.

A test of the performance differences that can occur with data aggregation was performed on two similar 300 Mhz NT computers using a commercial Object Request Broker (ORB). A chart comparing the transfer of a tessellated surface (message type 1) versus an equivalent series of point queries (message type 2) can be seen in figure 3. The timings display approximately an order-of-magnitude slower data access with the point queries. The tessellated surface information is transferred in only one distributed call. The point queries involved 8100 individual distributed calls. This chart clearly indicates the importance of aggregation to achieve high performance data access.
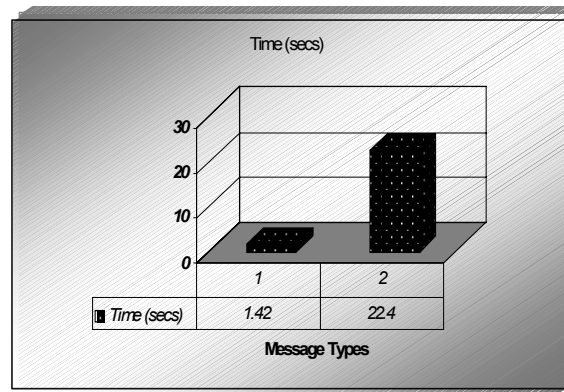

Figure 3. Performance Chart

CAD Services interfaces have been designed to aggregate distributed calls. Most geometric interfaces have been designed to allow a single call to return all relevant properties for that interface.

6.9   Accuracy

The accurate representation of model information to external applications was a key consideration in the CAD Services interface design. Native CAD kernels typically represent geometric entities through analytic curves (such as Non Uniform Rational B Splines, NURBS, ref. 6). This curve is frequently exported to external applications using a tessellation of the bounded surface. The process of creating the tessellated representation can result in an artificially roughen surface especially in regions of high curvature.

The CAD Services interface provides multiple options to reduce or eliminate this source of errors. First, a NURBS representation of the geometric entity can be obtained. Second, the tessellation mechanism provides controls to allow the creation of good curvature approximations. Finally, the geometric surface can be exactly described through a series of point queries that will return the exact three-dimensional location of the surface. External applications are expected to use a combination of these options to obtain an accurate description of the geometric entity.

6.10   Feature-Based Design

A major use for CAD Services is to provide feature-based design linkages between engineering analysis and the CAD representation. This can be achieved by tagging the various CAD system entities with parametric information that provides some geometry regeneration capability. This parametric information can also be used to suppress certain features of the geometry. For example, a small detail that is not needed for flow analysis could be suppressed from the geometry.
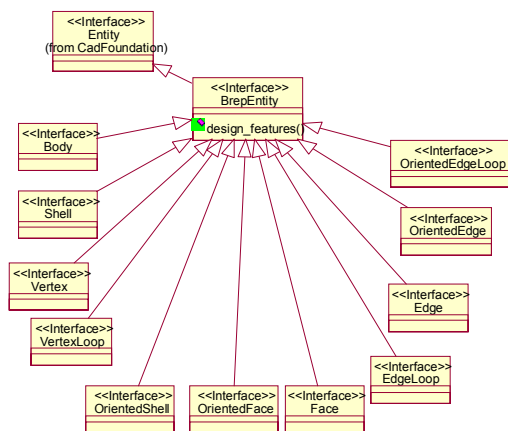

Figure 4. UML diagram of CadBrep Module.

This capability is supported in CAD Services through a BrepEntity interface that is inherited from all Bounded Representations (BREPs) in the CadBrep Module as seen in figure 4. The BrepEntity interface is inherited by all CadBrep interfaces and supports access to design features through a design_features() operation. This operation provides access to a sequence of named parameters that are identified as read-only or modifiable. If these parameters can be modified, a client can change the parameters and regenerate the model through an operation at the Model interface.

6.11   External Application References

The CAD Services V 1.0 provides interfaces that permit the CAD system geometry to be tagged with external application information. For example, cost,

inflow boundary conditions, and other parameters could be attached to relevant geometry entities. This connection to external application data should provide great flexibility to build integrated design systems with external applications providing important design feedback.

This connection can be made through the Attributable interface in the CadFoundation Module. This interface allows a client (user) to associate any data structure with a geometric entity.

6.12   Additional Requirements

CAD Services V 1.0 supports querying capability to obtain high-level engineering data from the CAD system. Clients can query for mass properties including volume, center-of-gravity (CG), principal axes, and moments of inertia.

An additional aspect of CAD Services V 1.0 is the optional support for a Graphic User Interface. Placing an additional interface into the CAD system graphics event loop can be a significant challenge. For this reason, the CAD Services User Interface support is optional. When supported, it provides the ability to select, highlight and tag (with text) geometric entities that are being displayed in the native CAD system. It also provides for user input in the form of a text string.

7   CAD SERVICES APPLICATIONS

To develop CAD Services interfaces a series of engineering Use Cases were examined.

7.1   Computation Fluid Dynamics (CFD)

NASA Glenn has developed a prototype CAD Services implementation applied to CFD grid generation. The approach has been tested for a Reusable Launch Vehicle geometry as shown in figure 5.
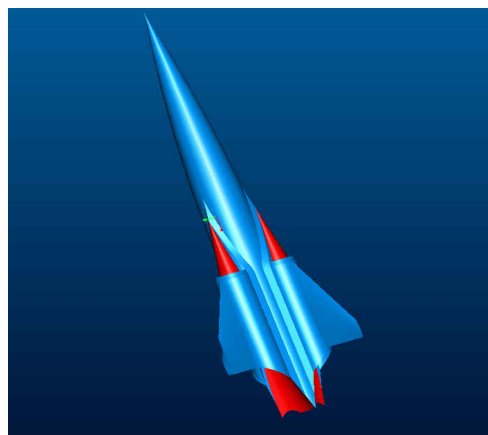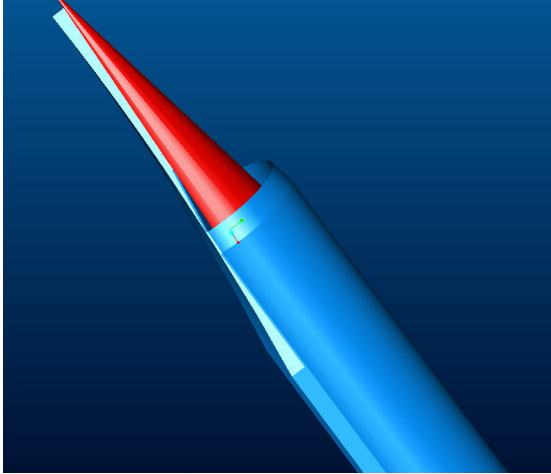

Figure 5. Reusable Launch Vehicle geometry used for demonstration purposes.

This vehicle was modeled using the ProEngineer CAD system. It employed parametric variables that could change the position of an inlet-spike. This inlet-

spike can change the flow capture area to optimize inlet aerodynamic performance over the operating envelope. A close-up view of this inlet is shown in figure 6.

CAD Services interfaces exposed parametric features that permitted automated grid generation for a variety of flow conditions.
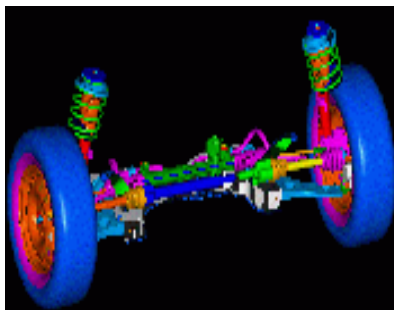

Figure 6. Close-up view of variable-geometry inlet used in the RLV concept.

7.2 Suspension Analysis

At Ford, a CAD Service prototype was developed for suspension analysis. This application requires interaction with a CAD tool to access car platform geometry and the suspension system attributes.

A suspension analysis (figure 7) was developed that simplifies the interaction of a geometry-authoring tool and with analysis enhancements such as distribution and collaboration. This approach proved to be a good fit for other client applications and geometry tools acting as geometry servers.

Figure 7. Illustration of a suspension analysis.

8 CONCLUSIONS

Design and engineering tools are no longer merely exchanging geometric data, but interact with other tools to acquire knowledge including analysis, simulation, constraints, and rules. Furthermore, these exchanges of knowledge increasingly cross organization boundaries, product line and tool set. The need for interoperability and rapid integration between systems, more than ever, reveals the need for domain specific services captured in well defined standard interfaces.

The CAD Services standard defines a stable standard interfaces to CAD tools, which is essential for achieving rapid integration with design, engineering and analysis applications. Ultimately, it should provide a major step toward achieving a CAD "plug-and-play" environment that will enable users of design and engineering systems to seamlessly integrate, best-in-class, software across a wide variety of CAD/CAM and CAE applications.

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