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ROMULUS - A SOLID MODELING EVOLUTION

Abstract

The integration of computer-aided solid modeling technology in engineering is an evolutionary process rather than a revolutionary one. The technology is there, but many of the products available today ignore the engineer's requirements for designing, analyzing and manufacturing a finished product.

This paper discusses ROMULUS, a solid modeling software system from Evans & Sutherland which attempts to address the engineer's needs by providing engineering tools in a system which expands the engineer's creativity.

The key features of the ROMULUS system are discussed. Then a summary is given of the applications for which ROMULUS is currently being used, the interfaces available, the customer base, and pricing.

INTRODUCTION

The topic of this conference is the revolution of integrating computer-aided solid modeling technology into engineering design. At Evans & Sutherland, our position is that this is still a process of evolution, not revolution.

The technology needed for that revolution to take place already exists. Computer graphics systems are now able to perform the complex equations needed to calculate surfaces, volumes, curvatures and so on, and to create and display a mathematical model of a solid object. The problem is that few solid-modeling systems available today are designed to meet an engineer's needs. At E&S, the engineer has been as important a focus of our research as computer hardware and software have been. We have been engaged in computer-aided modeling for over 16 years. Our hardware products range from interactive, high-performance graphics workstations to the world's most advanced visual systems for pilot training and simulation. The evolution of our research and development in computer-aided systems has brought a solid modeling software system called ROMULUS to the market.

The ROMULUS system, developed by Shape Data Ltd., a wholly owned subsidiary of Evans & Sutherland, is a design tool for engineers. Like other modeling systems, ROMULUS provides tools for building and modifying, manipulating and interrogating solid models. Unlike other systems, ROMULUS does not stop there. This system is so flexibile in its approach to modeling that it truly extends a designer's creativity, and does not limit him to a single design methodology. ROMULUS can be programmed to any level of complexity. As the engineer evolves, using the power of the computer to extend his creativity, ROMULUS evolves with him.

This paper discusses the key features of ROMULUS which make it a useful and usable system for design engineers.

KEY FEATURES

The features of the ROMULUS system that give an engineer the flexibility to design solid objects in his own way are:

- Variety of building techniques that can be used
- Fast and easy modification to existing models
- Attachment of attributes to a model to capture more information than just the model's shape
- Multiple levels of programmability to suit users of any degree of sophistication
- Flexible interfacing to other systems
- Ease of use.

Variety of Building Techniques

Users of ROMULUS are not restricted to one or two modeling approaches. ROMULUS provides the engineer with the much needed flexibility of creating a design in any of several industry-accepted ways: sweeping profiles about an arbitrary axis, sweeping faces in arbitrary directions, and connecting points in 3D space with edges to define new faces or solids. The designer may also specify parametric primitives including cubes, blocks, cylinders, prisms, cones and tori.

ROMULUS also performs Boolean operations of uniting, subtracting and intersection given any 2D sheet or 3D solid. Parts can also be created by sectioning with planes, cylinders and arbitrary profiles.

Model Modification

ROMULUS provides tools for fast, easy modifications to a model, so that an existing design can be used to create a new one. One of the most powerful tools is the ability to perform local modifications ("tweaking") through "feature manipulations". With ROMULUS, features are regions of interest on a solid model such as a boss, depression, or through-hole which can be named and referred to by name. Once features are defined, it is an easy matter to alter them in a model to produce a new design. A boss can be moved, a series of holes can be rotated to fit a new design, or a feature can be removed entirely, for example. Modeled geometry can be further modified by picking points on profiles or edges on solids which require chamfering or blending.

Attachment of Attributes

Since engineers are utlimately involved with products not shapes, there is a need for non-geometric data to be associated with a solid.

Information such as surface finish, sheet thickness, threads, part numbers, color, and so on are essential aspects of the final product that must be maintained in the computer's definition of an object.

ROMULUS allows you to capture non-geometric information as "attributes" of a model. This data is stored in the same structure as the model's geometry. Attributes can be associated with bodies and the elements of bodies, both topological and geometrical. With user-defined attributes in ROMULUS, data for other applications no longer needs to be conveyed on a separate data sheet, in a drawing, in a file, or worse still, by word of mouth.

Programmability

Programmability in ROMULUS means two things: first, the ability to use at any level of programming sophistication; second, the ability to extend ROMULUS with user-written code. Engineers with little programming experience can run ROMULUS as a "naive user" from a well-designed set of menu selections. Users with more programming experience can program the system in a more sophisticated manner. In addition, the current ROMULUS command set can be extended to integrate user defined functionality into the program. This is done on various levels ranging from defining a simple macro command to writing code to be compiled and linked with the modeling software.

Flexible Interfacing

Many users of solid modeling systems already have large software packages that incorporate valuable knowledge about their design, analysis, and manufacturing techniques. It is most likely that they will want to retain these systems and make them work with new modeling software.

ROMULUS provides 5 main avenues of interfacing, yielding required flexibility to the engineer.

1. IGES
2. Neutral file
3. Command file
4. Programmer Interface
5. Kernel Interface

ROMULUS also provides links in the form of interfaces to several external systems for doing finite element modeling (FEM), NC programming, kinematics analysis and documentation. Some of these programs include Patran, GNC, and CADAM. ROMULUS also supports an IGES transfer of three-dimensional wireframe data from ROMULUS to other systems.

Ease of Use

ROMULUS provides a friendly, interactive user interface with extensive user-prompting and help facilities. Input is provided through keyboard, menu, data tablet, or mouse. With its multiple level prompting and message output capabilities, ROMULUS can easily be used by both experienced users and novices.

The ROMULUS user interface offers a flexibility to the engineer which enhances his creativity. He can approach model building in various ways and can modify existing models with ease. The ROMULUS interactive user environment is best exemplified with Evans & Sutherlands PS 330 graphics system. The PS 330/ROMULUS combination is a unique partnership between high-performance interactive computer graphics and 3-dimensional solid modeling.

The interactive features of ROMULUS on the PS 330 include dynamic menuing and local viewing operations for 3-dimensional rotation, translation, zooming, clipping plane manipulation, going from perspective to orthographic views automatically, depth cueing, display toggling and user definable, recallable views.

The ROMULUS user interface consists of a set of high level modeling commands. The user communicates with ROMULUS by issuing one of the ROMULUS commands and supplying data for that command such as keywords, names and numerical information. There are approximately 80 commands in the ROMULUS system and a high level Macro Command Language (MCL) to give the user added modeling, interrogation and programming capabilities.

ROMULUS has the full range of facilities needed to archive and retrieve files. Each ROMULUS session produces a journal file of the commands used during the session. These files can also be read into ROMULUS again to recover from errors or computer malfunctions.

DATA REPRESENTATION

The key to the flexibility of ROMULUS is the way in which data is stored in a "data structure". The nature of the ROMULUS data structure allows a variety of modeling approaches and operations, and permits the programmability of the system.

There are two basic features of the data structure.

First the structure allows access to all data, geometric and non-geometric, associated with the model.

This access is fast and does not entail lengthy scanning of the structure. It is possible to begin anywhere in the structure, at a vertex for example, and navigate to any other stored entity such as the geometry of the curve on which the geometry of the vertex (point) lies. The structure can be traversed forward and backward to find owner and ownee relationships as well as geometric information.

Second, the structure is dynamic. It grows and shrinks as parts are modeled, and allows expansion of data content and the addition of user defined attributes.

The internal model database structure of ROMULUS allows models to be held as collections of assemblies, subassemblies and single components. This allows interference detections and other like operations between assembled bodies to be performed.

PRECISION

The reason ROMULUS is successful in providing advanced engineering capabilities is its precise boundary model representation. Using this precise geometric approach, every topological entity (face, edge and vertex) of the final object is represented together with the geometry (surface, curve and point). The combination of geometry and topology define the model unambiguously.

Entities of a ROMULUS model are represented in pure analytic form when possible. Surfaces are not approximated by planar facets. Every entity is represented explicitly, facilitating the attachment of attributes to the entities themselves and the modification of individual model elements.

APPLICATIONS

ROMULUS is currently being used in a number of application areas. Most of these are in engineering design, where ROMULUS is used as a design tool and model building system. ROMULUS provides a comprehensive, unambiguous database for the design cycle and can provide this data to other application areas in manufacturing.

We have customers using ROMULUS in robotics cell design and programming and packaging, which requires fitting a number of electromechanical components inside a confined area or putting a package around a set of components. The interference checking in ROMULUS is used extensively in these engineering application areas.

ROMULUS is also being used in tool, die and mold design. ROMULUS has direct application in these areas by generating draft angles and by providing the data required for NC machining.

ROMULUS supports sheet objects and provides tools for sheet metal applications. The user can bend and unbend models and perform Boolean operations with sheet metal objects.

One of the direct applications of ROMULUS is the automatic generation of mass properties. ROMULUS calculates volume, moments of inertia, direction of principle axis and radius of gyration. Surface properties may also be obtained.

USERS & CUSTOMERS

Present users of the ROMULUS system include some of the largest aerospace and automotive companies in the United States and abroad. Our customers range from the end-user to full system integrators. Some choose to use our supplied user interface and associated application interfaces. Others, such as large industrial and commercial system builders, use their own methods of modeling and design.

One of our industrial users is the Caterpillar Tractor Company, which is represented at this conference today. ROMULUS is also in a number of universities, where it is used for research and for educational programs. The institutions include Brigham Young University, University of Utah, Colorado State University, Purdue University and the United States Naval Academy. There are approximately 100 sites using the ROMULUS system worldwide. ROMULUS is sold abroad by agents in Europe, Japan, Australia, Israel and Italy.

SUPPORTED HARDWARE & CONFIGURATIONS

The ROMULUS Design System is supported on various hardware configurations including Apollo Domain, running Aegis, DEC VAX running VMS and UNIX and IBM 4300 and 3000 series mainframes running both IBM operating systems MVS and VM/CMS.

ROMULUS supports various display types on the computers previously mentioned; the Evans & Sutherland PS 330 high performance graphics system on Apollo, DEC and IBM and Tektronix 4014 and emulators on the same CPU's. ROMULUS supports Apollo graphics systems and can also run non-graphically.

There is no quantitative restriction on the number of points, edges, faces or bodies in a ROMULUS model. The dimensions and detailed information associated with a ROMULUS model are only limited by the virtual memory size of the host computer on which it runs.

PRICING

ROMULUS software is normally available as executable code but can also be supplied in a programmable package which will allow the end-user to integrate his own local systems and interfaces into the ROMULUS modeler. The programmable version of ROMULUS also allows the user to extend the ROMULUS modeling package by adding his own commands and data structure attributes. The full ROMULUS model structure can be interrogated by the ROMULUS user at any time.

The cost of the ROMULUS system depends on the hardware that ROMULUS is to run on and the type of software license. Licenses start at $30,000 for a perpetual end-user license and can extend up to $100,000. Yearly support fees range between $7,000 - $12,000.

FUTURE

A large team of computer scientists, mathematicians and engineers are continually working on the evolution of ROMULUS and other computer-aided engineering software. Some development areas include NC, FEM, Dimensioning, Tolerancing and Drafting, Surface, Database Management, and User Interfaces. A system called ROMAPT deals with the semi-automatic generation of APT geometry and motion statements along with other needed NC data from within the ROMULUS system. Another current development area includes dimensioning and tolerancing of 3D solid objects and the automatic production of fully dimensioned and annotated engineering ANSI or DIN standard drawings. The blending and sculpting of complex surfaces and integration of these surfaces into the ROMULUS geometric modeler is another development area.

CONCLUSION

The introduction of solid modeling systems into design engineering has been an evolutionary process. The revolution will not occur until system designers create solid modelers that truly meet an engineer's needs in the real world. ROMULUS is such a system. Since 1978, it has been tested, benchmarked and used. It has evolved with the industry to meet industry requirements. We think of it as the standard by which other systems should be measured.

ABOUT THE AUTHOR

Kevin H. Auger is a ROMULUS Product Specialist in the newly formed ROMULUS Product Support Group in the Interactive Systems division of Evans & Sutherland Computer Corporation, Salt Lake City, Utah.

Auger specializes in the area of solid modeling as it relates to manufacturing and design processes.

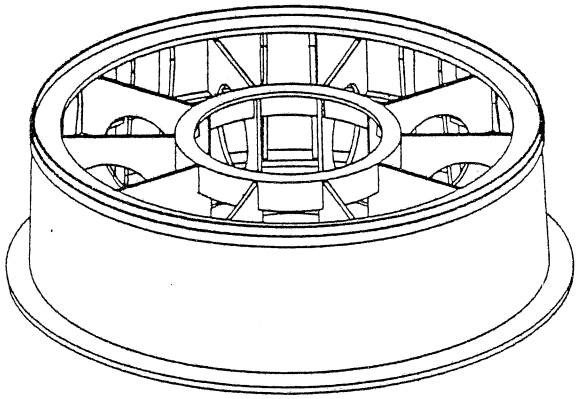
Auger has been with Evans & Sutherland for 4 years, working with the ROMULUS Solid Modeling System. He has functioned in various departments including Research & Development and Marketing/Sales performing many ROMULUS tasks such as software development and competitive analysis of CAE systems. Prior to employment at E&S, he had two years experience working with CAD/CAM systems.

Some of Auger's current ROMULUS responsibilities include directing product development, providing technical support and investigating solid modeling application areas.

Auger received his BS in Engineering Design and Computer Graphics from Brigham Young University in Provo, Utah in 1978.

ROMULUS

ROMULUS is a *Solid Geometric Modeling System* which builds and maintains *Solid Models* and which provides engineering tools that expand the engineer's creativity.



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ROMULUS Key Features

Variety of Building Techniques

Fast and Easy Modifications

Attachment of Attributes

Multiple Levels of Programmability

Flexible Interfacing

Ease of Use

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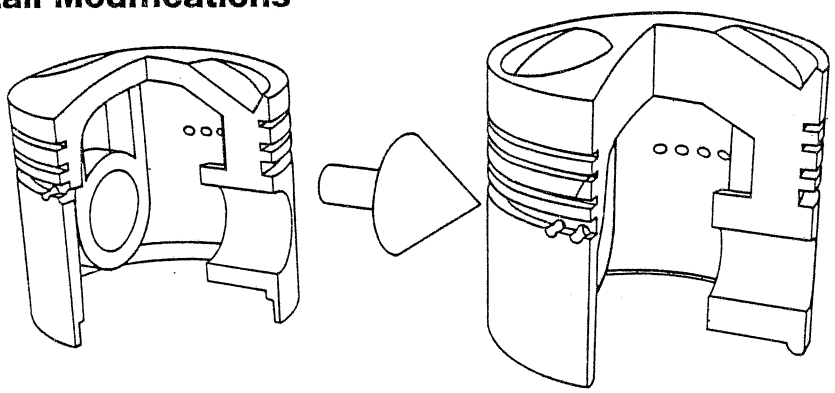
Model Building

Simple Elements

Combination of Elements

Detail Modifications



Building Techniques

Boolean Operations —
Union, Difference, Intersection

Sweeping —
Translational or Rotational

Tweaking —
Operations on Geometry, Not Affecting Topology

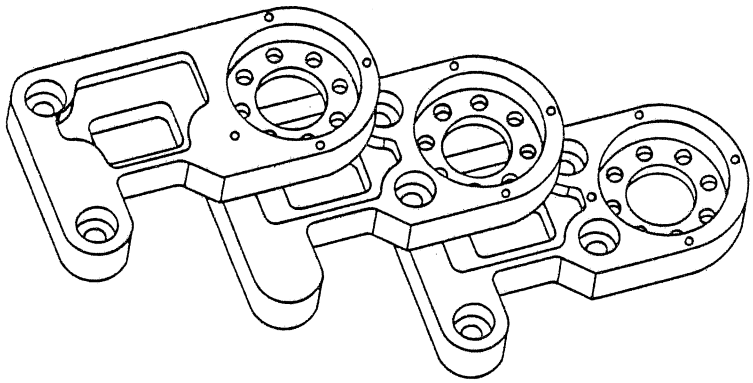
Edge Based —
3D Model Building by Adding Edges Individually

Sectioning —
Carving solids by Sectioning with Planar, Cylindrical, or arbitrary shapes

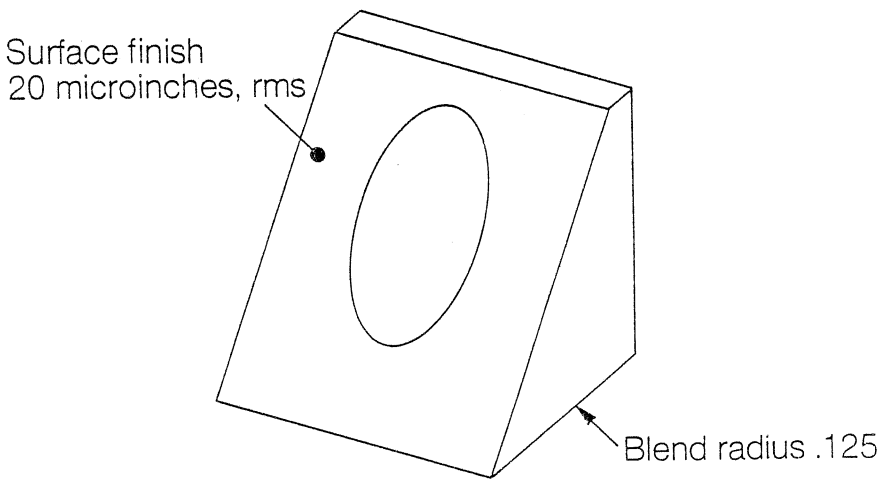
Features

Identification of Useful Features (Boss, Pocket, Etc.)

Translations, Rotation, Removal and Copying of Features

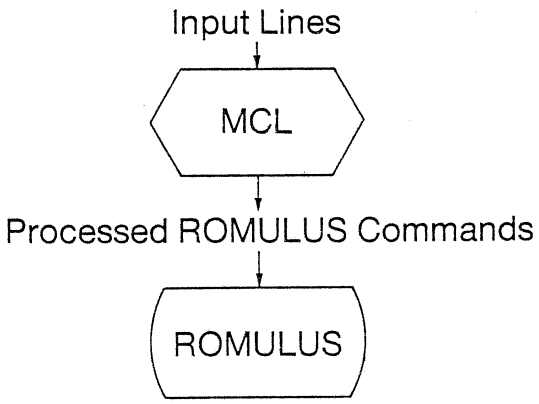


Attributes



MACRO COMMAND LANGUAGE (MCL)

MCL—a simple programming language designed to provide *expression analysis* and *control structures* for the ROMULUS modeler.



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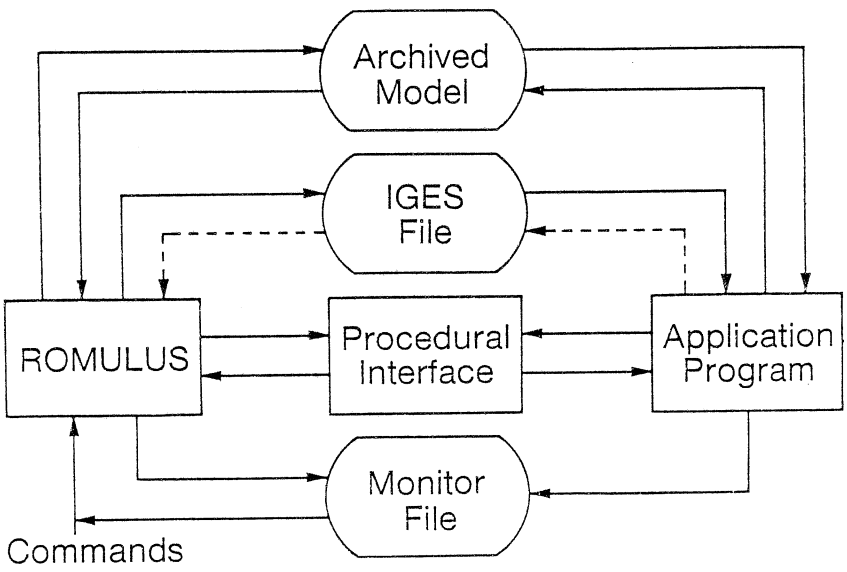
Interfacing



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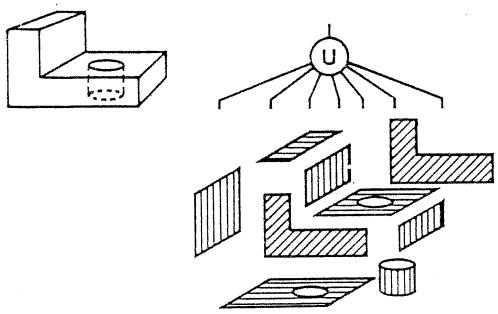
ROMULUS Applications

Engineering Design
Mass Property Calculations
Interference Checking
Tool, Die and Mold design
Numerical Control
Finite Element Modeling
Robotics
Kinematics
Packaging

ROMULUS Data Representation

A ROMULUS model is represented as the sum of all bounding, oriented surfaces.



Precise Boundary Representation

Supported Computer and Operating Systems:

Manufacturer	Model	Operating System
Apollo	DN320 DN460 DN660	Aegis
DEC	VAX 11/730 11/750 11/780	VMS

Supported Display Types:

Manufacturer	Model
Evans & Sutherland	PS330
Tektronix	4010 and 4014 and emulators
Apollo	DN320 DN460 DN660