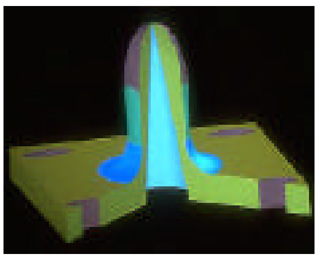
Jarek Rossignac's research accomplishments

A selected subset of my research contributions is presented below, organized into several primary areas. Although I have initiated these projects and invented or co-invented the underlying technologies, much of this work would not have been possible without the involvement of my collaborators (colleagues, students, and PostDocs). I will refer to them in the text to stress my advisory responsibility over students and PostDocs. Their contributions as co-authors are acknowledged in the enclosed references.

Constructive Solid Geometry (CSG) formulations and algorithms

The objective of this research area was to improve the efficiency, reliability, and power of CSG (a core technology for solid modeling). Advances were made both at the algorithmic level and at the theoretical level, introducing new concepts and methodologies.



Solid models (i.e., computer representations of the shapes of physical objects) are often specified by combining simpler shapes through Boolean operations that mimic material removal (Boolean difference), addition (union), and restriction (intersection). Such set-theoretic combinations may be represented by a binary tree or rooted graph whose leaves correspond to *primitives* (blocks, spheres, cylinders, cones) and whose internal nodes are Boolean operators or linear space transformations. These Constructive Solid Geometry (CSG) representations are suitable for editing and parameterization, because they conveniently mimic important design and manufacturing operations. Unfortunately, the conversion of these CSG recipes into explicit shape representations or their direct display involve complex and time-consuming processes. To make these processes simpler and more efficient, I have analyzed the contribution to the final shape of an individual CSG primitive. This insight was precisely formulated in my influential paper on **Active Zones**, which has lead to a generation of simpler and more efficient approaches to the design, editing, evaluation, and rendering of CSG models. The paper is widely cited and contains a thorough analysis of CSG properties and algorithms.

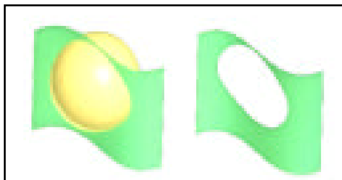
"Active Zones in CSG for Accelerating Boundary Evaluation, Redundancy Elimination, Interference Detection and Shading Algorithms", J. Rossignac and H. Voelcker, ***ACM Transactions on Graphics****, Vol. 8, pp. 51-87, 1989.*

The application of active zones to **feature-based editing in CSG** has received the **Best Paper Award from Computers&Graphics.** In this study, I explain how a set of faces or a volumetric feature of a CSG model should be represented, so that the feature may be restored in an edited version of the CSG models, where the dimensions and position of primitives, or even the CSG graph, may have been altered.

"Issues on feature-based editing and interrogation of solid models", J.R. Rossignac. ***Computers&Graphics****, Vol. 14, No. 2, pp. 149-172, 1990.*

A face of a solid is usually represented by a supporting surface and a set of *trimming edges*. The computation of these trimming edges from a CSG representation of the solid is expensive and numerically unstable. With PhD student Raja Banerjee, I have developed a very simple algorithm that is free from numeric round-off errors for generating the polyhedral representation of a CSG model with planar half-spaces as primitives. Intersections of such planar half-spaces are often used to approximate simple primitives. The approach is based on the reduction of all geometric tests to the evaluation of the sign of a 4x4 determinant, which may be done reliably and efficiently using fixed precision arithmetic. This error-free approach handles all possible geometric and numeric singularities.

"Topologically exact evaluation of polyhedra defined in CSG with loose primitives", R. Banerjee and J. Rossignac, ***Computer Graphics Forum****, Vol. 15, No. 4, pp. 205-217, 1996.*



When curved surfaces are involved, trimming edges are usually approximated through a computationally expensive and error-prone process. To fully eliminate the need for this computation, I have introduced the notion of a *trimming volume,* which defines a face as the part of the supporting surface that it contains. I have provided simple expressions for such volumes and algorithms to derive such expressions from CSG representations, even when they involved singular situations, where primitives have coincident boundaries.

"CSG formulations for identifying and for trimming faces of CSG models", J. Rossignac. CSG'96: Set-theoretic solid modeling techniques and applications, Information Geometers, Ed. John Woodwark. 1996.

A typical way to evaluate a Boolean expression is to recursively merge the evaluation results of the arguments of each Boolean operator. This process requires a stack whose size is proportional to the height of the CSG tree that represents the Boolean expression—a prohibitive cost for graphics, where primitives are scan-converted one at a time and thus a stack must be maintained at each pixel. I have devised a linear formulations of arbitrary Boolean expressions that can be evaluated using storage proportional to the log(log(N)), where N is the number of literals (primitive instances) in the CSG expression. I expect this discovery to have consequences beyond solid modeling.

"Blist: A Boolean list formulation of CSG trees", J. Rossignac. Technical Report, GIT-GVU-99-04. October 98.

Procedural models for parametric shapes

The objective of this research area was to facilitate the design of complex solid models.

When closely inspected, the simplest shapes, such as a pen or cell phone, have intricate surface features or complex internal structures. This complexity makes it expensive to design computer models of such parts using CSG primitives. Designers need high-level design operations, which automatically create the desired shape features and adjust their parameters to the user constraints. I have made possible and practical to use geometric **constraints** in the CSG design paradigm. I have proposed and demonstrated an approach, where the dimension and position of groups of curved primitives would be specified in terms of contacts or distances. I have provided techniques for computing minimum translations and rotations that achieve these contacts or distance constraints for planes, spheres, cylinders, and cones. I have also shown that often these constraints may be satisfied without invalidating previously satisfied constraints, thus avoiding the need for a general solver for systems of simultaneous non-linear equations. This approach has been **incorporated in the GDP solid modeler, developed by IBM**.

"Constraints in Constructive Solid Geometry", J. Rossignac, Proc. ***ACM Workshop on Interactive 3D Graphics,*** *ACM Press, pp. 93-110, Chapel Hill, 1986.*

I have generalized the CSG representation and developed a **procedural representation** for shapes, which capture a sequence of parameterized operations that create, identify, and measure features. The parameters of new constraints or operations are defined in terms of such measures. Each expression, that either measures a feature or defines a parameter is evaluated in the current context, which includes the CSG and boundary representations of the current shape and all previously defined variables (scalars, points, vectors, coordinate systems).

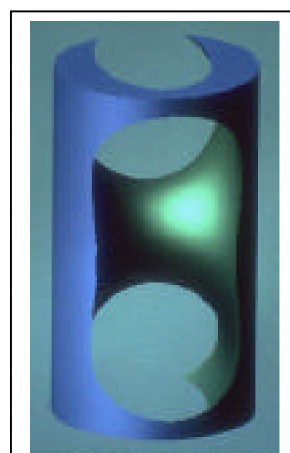
"Interactive Design with Sequences of Parameterized Transformations," J. Rossignac, P. Borrel, and L. Nackman, Proc. 2nd ***Eurographics Workshop on Intelligent CAD Systems: Implementation Issues****, April 11-15, Veldhoven, The Netherlands, pp. 95-127, 1988.*

"Procedural Models for Design and Fabrication," J. Rossignac, P. Borrel, and L. Nackman, in Automation in the Design and Manufacture of Large Marine Systems, Ed. C. Chrissostomidis, pp. 147-175, Hemisphere Publishing Co., 1990. Proc. of ***the MIT Sea Grant Symposium****, Boston, October 1988.*

To further increase the complexity of 3D models that may be easily designed by humans, I have developed, with PostDocs van Emmerik and Rappoport, a multi-view graphic editor of 3D assemblies, which makes it easy to create and edit hierarchical **patterns specified** by setting **iteration or recursion** parameters. This design front-end was interfaced to the CATIA solid modeler developed by Dassault Systemes, thus making it possible to design highly complex models in minutes, rather than days.

"Simplifying interactive design of solid models: A hypertext approach," M. van Emmerik, A. Rappoport, and J. Rossignac. ***The Visual Computer,*** *vol. 9, No. 5, pp. 239-254, March 1993.*

Direct display of CSG models

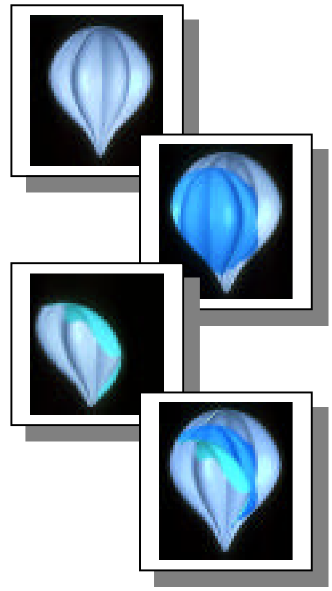


The objective of this research area was to accelerate the rendering of CSG models by exploiting the capabilities of graphics hardware.

CSG models may be displayed through ray-casting (which amounts to intersecting each ray with all the primitives and combining the resulting intervals along the ray) or through boundary evaluation (which amounts to the computation and topological organization of the edges and vertices that are intersections of pairs and triplets of surfaces). Both techniques are time consuming, and thus ill-suited for providing graphic feedback during editing. I have developed several direct techniques for **rendering CSG models** using a **z-buffer** (also called depth-buffer). The simplest one uses a software rendering system to sample points on the boundary primitives and to classify them against possibly occluding points (depth test) and also against their active zones in the CSG representation (point-in-primitive tests and evaluation of a Boolean expression).

"Depth Buffering Display Techniques for Constructive Solid Geometry", J. Rossignac and A. Requicha, ***IEEE Computer Graphics&Applications,*** *Vol. 6, pp. 29-39, 1986.*

The above technique requires processing each sample point in software. To benefit from graphics hardware possibilities, I have developed the concept of a **Depth-Interval Buffer** (which stores two depth values



per pixel) and have devised a technique for producing correct images of CSG models by processing, one at a time, the products of the disjunctive form of the Boolean expression. This new approach replaces the software point-in-primitive tests, which were restricting the previous approach to algebraic primitives, with a series of depth-tests that may be implemented in parallel for all the pixels of a graphic adapter. It permits to display Boolean combinations of sculptured objects.

> *"Correct Shading of Regularized CSG solids using a Depth-Interval Buffer", J. Rossignac and J. Wu. In Advances in Computer Graphics Hardware V, Eds. R.L. Grimsdale and A. Kaufman, Springer Verlag, pp. 117-138, 1992. Proc of the* ***Eurographics Workshop on Graphics Hardware.***

To avoid the generation and storage of the **disjunctive form**, I have developed an elegant, inline algorithm that processes the products one by one directly from the CSG tree.

> *"Processing Disjunctive forms directly from CSG graphs", J. Rossignac, in the proceedings of* ***CSG 94: Set-theoretic Solid Modelling Techniques and Applications****, Information Geometers, pp. 55-70, Winchester, UK, April 1994.*

Depth-Interval Buffers were not supported by standard graphics architectures. I have generalized this concept to a programmable frame-buffer, where operations on pixel memory could be programmed dynamically and executed efficiently.

> *"M-Buffer: A flexible MISD Architecture for Advanced Graphics" B.O. Schneider and J. Rossignac. Proc. 7th* ***Eurographics Workshop on Computer Graphics Hardware,*** *Cambridge, UK, September 1992.*

These techniques use hardware-supported scan-conversion to perform point-inclusion tests in parallel on all the pixels through depth comparison. They assume that the graphics calculations are free from numerical errors. I have devised an approach that eliminates such errors.

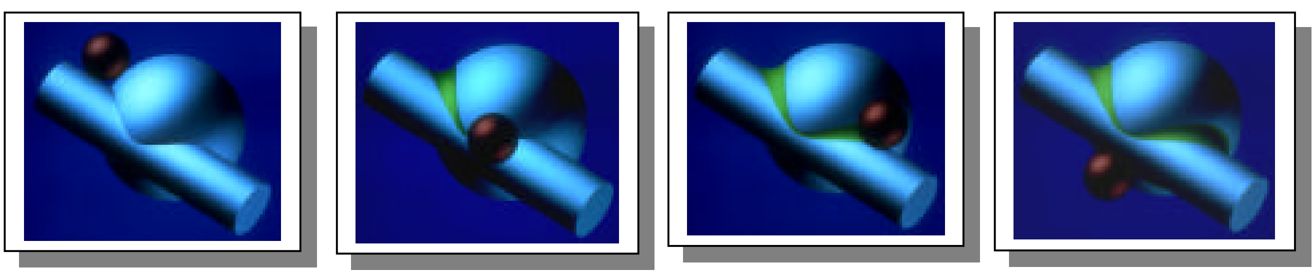
> *"Accurate scan-conversion of triangulated surfaces" J. Rossignac. In Advances in Computer Graphics Hardware VI, Ed. A. Kaufman, Springer Verlag, Berlin. Proc. of the 6th* ***Eurographics Workshop on Computer Graphics Hardware****, Vienna, September 1991.*

Growing and shrinking operators in CSG

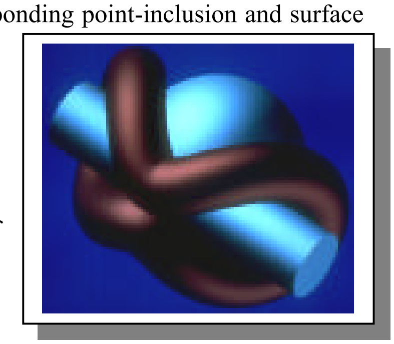
The objective of this area was to expand the capabilities of CSG solid modelers to support set-theoretical blending and offsetting operations.

Most man-made parts contain blends that provide smooth transitions between faces. Such blends cannot in general be designed with CSG operators. I have formulated such 3D **blending** operators in terms of solid **growing** and **shrinking** operations.

> *"Constant-Radius Blending in Solid Modeling", J. Rossignac and A. Requicha,* ***ASME Computers In Mechanical Engineering*** *(CIME), Vol. 3, pp. 65-73, 1984.*



I have studied the support of these operations in CSG and have developed the corresponding point-inclusion and surface generation algorithms.



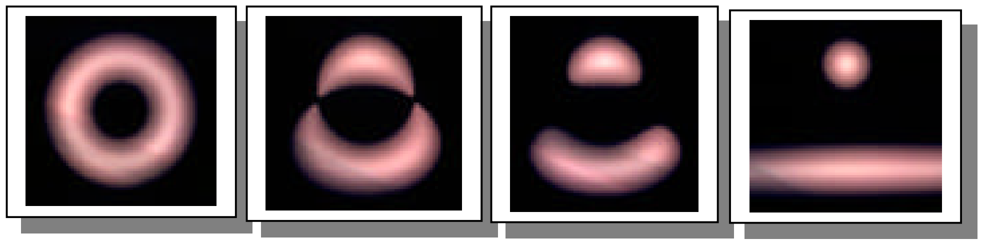
> *"Offsetting Operations in Solid Modelling", J. Rossignac and A. Requicha,* ***Computer-Aided Geometric Design****, Vol. 3, pp. 129-148, 1986.*

In particular, I had to develop a new approach to the computation of surface-surface intersections, because the growing and shrinking operations create canal surfaces (offsets of curves), which must be supported and processed by the modeler. I have devised an efficient technique for computing **piecewise-circular approximations** of the intersections of CSG surfaces and of piecewise-toroidal approximations of canal surfaces. The offsets of these piecewise-circular 3D curves are smooth piecewise-toroidal approximations of canal surfaces. I have expressed the vertices of the resulting shapes and the sample points of the approximating curves as the **intersections** of lines or circles with planes, spheres, cylinders, cones, and tori. My approach has been **adopted in a solid modeling product developed by Unigraphics** for the aerospace and automotive industry.

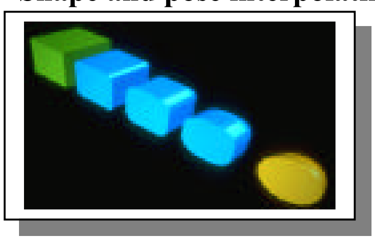
"Piecewise-Circular Curves for Geometric Modeling," J. Rossignac and A. Requicha, ***IBM Journal of Research and Development****, Vol. 13, pp. 296-313, 1987.*

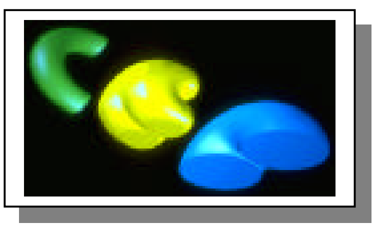
I was able to formulate these intersections as the roots of quartic polynomials. The **closed-form solutions to quartic equations** that were available in the literature were fast, but numerically unstable. I have guided the development of a numerically stable closed form solution to the computation of the roots of quartic polynomials. Its robustness was demonstrated by ray-casting on a family of quartic surfaces, generated as weighted combinations of implicit forms.

"Quartics: Robust Root Finding and Applications to Geometric Modeling," S. Lodha. IBM Research Report, November, 1990.



Shape and pose interpolating animations

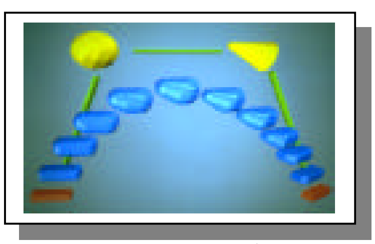


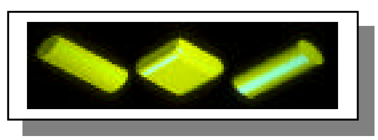


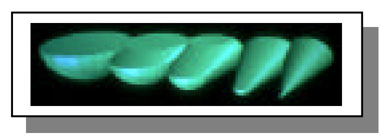
The objective of this area was to facilitate the design and visualization of shape and pose interpolations.

Boolean operations cannot create new surface types. With PhD student A. Kaul, I have invented a technique for blending two 3D objects through convex Minkowski combinations. Given two objects A and B, a parametric model is computed automatically as (1-t)A+tB, where "+" denotes a Minkowski sum. It may be used interactively to animate in realtime the morph between A and B or to select how much of the shape characteristic of A and of B should be reflected in the final object. For its applications to the automatic animations of the **3D morphing** between arbitrary shapes and for its value in the blending of 3D shapes during design, this work has received the prestigious **Gunter Enderle Best Paper Award** at the Eurographics Conference.

"Solid-Interpolating Deformations: Construction and Animation of PIPs", A. Kaul and J. Rossignac, ***Computers&Graphics****, Vol. 16, No. 1, pp. 107-115, 1992.*





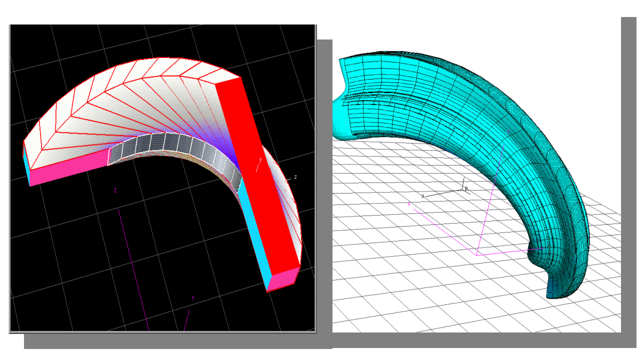


I have further expanded this approach to convex combinations of more than two shapes and have demonstrated its power by creating Bezier curves in the space of polyhedra. These curves represent parameterized 3D shapes that start as the initial input shape, finish as the final input shape, but are influenced by a sequence of intermediate control shapes.

"AGRELs and BIPs: Metamorphosis as a Bezier curve in the space of polyhedra", Jarek Rossignac and Anil Kaul, Proc. Eurographics'94, Oslo, Norway, ***Computer Graphics Forum****, Vol 13, No 3, pp. C179-C184, Sept 1994.*

To provide additional support for animation design, I have developed, a very simple technique for computing and adjusting **minimal motions** between arbitrary key-poses and for quickly displaying the **volume swept** by the moving object.

"Computing and visualizing pose-interpolating 3-D motions", J. Rossignac and J. Kim, To appear in Computer-Aided Design. 2000. (Collaboration with the Hanyang University in Korea.)



Topological extensions to solid modeling

The objective of this research area was to enable CSG and non-CSG modelers to support a broader domain of geometric structures.

The design and modeling techniques discussed so far may produce representations of solids or of assemblies of solids. They are insufficient to capture the internal structure of the solids, the contacts and overlaps between solids, or the geometric structures that combine entities of mixed dimensions (points, curves, sheets, volumes, hyper-volumes). To overcome this initial limitation of the solid modeling technology, I have developed the concept of **Selective Geometric Complexes** (SGC), which provide a simple and general framework for representing mixed-dimensional structures that are produced by the interaction of a set of overlapping entities. Basically, these entities partition the n-dimensional space into cells (vertices, edges, faces, volumes, and so on). I have developed mathematically rigorous definitions and simple representations of cells that are more general than the cells of simplicial complexes or CW complexes and that are a natural extension of the concepts of faces and volumes used in solid modeling. I have also proposed a set of algorithms for the subdivision, selection, and simplification operators. I have shown how to combine these operators to easily define CSG operators, their non-regularized extensions, and a set of new topological operators that could not be supported by existing technologies. The SGC work is broadly recognized as a decisive step in the extension of solid modeling technology to mixed-dimensional models. **It has inspired a generation of new systems in academia** (MIT, Brazil) **and in industry** (EccoCAD, Dassault Systemes).

*"SGC: A Dimension-Independent Model for Pointsets with Internal Structures and Incomplete Boundaries", J. Rossignac and M. O'Connor, in Geometric Modeling for Product Engineering, Eds. M. Wosny, J. Turner, K. Preiss, North-Holland, pp. 145-180, Proceedings of the **IFIP Workshop on CAD/CAM**, 1989.*

The SGC model is an explicit representation of a subdivision of space, whose elements may be selected and grouped into features. In order to support a representation of the recipe for defining the SGC and the associated features, I have extended the concept of CSG to support SGC operations and a variety of topological selection filters, which make it easy to query a model and for example obtain two-dimensional areas of contact or true three-dimensional volumes of overlap. These extensions have led to the concepts of **Constructive Non-Regularized Geometry** and of **Structured Topological Complexes**, which provide the theoretical background for specifying complex structures and their partitions through a series of simple operations that enumerate geometric entities (which extend the CSG primitives with lower and higher-dimensional sets) and provide filters (which extend the CSG operators with topological operators, such as k-cells, interior, closure, and boundary).

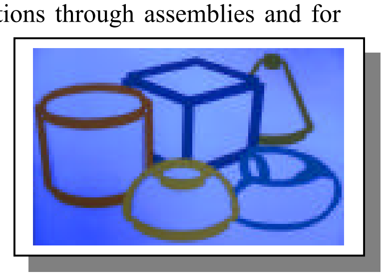
*"Constructive Non-Regularized Geometry", J. Rossignac, and A. Requicha. **Computer-Aided Design**, Vol. 23, No. 1, pp. 21-32, Jan./Feb. 1991.*

*"Structured Topological Complexes: A feature-based API for non-manifold topologies", J. Rossignac, Proceedings of the **ACM Symposium on Solid Modeling**'97, pp. 1-9, 1997. (Top conference in the area, 30% acceptance rate.)*

Non-realistic rendering of complex structures and higher-dimensional sets

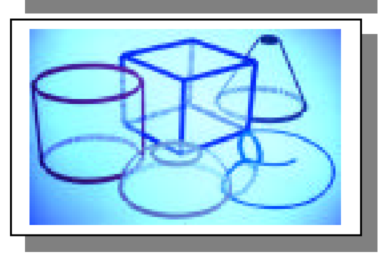
The objective of this area was to support engineering/scientific visualization needs.

The visual inspection of structures can rarely be carried out by simply looking at their external shape. Cross-sections and silhouettes are essential to reveal hidden parts, interior structures, and interferences in assemblies. I have invented a set of algorithms that use the standard 3D graphics hardware to quickly produce cross-sections and hidden contours of 3D models. With summer student A. Megahed, I have developed a set of algorithms for simultaneously showing multiple color-coded cross-sections through assemblies and for graphically revealing areas where assembly component overlap.



*"Interactive Inspection of Solids: Cross-Sections and Interferences" J. Rossignac, A. Megahed, and B.O. Schneider**, ACM Computer Graphics,** Vol. 26, No. 2, pp. 353-360, **Proc. ACM Siggraph**, July 1992.*

In engineering drawings, often only intersection and silhouette curves are shown—the hidden ones are identified by a different drawing style. Deciding, for a given view, which edge-portions are silhouette edges and which are hidden is a computationally intensive process that has been extensively studied since the 70s. I have solved this problem by developing an approach that exploits the graphics hardware to produce the correct pictures without the need for software tests.



*"Hidden contours on a frame-buffer" J. Rossignac and M. van Emmerik. Proceedings of the 7th **Eurographics Workshop on Computer Graphics Hardware,** Cambridge, UK, September 1992.*

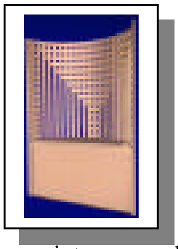
Solids, or even cells in more complex structures, are assumed homogeneous. The variation of their physical properties is often approximated by sampling these properties at discrete locations and by defining an interpolating (finite-element) mesh. A continuous model of these variations—and of their evolution—may be represented as a hyper-surface in higher-dimensional space. The display of such data sets poses additional challenges. I have explored the use of 4-D models for the visualization of manufacturing operations and am exploring their use for the visualization of time-dependent volumetric analysis results.

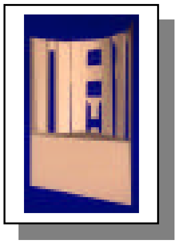
"Considerations on the Interactive Rendering of Four-dimensional Volumes," J. Rossignac, Proc. of the Chapel Hill ***Workshop on Volume Visualization,*** *pp. 67-76, 1989.*

"Exploring the 2D space of iso-surfaces in time-dependent 3D scalar fields", J. Rossignac and J. Snoeyink. (In preparation in collaboration with UNC at Chapel Hill). April 2000.

Graphic acceleration through model simplification

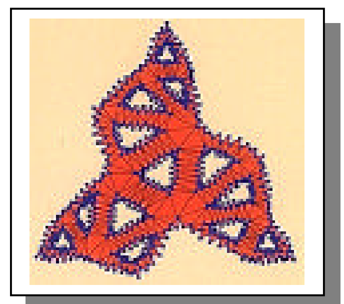
The objective of this area was to accelerate the rendering of highly complex 3D models.





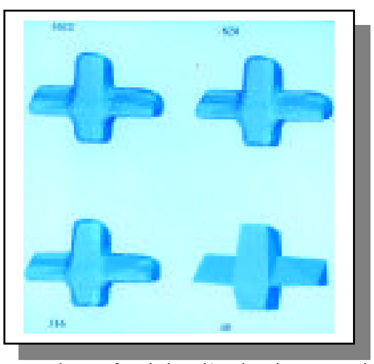
As I was visiting Boeing, which was moving towards the use of 3D models for all their design activities on the 777, I realized that the complexity of the models they had to manipulate was significantly exceeding the realtime rendering capabilities of graphics workstations. To help them, in 1991, I have invented the first automatic solution to this problem. My approach quickly computes simplified models and uses them when the projection of the displayed objects on the screen is small. The solution was so simple and so efficient, that it has **been incorporated into several products by IBM and other companies, and still remains in use**. It expresses the vertex coordinates in fixed-length integers and removes degenerate triangles. The vertex quantization defines vertex clusters. Geometric heuristics were applied to select the cluster representatives. This approach is **widely referenced and has inspired several recent advances in this field,** especially for selecting better cluster representatives, as demonstrated in several Siggraph publications.

"Multi-resolution 3D approximations for rendering complex scenes" J. Rossignac and P. Borrel, pp. 455-465, in ***Geometric Modeling in Computer Graphics****, Springer Verlag, Eds. B. Falcidieno and T.L. Kunii, Genova, Italy, June 28-July 2, 1993.*

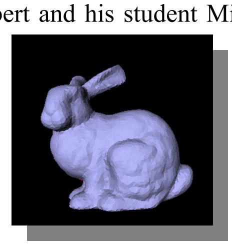


In order to apply the above solution, the faces of the models had to be triangulated. Because faces of CAD models may involve thousands of edges, a very efficient, and yet simple and robust triangulation algorithm was needed. Since none was available, I developed my own with Dr. Ronfard, who was a PostDoc in my lab. It was successfully tested on hundreds of millions of faces and was incorporated in an IBM product. The technique received the **Second Prize at the Eurographics Conference Best Paper Award Ceremony.**

"Triangulating multiply-connected polygons: A simple, yet efficient algorithm", Remi Ronfard and Jarek Rossignac, Proc. Eurographics'94, Oslo, Norway, ***Computer Graphics Forum****, Vol 13, No 3, pp. C281-C292, Sept 1994.*



The above simplification is efficient and reliable, but produces sub-optimal results. I have developed a more complex approach that produces much better results by collapsing adjacent vertices in an order that minimize an error estimate. The contribution in this paper was the use of an efficient error metric that would guarantee a Hausdorff distance between the original and the simplified shape. The measure was formulated as the MAX of the distances between the new vertex V and the planes that support all triangles incident upon the vertices that were collapsed into V. This **solution has inspired a PhD dissertation at CMU,** where, by giving up the Hausdorff distance guarantee, Paul Heckbert and his student Michael Garland, have reduced the cost of the error propagation and have produced the most popular simplification technique to date. I was a member of Michael's thesis committee.

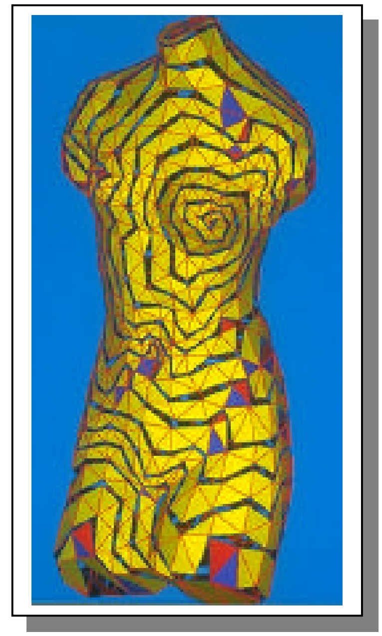


"Full-range approximations of triangulated polyhedra", Remi Ronfard and Jarek Rossignac, Proceedings of Eurographics'96, ***Computer Graphics Forum,*** *pp. C-67, Vol. 15, No. 3, August 1996.*

Several enclosing bounds have been proposed to speed up interference tests and to display crude approximations of 3D shapes. I have developed a very efficient algorithm for computing a bound that is the intersection of 3 enclosing boxes, each one obtained by rotating a nominal box by 45 degrees around a different axis.

"Tribox-based simplification of three-dimensional objects", A. Crosnier and J. Rossignac. ***Computers&Graphics****, March 1999. (Collaboration with the University of Montpellier in France.)*

Geometric Compression



The objective of this area of research is to accelerate the transfer of highly complex 3D models.

The geometric compression work addresses the problem of accessing complex 3D data sets over Internet, phone, and wireless connections. The **Topological Surgery** approach that I have developed at IBM Research cuts the triangulated boundary of a 3D model into a connected set of corridors. It encodes the topologies of the cuts and of the corridors and uses one bit per triangle to encode the triangulation of each corridor. It also uses geometric predictors along the cut to compress vertex locations. This technology has been adapted by the IBM team to compress VRML models and is now the official basis of the **MPEG-4 standard** for 3D data transmission. The Topological Surgery paper was selected from all papers published in 1998 and co-authored by IBM employees to receive the IBM award for the **Best Paper in Computer Science.**

"Geometric Compression through Topological Surgery", G. Taubin and J. Rossignac. ***ACM Transactions on Graphics****, Volume 17, Number 2, pp. 84-115, April 1998.*

"Geometry coding and VRML", G. Taubin, W. Horn, F. Lazarus, and J. Rossignac, ***Proceedings of the IEEE****, pp. 1228-1243, vol. 96, no. 6, June 1998.*

The **Edgebreaker** compression technique that I have developed at Georgia Tech is based on a finite state machine that visits the triangles, walking through common edges, and labels each triangle with a single letter taken from the set {C,L,E,R,S}. I have developed an efficient decision test for assigning the letters and for selecting the next triangle. They lead to an extremely simple compression algorithm. My **theoretical contribution** lies in the discovery that the sequence of labels suffices to reconstruct the graph and in the proof that for any mesh of T triangles that is homeomorphic to a sphere the sequence may be trivially encoded using **less than 2T bits**. Previously published compression techniques were based on significantly more complex algorithms and often required encoding vertex identifiers. Edgebreaker's simplicity and guaranteed compression ratio have made it a popular approach, upon which several improvements and extensions, developed in my group and elsewhere, have been based. This paper was selected as **the best paper published by a Georgia Tech faculty in 1999 and has received the Best Paper Award from Georgia Tech's chapter of Sigma Xi**.

"Edgebreaker: Connectivity compression for triangle meshes", J. Rossignac. ***IEEE Transactions on Visualization and Computer Graphics,*** *Vol. 5, No. 1, pp. 47-61, January - March 1999.*

An efficient decompression algorithm for the Edgebreaker encoding and experimental results of advanced entropy coding methods for the CLERS sequence produced by Edgebreaker were developed with A. Szymczak, who was a PhD student in the Math Department at Georgia Tech.

"Wrap&Zip decompression of the connectivity of triangle meshes compressed with Edgebreaker", J. Rossignac and A. Szymczak, Journal of ***Computational Geometry, Theory and Applications****, Volume 14, Issue 1-3, pp. 119-135, November 1999.*

A **custom binary encoding** for the sequences of Edgebreaker labels, developed with my PhD student D. King, further reduced the guaranteed storage cost of the compressed format to less than **1.84T bits**. This significant achievement reduces by 67%, the gap between the 2.3T bit record established in 1995 by Keeler and Westbrook and the 1.62T bit proven to be the theoretical minimum by W. Tutte in 1962.

"Guaranteed 3.67V bit encoding of planar triangle graphs" D. King and J. Rossignac, 11th ***Canadian Conference on Computational Geometry*** *(CCCG''99), pp. 146-149, Vancouver, CA, August 15-18, 1999.*

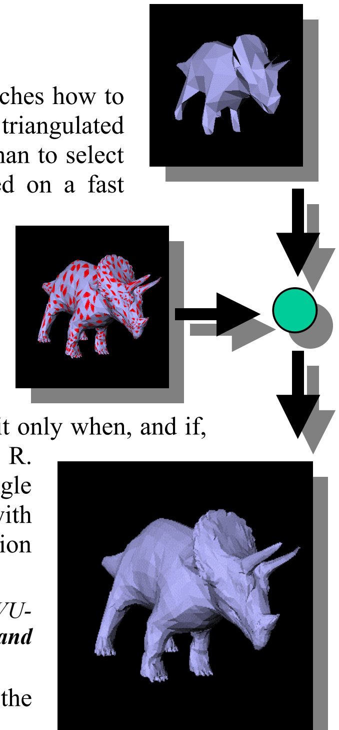
D. King and I have extended the Edgebreaker approach to meshes that have not only triangles, but also quadrilaterals.

"Connectivity Compression for Irregular Quadrilateral Meshes" D. King, J. Rossignac, submitted to the ***ACM Transactions on Graphics****, Manuscript 99-29, Dec 1999.*

Because many models are non-manifold, I have developed, with PhD student D. Cardoze, a technique for representing these non-manifold meshes using manifold data structures. My contribution was the significant reduction of the number of vertices that must be replicated in this process. In particular, I have shown that a non-manifold vertex may always be converted into a manifold vertex without vertex replication if its topological neighborhood is connected.

"Matchmaker: Manifold BReps for non-manifold r-sets", J. Rossignac and D. Cardoze. Proceedings of the ***ACM Symposium on Solid Modeling****, pp. 31-41, June 1999. (Top conference in the area, 30% acceptance rate.)*

Progressive transmission



The concept of ***Shape Complexity***, which I have developed with PhD student D. King, teaches how to balance the number of vertices and the accuracy of vertex coordinates in a compressed triangulated approximation of a 3D shape. Previously proposed compressing schemes expected the human to select these parameters with no algorithmic or theoretical support. The new approach is based on a fast estimate of the shape's complexity and on its relation to the optimal bit allocation between more vertices in the approximating mesh or more bits for encoding their coordinates.

"Optimal Bit Allocation in Compressed 3D Models", D. King and J. Rossignac, Journal of ***Computational Geometry, Theory and Applications****. Volume 14, Issue 1-3, pp. 91-118. November 1999.*

The benefit of progressive schemes lies in the fact that the remote viewer may start the interaction with a crude model long before the fully accurate model is retrieved. Furthermore, the viewer may interrupt the downloading process for that model and restart it only when, and if, more accuracy is needed. My work on ***Compressed Progressive Meshes,*** with PostDoc R. Pajarola, has set the standard for comparing progressive transmission schemes for 3D triangle meshes and has demonstrated that it is possible to combine progressivity and compression with low overhead over a one-time (non-progressive) compressed transmission of the full resolution model.

"Compressed Progressive Meshes", R. Pajarola and J. Rossignac, Technical Report, GIT-GVU-99-05. January 1999. Accepted for publication in the ***IEEE Transactions on Visualization and Computer Graphics****.*

This work was recently extended in our ***Squeeze*** approach to increase the performance of the decompression and refinement procedures for progressive 3D models.

"Squeeze: Fast and Progressive Decompression of Triangle Meshes", R. Pajarola and J. Rossignac, accepted to the ***Computer Graphics International*** *conference, Switzerland, June 2000.*

The decision of which portion of a shape to download is affected by occlusion. Models that cannot be seen from anywhere inside a cell in which the viewer is currently located need not be downloaded until the viewer moves out of the cell. In order to identify good occluders automatically and to use them to identify what can be seen from a cell, I have, with PhD student Saona-Vazquez and colleagues at UPC in Barcelona, developed a new theory, which uses the boundary of a piece of a surface to decide whether it is a strong occluder for a given convex cell. If so, what is occluded from the vertices of the cell will be occluded from all viewpoints inside the cell.

"View-Dependent Strong Occluder Synthesis", C. Saona-Vazquez, J. Rossignac, I. Navazo, P. Brunet. (In preparation in collaboration with the University of Catalunya, Barcelona, Spain). April 2000.

Compression and progressive transmission of tetrahedra

Without compression, the connectivity of large triangle meshes is the dominant storage cost, exceeding the cost of storing vertex locations. This relative cost of connectivity is even greater for **tetrahedral meshes**, which are used for 3D finite element analysis in scientific and engineering applications. The *Grow&Fold* technique, which I invented with PhD student A. Szymczak, was the first technique published for the topological compression of the connectivity of tetrahedral meshes. It has resulted in a **patent application filed by Georgia Tech** in January 2000. Our paper, presented at the ACM Solid Modeling Symposium has been **selected by the organizing committee** and we have been invited to publish an extended version in a special issue of CAD.

"Grow&Fold: Compression of Tetrahedral Meshes", A. Szymczak and J. Rossignac. Proc. ***ACM Symposium on Solid Modeling****, June 1999, pp. 54-64. (Top conference in the area, 30% acceptance rate.)*

"Grow&Fold: Compressing the connectivity of tetrahedral meshes", A. Szymczak and J. Rossignac. Selected to appear in a special issue of ***Computer-Aided Design****. 2000.*

The *ImplantSpray* technique, developed jointly with student Szymczak and PostDoc Pajarola, combines the previous ideas to produce a very compact and **progressive encoding for tetrahedra meshes**.

"Implant Sprays: Compression of Progressive Tetrahedral Mesh Connectivity", R. Pajarola, J. Rossignac, and A. Szymczak, ***IEEE Visualization*** *1999, San Francisco, October 24-29, 1999. (47 papers were selected out of out of the 130 submitted).*