ARMY RESEARCH LABORATORY

Comprehensive BRL–CAD Primitive Database

by Mitchell Roberts

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Comprehensive BRL–CAD Primitive Database

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14. ABSTRACT Ballistic Research Laboratory–Computer-Aided Design (BRL–CAD) is an open-source computer-aided design tool that uses constructive solid geometry (CSG) to create models of primitive shapes. However, no database of all (primitive) shapes exists in BRL–CAD. The goal of this project was to create a database containing one instance of every primitive shape supported by BRL–CAD. The database includes special cases of other primitive shapes, such as a rectangular parallelepiped (rpp), an arbitrary convex solid with 8 vertices (arb8). After the database was completed, a tool was created to perform the same task automatically. The primitive-shape database provides the target describers of BRL–CAD with a representative example of each primitive's shape and its properties. In addition to the database, part of BRL–CAD's large code base was debugged, specifically the hypersampling feature in rtarea and the error checking in rtweight were corrected by taking into account the sampling rate.			
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Student Bio

Mitchell Roberts is a senior at the Science and Mathematics Academy at Aberdeen High School in Maryland. The US Army Science and Engineering Apprenticeship Program is his first research experience, but he will be doing a senior capstone research project on Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) starting in the fall. He plans to attend college starting in 2015 and major in computer engineering.

1. Introduction

Ballistic Research Laboratory–Computer-Aided Design (BRL–CAD), an open source, computer-aided design tool, uses constructive solid geometry (CSG) to compose solid geometry models. This type of modeling requires a large and diverse collection of primitive shapes that can be combined using the Boolean operations of union, subtraction, and intersection. CSG allows BRL–CAD to create large and intricate models using much less data than models made with other approaches, such as polygonal mesh modeling. CSG not only decreases the file size but also increases the speed of the raytracer, the tool BRL–CAD uses to render images. CSG also increases the speed of the raytracer to calculate information about the primitives, such as their weight and thermal properties.

There are more than 3 dozen primitive shapes supported by BRL–CAD, but no database containing examples of each shape currently exists. Though such a database would be useful for training purposes, its most important use would be for regression testing. For example, with a single database that contains every primitive shape, regression tests using tools such as rtarea and rtweight could be used to ensure that no code change caused unexpected problems. This would be ensured by confirming the area and weight of each primitive shape conformed to established, correct values. Such regression tests can prevent coding errors (bugs) from being released, as well as trace the origins of existing bugs.

The goal of this project was to create a database containing one instance of every primitive shape supported by BRL–CAD. This database includes those shapes that are special cases of other primitive shapes such as a rectangular parallelepiped (rpp): a special case of an arbitrary convex solid with 8 vertices (arb8). Once the database was completed, a tool was created to generate primitive shapes automatically. This provides target describers—CAD experts who generate detailed descriptions of military systems for threat analysis—using BRL–CAD complete examples of each primitive along with their properties. In the process of creating this database, time was spent debugging portions of the large code base in BRL–CAD; this included debugging the hypersampling feature in rtarea and the error-checking feature in rtweight.

2. Experiment and Calculations

The project began with 2 weeks of digitizing historical tapes and debugging existing source code. The tapes dated as far back as 1974 and contained historical demonstrations of BRL–CAD features, such as the real-time raytracer, virtual wheels, and simple shotlining. The tapes also included some history of computing in general, such as a virtual tour of the Cray supercomputer.

The source code that was debugged was the rtweight function, which used the raytracer to calculate the volume and the weight of a BRL–CAD object. When users tried to activate the hypersampling mode in which more than one ray is shot at each target cell, the program would report incorrect results. This error was resolved by dividing all results by the hypersampling rate to produce the correct values. Another problem in activating the hypersampling mode: program stalled in an infinite loop if no density file existed to compute the weight. This infinite looping was resolved by simply notifying users that the density file was missing and then stopping the program without reporting a weight.

After debugging rtweight, the primary project objective of creating a database of primitives commenced. Three major types of primitive shapes currently exist in BRL–CAD: geometry based, 2-dimensional (2D) based, and data-based primitives. The geometry-based primitives are the simplest and most common type of geometry used in computer models. They take very few parameters that are attributes of the shape. The remaining geometry-based shape is derived from that information. For example, the ellipsoid (ell) primitive only requires the data of 1 center and 3 radii to calculate the bounds of its shape based on the general equation of an ellipsoid. Figure 1 is a rendering of each of the geometry-based primitives.

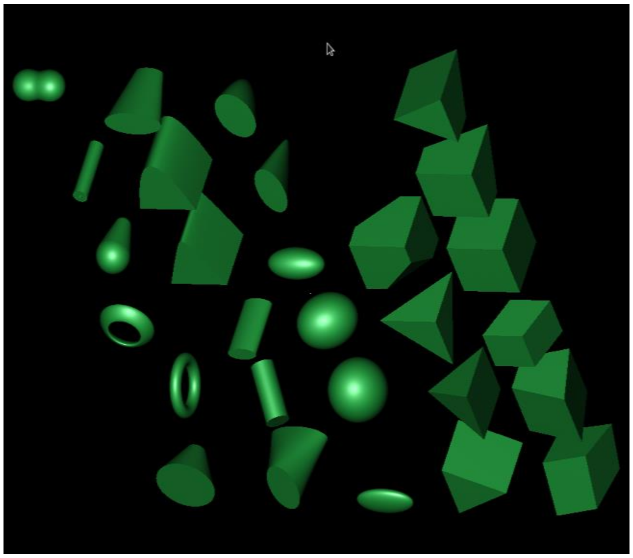

Fig. 1 Geometric primitives

The 2D-based primitive shapes are mostly centered around the sketch primitive, shown in Fig. 2. They are shapes made of line segments and arcs that have no thickness and, therefore, cannot be rendered with the raytracer (because they have no volume for the ray to intersect). They consist of extrude and revolve primitives as provided in Fig. 3.

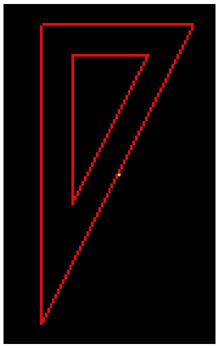

Fig. 2 Sketch primitive

The extrude and revolve primitives do render with the raytracer. The extrude primitive simply takes the area bounded by the sketch and adds depth to it. The revolve is more complicated, adding a third dimension to the extrude primitive by rotating the sketch around an axis. In this example, the revolve primitive was rotated about the longer leg of the triangle. The revolve primitive does not currently support revolution of a sketch with curves, which is the reason the example uses only line segments.

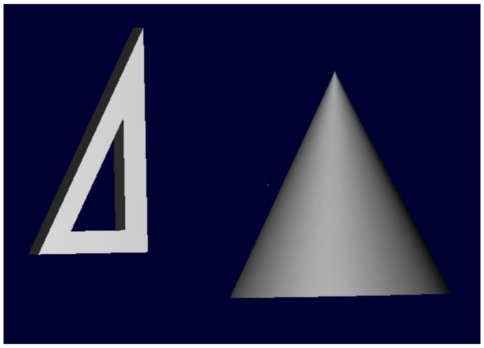

Fig. 3 Extrude and revolve primitives

The last 2D-based primitive is the extruded bitmap (ebm). This primitive takes a 2D black and white image and, for each pixel in white, extrudes it to a given height. Figure 4 shows the process of transforming a 2D BRL–CAD logo[1] to an ebm primitive.

Fig. 4 Creation of an ebm primitive–BRL–CAD logo

Primitives based on an application-specific data set are the most complex to model. As such, they require the most memory. However, they can also model geometry that no other primitives can. The first data-based primitive is the waterline solid, or arbitrary faceted solid (ars). This primitive uses ordered points to create faces. Then each point is connected to the corresponding point on the next face to create a 3-dimensional (3D) shape from the 2D faces. An example of this geometric primitive is the wing shown in Fig. 5, in which the points on the airfoil face were given then were connected to the next face of the wing. Note: While the airfoil face appears to be smooth, it is actually composed of very closely spaced points connected by straight lines.[2]

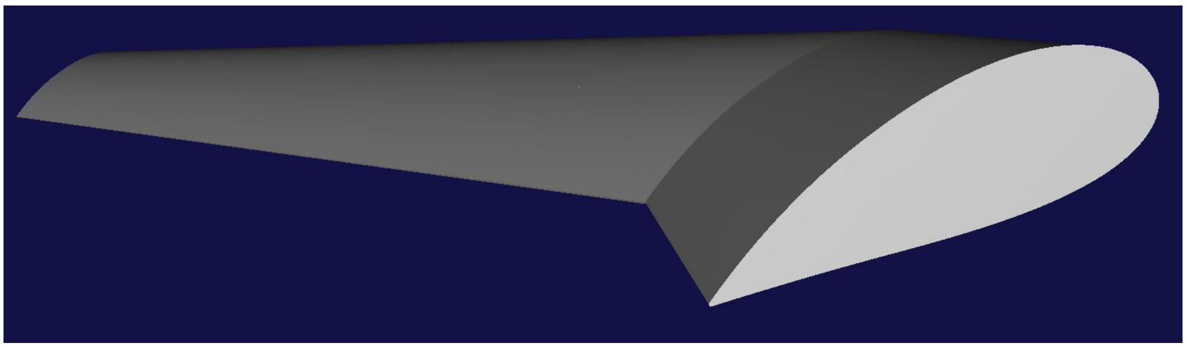

Fig. 5 The ars primitive–airplane wing

The next data-based primitive that had to be implemented was the displacement map primitive (dsp) shown in Fig. 6. This type of primitive requires a height-data file or a grayscale (pixel) image; then, it raises each point to a different height based on its height or pixel-input value. This technique can be used to map terrain very accurately; for example, the terrain model of Anderson Canyon in Arizona[3] shown in Fig. 6.

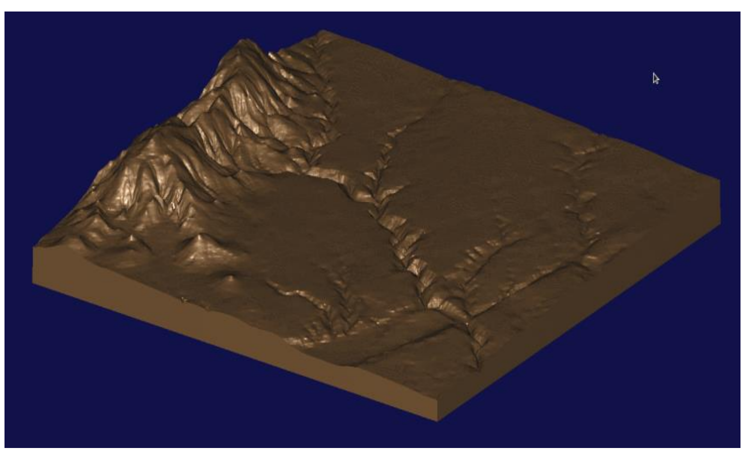

Fig. 6 The dsp primitive–Anderson Canyon

The next primitive is the boundary representation (brep). It is a Non-Uniform Rational B-Spline (NURBS) model, as shown in Fig. 7. This primitive is a complex mathematical equation based on piecewise curves that are used to model round boundaries. An example of a 2D NURBS is shown in Fig. 7, where the B-Spline curve is used to fit the points.[4]

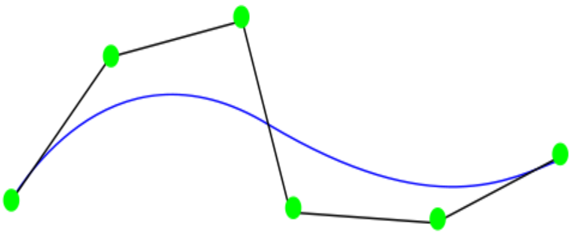

Fig. 7 NURBS example

Figure 8 is an example of a solid made in BRL–CAD with breps. This model, called the Utah Teapot, is a famous example of NURBS modeling.

Fig. 8 The boundary representation (brep) primitive–Utah Teapot

The next data-based primitive is the Bag o' Triangles (bot). The bot is an important format for BRL–CAD because it is the basis of many converters. Clearly, not all CAD tools are going to save files in the .g format used by BRL–CAD. But other formats, such as STP, 3DM, and AutoCAD (ACAD), can be converted to a mesh of triangles and represented in BRL–CAD. The model shown in Fig. 9 below is a dragon converted from the Polygon File Format (PLY) data type. The dragon appears smooth but is actually more than 1 million triangles lined up edge-to-edge to form its shape. The some of these triangles can be seen up close in the yellow wireframe in Fig. 10. One interesting thing about a bot model is that, unlike traditional CSG modeling, it is not a solid object. Instead it is a mesh representing only the surface of the geometry, analogous to an empty egg shell.

Fig. 9 The bot primitive–Chinese dragon

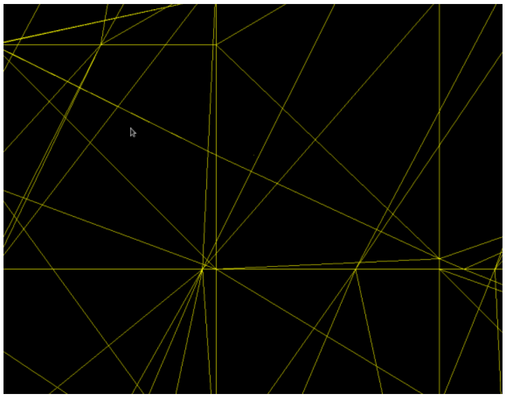

Fig. 10 The bot wireframe

An example of the final primitive type can be seen in Fig. 11 (the volumetric pixel data [vol]). In a vol, a series of images must be converted to 8-bit grayscale. The images, as well as the upper- and lower-threshold values, are required as parameters. Then, for each image in the series, each pixel whose value is between the values of the upper and lower thresholds is represented as a cube. All of the cubed images are stacked on top of each other to create a 3D model of images. In Fig. 11, all the frames from a full-body magnetic resonance imaging (MRI) are converted into a model of a full-body human.[5] One frame from the MRI taken of the body's torso is shown in Fig. 12.

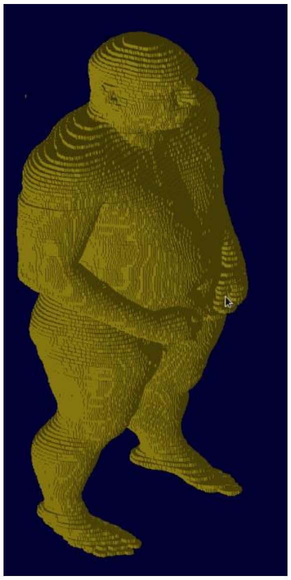

Fig. 11   The vol primitive–human body

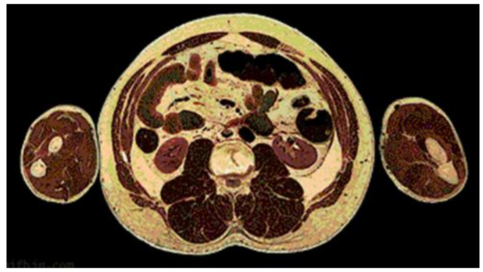

Fig. 12 The vol MRI source image

3. Results and Discussion

The two changes made to the rtweight function were submitted to Sourceforge (BRL–CAD's open-source repository), were accepted, and have been implemented into the official BRL–CAD code. The database with all primitives is shown in Fig. 13.

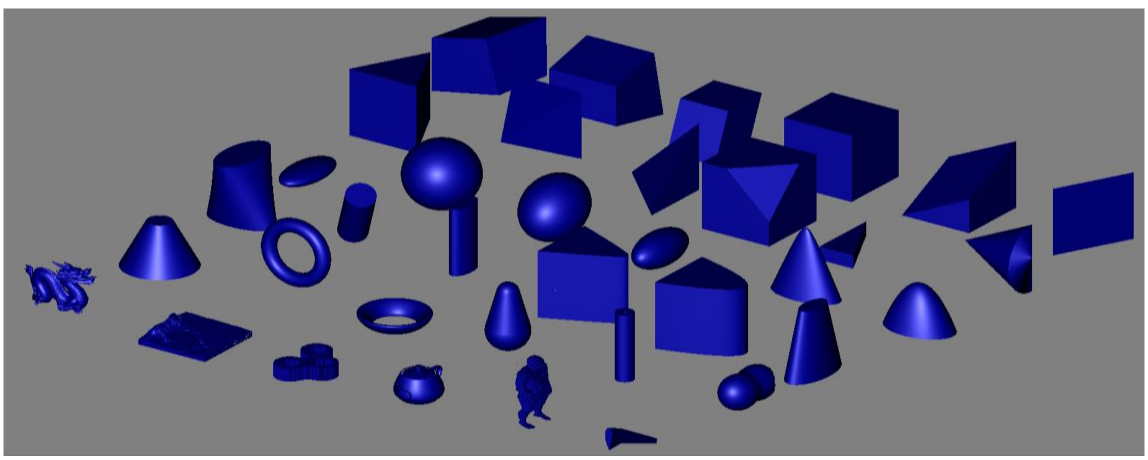

Fig. 13 Completed database of primitives

It is useful to have measurements (such as the geometry's volume and exposed area) to verify BRL–CAD's algorithms are consistent over time. Arranging all the primitives in this gridded pattern returned a total exposed area of $1.78998*10^{7}$ mm^2 and a total volume of $1.02435*10^{10}$ mm^3. These values were calculated by the rtarea and rtweight functions run with a grid-cell size of 48 × 48 pixels, an azimuth of 270°, and an elevation of 90°.

4. Conclusions

The values, $1.78998*10^{7}$ mm^2 and a total volume of $1.02435*10^{10}$ mm^3 , can be used for regression testing to ensure no unanticipated changes to the performance of the raytracer or to any the primitives is published into the BRL–CAD source code. The chart of primitives in Fig.14 can be distributed as an example of each primitive shape BRL–CAD supports in groups with common features.

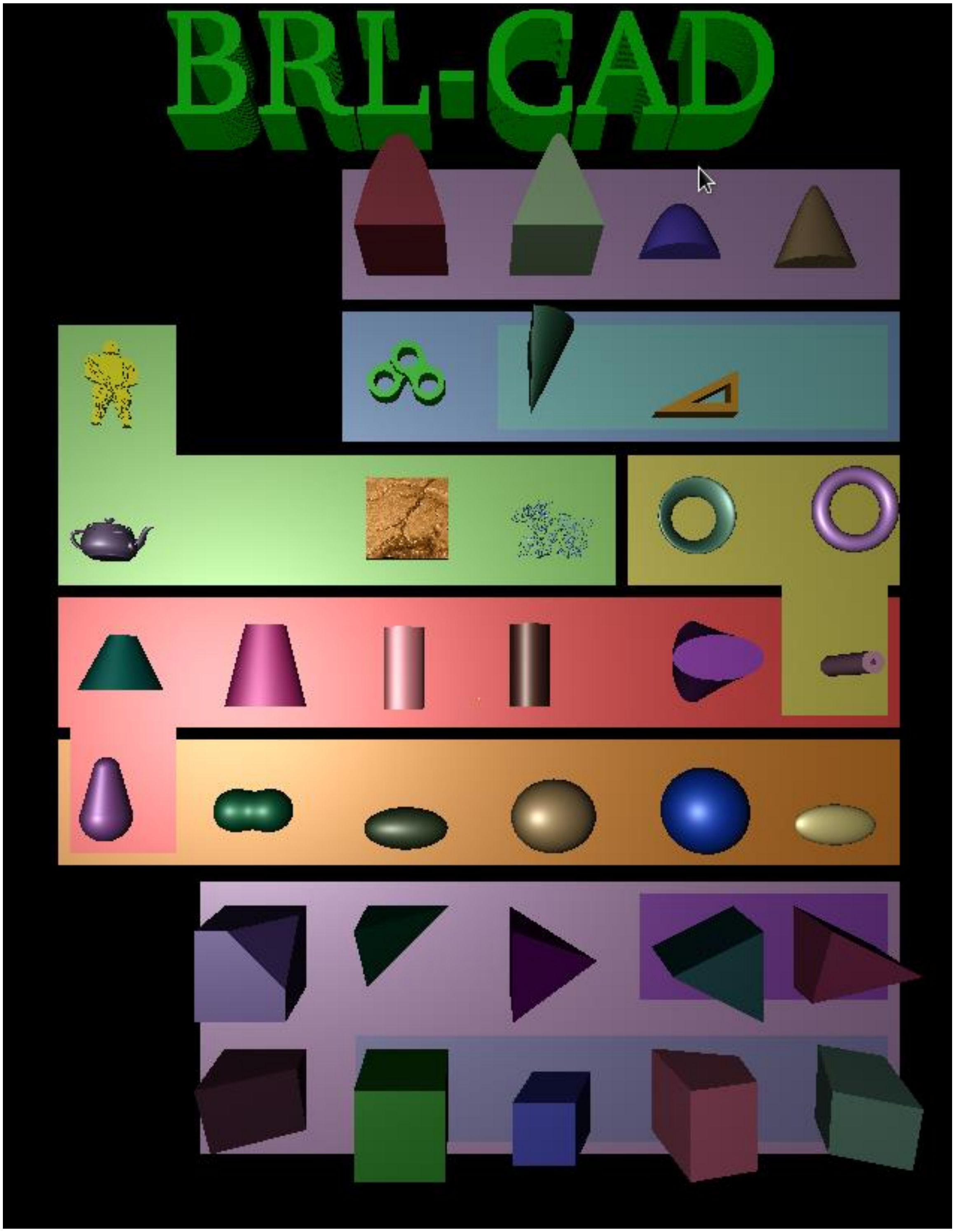

Fig. 14 Chart of primitives

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List of Symbols, Abbreviations, and Acronyms

2D	2 dimensional
3D	3 dimensional
3DM	The Rhino(ceros) CAD system's file format (file extension .3dm)
ACAD	AutoCAD
arb8	arb with 8 vertices
ars	arbitrary faceted solid
bot	Bag o' Triangles
brep	boundary representation
BRL–CAD	Ballistic Research Laboratory–Computer-Aided Design
CAD	computer-aided design
CSG	constructive solid geometry
dsp	displacement map primitive
ebm	extruded bitmap
ell	ellipsoid
MRI	magnetic resonance imaging
NURBS	Non-Uniform Rational B-Spline
PLY	Polygon File Format (file extension .ply)
rpp	rectangular parallepiped
STP	Standard for the Exchange of Product (STEP) model data (file extension .stp)
vol	volumetric pixel data, (also referred to as voxel) primitive

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