3DESS: A Search Engine Enters the Third Dimension

By Pam Frost Gorder

GIANT DATABASES OF 3D COMPUTER-AIDED DESIGN (CAD) PARTS MIGHT BE THE STUFF OF COMMERCIAL DESIGN FIRMS AND MANUFACTURERS, BUT KARTHIK RAMANI DOESN'T have to venture out of his Purdue University lab to see the need for a search engine that can sort through it all. After years of teaching an undergraduate mechanical engineering course that required students to design and build toys—each with around 10 working components—Ramani has amassed a database of some 5,000 parts.

"Someone will ask, 'Now, where was that part again?'" he says. "You can imagine that searching for parts is even more difficult, and much more important, in industry."

Ramani directs the Purdue Research and Education Center for Information Systems in Engineering, which focuses on information systems for supply-chain design, product design, and manufacturing. While his students are building wind-up clocks and models of the school mascot that spit candy, his commercial partners are building cars and jet planes.

Ramani and his colleagues have created a program, 3DESS (three-dimensional engineering shape-search system), that promises to make searching for 3D CAD files easier. Internet search engines find two-dimensional images based on associated text, but 3DESS can find 3D images based on the shape of the object alone. In one application, users sketch the general features of the object they're looking for, and the program employs unique algorithms that search a database visually, to find the best match.

3DESS could give manufacturers an edge in today's economy. Ultimately, it could aid other 3D tasks, from surgery to drug discovery.

Good, Fast, Cheap—Pick Any Two

An old engineering axiom graces cubicle walls in offices everywhere, warning those who would hurry a project that they can't have it all—and with good reason. Coordinating a job across different engineering departments can be difficult under normal circumstances, and rush jobs are expensive because they marshal the efforts of many employees under a tight deadline.

For businesses that design 3D objects on computers, an in-house database is at once a potential time-saver and potential time-sink. If engineers can't find a part like the one they're trying to design, they have to start from scratch, but finding the right object among thousands or even millions can take so long that it's not worth the effort.

Ramani cites a 1997 study from the University of Toronto that found that design engineers spend up to 60 percent of their time on the very activity they rate most frustrating: looking for information.

"Engineers would rather walk down the corridor and ask someone about a file than try to find it on computer," he says. "But when that person retires, who are you going to ask? The database is like the entire company history, but if you can't find anything, what good is it?"

Satyandra K. Gupta, associate professor of mechanical engineering and associate director of the Computer Integrated Manufacturing Laboratory at the University of Maryland, agrees that many companies don't have the tools they need to harness useful information from CAD databases. Shape-similarity searches are the key.

"Purdue's system offers a new technique for searching CAD models," he says. "It has features that might be of significant value in certain applications such as part reuse."

Why are design databases so difficult to search? Because people create designs visually but index them textually, Ramani explains. An engineer may barely have time to add a few index terms to a CAD file before saving it in the database and moving on to the next assignment. Admittedly, indexing CAD files is not central to most people's job description. "Designers would rather be designing something—it's human nature," he says.

Whether index terms refer to the part shape or function, or even the material or manufacturing method, depends as much on the designer's personal style as company convention. And without index terms, odds are nobody will ever find that part again. All the knowledge gained—for instance,

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why the design worked, or didn't, for a particular application is lost. The next person to create a similar design from scratch could make the same mistakes all over again.

Parts search engines such as 3DESS could ease engineers' frustrations and save millions of dollars annually by enabling companies to reuse previous designs. Ramani thinks his program could cut search time by 80 percent.

Of Voxels and Vectors

3DESS starts with a 3D CAD model and converts it into a stack of small cubes called *voxels*, or volume elements. Voxels are analogous to the pixels that make up flat images in 2D.

After the program voxellizes a CAD file, it converts it to an array of feature vectors—the model's numeric fingerprints. It then transforms the vectors to skeletal graphs—drawings that capture the model's topology.

Ramani likens skeletal graphs to a human skeleton—the "bare bones" of a part's shape and features, such as how many holes it contains and where they are located. In the skeletal drawing, lines trace general features of the part's shape, and loops represent holes.

3DESS uses the distance between these features to index a part's shape and compare it to other parts. Whether a part is solid, hollow, or a combination of both determines how it is indexed. Though the skeletal graph is greatly simplified, it links to more complex part data. Searchers can uncover related meta-information, such as whether a part was created by casting or machining, and the manufacturing cost. The Purdue engineers believe this is the first time skeletal graphs have been used for 3D shape searching.

To make searching for the parts more effective, they designed a multistep process, which they presented in April at the Fifth International Symposium on Tools and Methods of Competitive Engineering, in Lausanne, Switzerland.

First, users sketch the shape of a part they're looking for (or choose one from the parts database that is similar) and sketch changes to it. 3DESS then searches the database and presents a small group of items that have similar skeletal graphs to the desired part.

If the desired part doesn't turn up in the first search, users can select which parts came close and which ones didn't. 3DESS uses this feedback to zero in on the right part. The system differs from one that employs a single-step search, where users would have to run a new search with different criteria if they wanted to see different results.

"It is also different from similarity, where one would need a model designed to look up similar shapes," Ramani says.

In tests, he and his colleagues initially implemented a

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database of 150 CAD parts. The 3DESS strategy found the desired parts 85 percent of the time—51 percent better accuracy than any single-step search.

3DESS stores the feedback in a user profile in a layer above the database. That way, the server keeps only one copy of the database, but each user gets a unique search experience. Because the program groups similar models on the same node during indexing, it also reduces disk usage during searches.

Ramani's graduate students—Kuiyang Lou, Subramaniam Jayanti, Natraj Iyer, and Yagnanarayanan Kalyanaraman—are continuing to work on 3DESS, as is Sunil Prabhakar, an assistant professor of computer science at Purdue. The engineers are studying whether artificial-intelligence techniques, such as neural networks, could enable the system to better learn from user feedback. Zygmunt Pizlo, associate professor of psychological sciences at Purdue, is helping improve the system by incorporating information about human perception.

"We're trying to bridge the semantic gap between the person and the computer system," Ramani says. "The challenge is how to make the system understand what you want, so that when you get search results and give it feedback, it can return with things that are more relevant. We still have to understand the human side of things."

A Question of Semantics

The Purdue work lies at a nexus of research—engineering design, graphics, artificial intelligence, computer vision, and psychology. All must be taken into account if engineers are to make the most of 3D technology, says William Regli, associate professor of mathematics and computer science and director of the Geometric and Intelligent Computing Laboratory at Drexel University.

"There's no silver bullet: our goal is to help engineers ask meaningful questions. The answers to these questions don't just come from the shape, they come from a part's meaning and behavior and cost. The challenge becomes how to find the questions," he says.

Regli understands the difficulty that Ramani is facing in trying to overcome the semantic gap between user and system.

"Very few people deal with engineering semantics, they just deal with shape. The challenge I see is how to connect shape to all the metadata. Representing complex engineering semantics is an ugly problem, and associating semantics with objects is another problem," Regli says.

He recently received a CAREER award from the US National Science Foundation to develop a search methodology for the National Design Repository (www.designrepository.org), a publicly available database of some 40,000 CAD files that he created while working at the US National Institute of Standards and Technology (NIST). Ramani has now expanded his initial test database—with additional help from NIST and Regli—for large-scale experiments.

Meanwhile, the University of Maryland's Gupta has received support from the US Navy and the commercial company Iktara and Associates to build a system called Design Navigator. This system improves product realization through intelligent information management and can perform searches based on 3D CAD data.

As Gupta pointed out in a recent issue of the *Journal of Computing and Information Science in Engineering* (vol. 3, no. 2, 2003, pp. 109–118; http://scitation.aip.org/ASMEJournals/JCISE/), another problem with shape searching is that CAD files lack specific measures of similarity; just evaluating a shape signature such as a skeletal graph is thus a difficult task in itself. He and his coauthors called for the development of publicly available benchmarking databases that will offer such metrics.

Business as Usual

Like much of the Midwest, Indiana's traditional industries are working to stay competitive against cheaper labor from abroad. The Indiana 21st Century Research and Technology Fund supports Ramani's research to aid high-tech development among manufacturers and boost the state's economy.

The university has filed a patent for the search methodology, and Imaginestics, a private software company in Purdue's research park, is licensing it. Because the company maintains an online community for Indiana's tooling manufacturers (www.toolingnet.org), 3DESS is well-positioned for statewide adoption.

Nainesh Rathod, head of Imaginestics, expects that 3DESS modules will be incorporated into some of his products by fall 2004.

"The underlying theme for all our products is reuse: how to leverage past and present data for improving product design, whatever the activity," Rathod says. "We concentrate on design and manufacturing data, but we're expanding to medical and life sciences data, too."

Some of Imaginestics' industrial partners have offered to fund the incorporation of 3DESS into i-advisor, a program that analyzes CAD models and recommends the optimal manufacturing process, but the company's initial offering of 3DESS has a direct link to medical applications. The module will be part of i-compare, a program that compares CAD images and metadata, which Rathod feels could be of particular use to orthopedic surgeons.

"Every person is built differently. Right now, doctors literally overlay pictures of implants and patient x-rays to determine which implant will fit. Using i-compare, they can automatically see which one is the right one," he says.

In the meantime, he and Ramani, who works as the company's chief scientist, have applied for funding from NIST to develop 3DESS for analyzing molecular structures.

"Shape is a central aspect in drug discovery, and it's important in studying proteins and drug docking [how drug proteins bind together]. There's a lot of knowledge built into a protein structures that can be mined—making sure a drug isn't toxic, for example—and the function is specific. As 3D imaging becomes more common, there will be other potential medical applications there," Ramani says.

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