mal form (CNF) that is based on the effects and preconditions of actions in an *n*-step plan. In the second step, the aforementioned research results are used to convert the CNF representation into a decomposable negation normal form (DNNF) representation. It turns out that the computation time needed to evaluate a DNNF expression to compute an optimal *n*-step plan increases only linearly with the DNNF representation size.

*This work was done by Anthony Barrett of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

*The software used in this innovation is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-40296.*

# Semantic Metrics for Analysis of Software

## These metrics represent a more human-oriented view of software.

*Goddard Space Flight Center, Greenbelt, Maryland*

A recently conceived suite of object-oriented software metrics focus is on semantic aspects of software, in contradistinction to traditional software metrics, which focus on syntactic aspects of software. Semantic metrics represent a more human-oriented view of software than do syntactic metrics. The semantic metrics of a given computer program are calculated by use of the output of a knowledge-based analysis of the program, and are substantially more representative of software quality and more readily comprehensible from a human perspective than are the syntactic metrics.

Semantic metrics have the potential to help software engineers identify fragile, low-quality sections of code much earlier in the development process than is possible by use of syntactic metrics. By enabling earlier and better detection of faults, semantic metrics are expected to make maintenance of software less time-consuming and expensive and to make software more reusable. Because it is less costly to correct faults found earlier than to correct faults found later in the software-development process, it is expected that the overall cost of developing software will be reduced. Moreover, because semantic metrics provide better measures of internal documentation descriptiveness (descriptiveness of the comments and identifiers in software), all aspects of development of software can be expected to benefit from improved understanding of the software.

Prototype software called "SemMet" for computing semantic metrics is undergoing development. In SemMet, semantic metrics are described within the context of knowledge-based systems that consist of semantic networks formed from conceptual graphs. Conceptual graphs are often used for semantic networks for natural language processing; however, the use of conceptual graphs is also a general and fairly common knowledge-representation technique. In the computation of semantic metrics, concepts and conceptual relations from conceptual graphs inside a knowledge base are used as input. The output semantic metrics are presented in a report.

*This work was done by Letha H. Etzkorn, Glenn W. Cox, Phil Farrington, Dawn R. Utley, Sampson Ghalston, and Cara Stein of the University of Alabama at Huntsville for* **Goddard Space Flight Center**.*Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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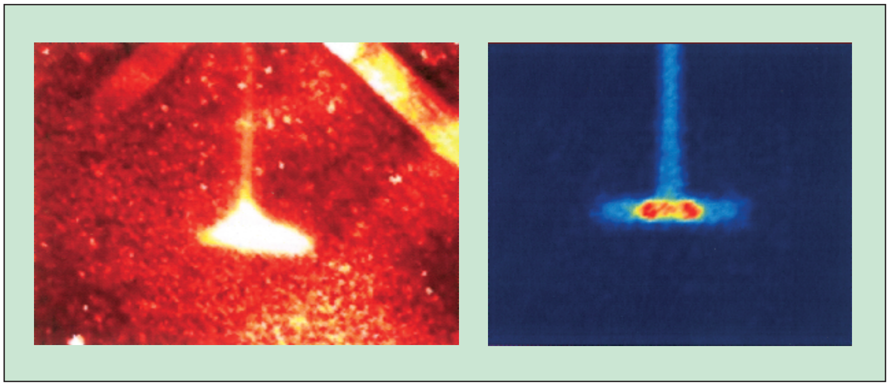
# Simulation of Laser Cooling and Trapping in Engineering Applications

## This design instrument shows good agreement with experimental measurements.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

An advanced computer code is undergoing development for numerically simulating laser cooling and trapping of large numbers of atoms. The code is expected to be useful in practical engineering applications and to contribute to understanding of the roles that light, atomic collisions, background pressure, and numbers of particles play in experiments using laser-cooled and -trapped atoms. The code is based on semiclassical theories of the forces exerted on atoms by magnetic and optical fields. Whereas computer codes developed previously for the same purpose account for only a few physical mechanisms, this code incorporates many more physical mechanisms (including atomic collisions, sub-Doppler cooling mechanisms, Stark and Zeeman energy shifts, gravitation, and evanescent-wave phenomena) that affect laser-matter interactions and the cooling of atoms to submillikelvin temperatures. Moreover, whereas the prior codes can simulate the interactions of at most a few atoms with a resonant light field, the number of atoms that can be included in a simulation by the present code is limited only by computer memory. Hence, the present code represents more nearly completely the complex physics involved when using laser-cooled and -trapped atoms in engineering applications.

Another advantage that the code incorporates is the possibility to analyze the interaction between cold atoms of different atomic number. Some properties that cold atoms of different atomic



A **Cold Atomic Beam** is shown emerging from a magneto-optical trap in a pyramidal-low-velocity-intense-source configuration. The figure shows a comparison between experiment (left) and simulation (right). The images depict an area of approximately 1.5 × 1.5 cm.

species have, like cross sections and the particular excited states they can occupy when interacting with each other and light fields, play important roles not yet completely understood in the new experiments that are under way in laboratories worldwide to form ultracold molecules. Other research efforts use cold atoms as holders of quantum information, and more recent developments in cavity quantum electrodynamics also use ultracold atoms to explore and expand new information-technology ideas. These experiments give a hint on the wide range of applications and technology developments that can be tackled using cold atoms and light fields. From more precise atomic clocks and gravity sensors to the development of quantum computers, there will be a need to completely understand the whole ensemble of physical mechanisms that play a role in the development of such technologies.

The code also permits the study of the dynamic and steady-state operations of technologies that use cold atoms. The physical characteristics of lasers and fields can be time-controlled to give a realistic simulation of the processes involved such that the design process can determine the best control features to use.

It is expected that with the features incorporated into the code it will become a tool for the useful application of ultracold atoms in engineering applications. Currently, the software is being used for the analysis and understanding of simple experiments using cold atoms, and for the design of a modular compact source of cold atoms to be used in future research and development projects. The results so far indicate that the code is a useful design instrument that shows good agreement with experimental measurements (see figure), and a Windows-based user-friendly interface is also under development.

*This program was written by Jaime Ramirez-Serrano, James Kohel, Robert Thompson, Nan Yu, and Nathan Lunblad of Caltech for* **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30595.*