The
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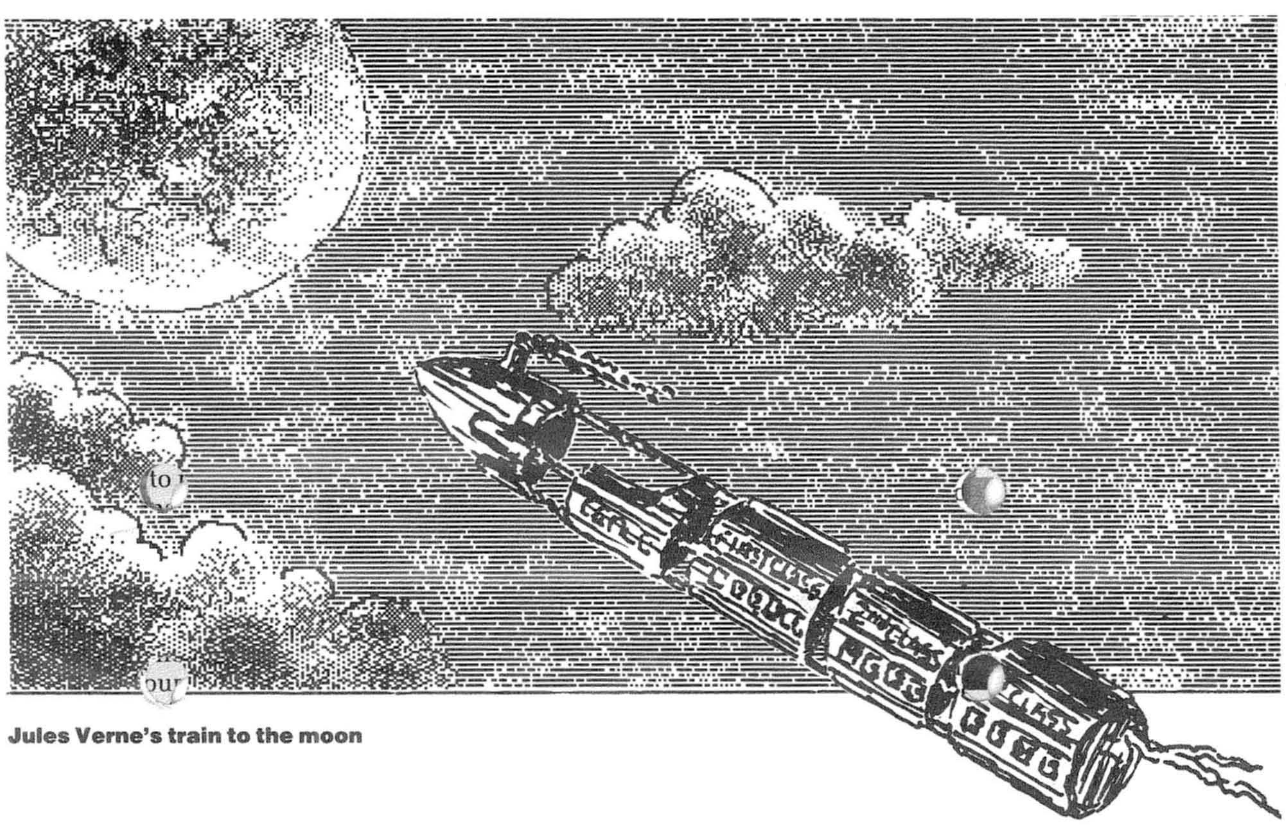
Ram Accelerator: space launch system of the future

by Mary Cooksey



Jules Verne's train to the moon

At first glance, the ram accelerator in the aerospace and energetics research laboratory (AERL) looks like an incarnation of the "big gun"created by Jules Verne in his story, *From the Earth to the Moon*. In Verne's 1904 story the hero, Impey Barbicane, came up with a splendid idea—to send a "trainload" of people up to and around the moon, using an enormous buried gun.

The shot to the moon in the story was successful, with the projectile containing the people, including Barbicane, returning to earth unharmed. In real life, of course, neither the projectile nor the passengers could have survived even the launch, let alone re-entry.

Nevertheless, the idea of shooting a projectile into space remains, and is, in a way, being realized here at AERL. The ram accelerator is not a gun and will not carry people, but it is a radical new method of sending acceleration-insensitive payloads into space, that is, payloads that don't deform under high launch acceleration. The accelerator was conceived, and a laboratory scale version built, by a group in the Aerospace and Energetics Research Program (AERP). The group, includes Abraham Hertzberg, director of AERP; Adam Bruckner, research associate professor of aeronautics and astronautics; David Bogdanoff, research engineer (now working at NASA Ames), and nine graduate students.

Sending people and delicate instruments into space requires protecting them from the forces necessary to launch and enter into orbit. A rocket such as the space shuttle must be designed to protect its contents and must carry all its own fuel and oxidizer. Because of this load, only a small fraction of a rocket's space is available to carry payload. Consequently, carrying anything on the space shuttle is very expensive—approaching several thousand dollars per pound. Payload costs using the ram accelerator would be significantly less, perhaps below $100 per pound, according to the AERL group.

Because 70 - 80 percent of all the supplies needed for building and maintaining a large, permanent space infrastructure are acceleration-insensitive, the ram accelerator is the perfect option for delivering these materials into space. "We need," says Hertzberg, "a 'pipeline' to carry insensitive loads into space, loads that can survive 1,000 times the force of gravity (or 1,000 gs), such as, water, fuel, raw materials, and food—even Campbell's chicken soup."

In operation, the accelerator will be a 4 kilometer-long tube through which a 2,000 kilogram payload-bearing projectile is launched into space. Using the controlled release of chemical energy, the ram accelerator operates on a propulsive cycle similar to that of a conventional ramjet engine, but it is unlike any ramjet ever flown. A conventional ramjet looks like a stovepipe, with a sculptured centerbody attached to an outer cowling, and it must be moving through air to operate; the air scooped up by the ramjet is ram-compressed inside the engine (hence the name ramjet). When fuel is added and burned, a high velocity exhaust jet is produced which creates forward thrust.

The ram accelerator resembles a ramjet, in which the centerbody has been detached from the cowling and the cowling has been lengthened into a long stationary tube. The centerbody, which is now the projectile, flies through the tube (see diagram, page 11). Bruckner explains, "It's a traveling centerbody in a very long cowling. The same forces (as in a ramjet) are at work, but there is no fuel on board the projectile. The fuel and oxidizer, both gaseous, are premixed and fill the entire length of the tube. As the projectile travels through the tube, the combustible gas mixture burns behind the projectile, creating forward thrust."

Originally, the concept was called the ram cannon, but the group changed the name to ram accelerator to avoid any misconception. The accelerator is *not* a gun. A gun doesn't efficiently couple energy from

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In Brief

The artificial neural network concept is a hot topic in science and industry

A computer that can recognize and classify everything from bushes to voices is fast becoming reality. Using sophisticated techniques in optics and speech recognition, UW researchers are "wowing" their supporters with impressive neural net performance. See story on page 4.

Department of Energy forges closer ties with the University

D.O.E.'s Pacific Northwest Laboratories, with Battelle Memorial Institute, and the University of Washington are beginning a new era of mutual co-operation in the interests of improved interdisciplinary research efforts. For details of a new agreement see story on page 9.

Distinguished alumnus, Carl Hansen, featured in alumni profile

As a globe-trotting trouble-shooter, Carl Hansen can be found assessing earthquake damage in Peru one day and repairing a fire damaged U.S. Embassy in Moscow the next. His career is highlighted on page 10.

Benjamin Linder engineering scholarship supporters hope for $50,000 endowment

The first scholarship in memory of Benjamin Linder was recently awarded to a graduate student in civil engineering. A number of groups have combined their efforts to build an endowment in support of the scholarship. Story on page 10.

College Calendar

Friday, May 6	Golden W Reception*
Thursday, May 19	Vistas Lecture Mr. Dale Myers, NASA 210 Kane Hall, 7:30pm
Thursday, May 19	Corporate Associates Day 5:00 dinner
Saturday, October 29	Engineering Alumni Association Homecoming Reception*

*Call Jerry Ann Graham for details, (206) 543-0167.

Artificial neural networks model the human brain

by Sharon Kasper

The problems of the traveling salesman have long been a subject of considerable speculation and humor. But one such problem, that of mapping out a minimum-distance route among 30 or 40 cities, is part of the serious research effort in the field of optical computers. The Traveling Salesman Problem (TSP) represents the type of puzzle that a computer modeled on the neural network of the brain could solve with ease.

Robert J. Marks II, professor, and Les Atlas, assistant professor, both of electrical engineering, are combining their skills in optical computers and speech recognition to help uncover the secrets of neural networks. One possible outcome of their work might be a computer which could deal with problems of even greater complexity than the TSP.

Developing a computer that can deal with such complexity requires an understanding of the human (biological) brain and the way in which its billions and billions of neurons interact. Each neuron is connected to a large number of other neurons that make up individual neural networks. And the operation of the network is based on the changing status of each individually functioning neuron and its ability to sense changes in those neurons to which it is connected.

Professors Marks and Atlas, working with a team of graduate students, have developed and are training an *artificial* neural network in their Interactive Systems Design Lab (ISDL). Their model is called the APNN or Alternate Projection Neural Network. Marks points out that much conventional training is based on sets of rules, "but if you had to give rules by which something was a bush or a tree, it would be very, very difficult." It is necessary, then, to program a neural network in the same way that humans are programmed. "You show the neural network a bush and you say, 'That's a bush,' and you show it a tree and you say, 'That's a tree,' and you show it another tree and you say, 'That's another tree,' and after a while the neural network begins to learn to distinguish all by itself; it learns by example as opposed to learning by rules."

The motivation for developing an artificial neural network computer model of the biological network is plain. Every day the scientist can observe the results of human neural networks in action—a human can identify a tree or a bush in a picture that contains both trees and bushes. And, although we are naturally equipped with the ability to classify in this way, a non-biological neural network must be trained to make such distinctions.

Optics, Marks' specialty, will be used to 'show'images to the computer and to manipulate the data internally. "At the front end of the computer, where you gather the data," Marks explains, "there might be an array of photo-detectors that would detect the image. Internal manipulation of the data that is conventionally done electronically would be done using light instead of electrons. It's obviously faster; you can't get much faster than light."

More than just a search for speed is involved in modeling the internal architecture of a neural network. The hundreds of electronic connections required between the neurons, using a conventional computer, would be impossible due to interference, but using photons rather than electrons eliminates that interference. The basic artificial neural network consists of many nodes or neurons that do very simple operations, and in some models, every neuron is connected to every other neuron. Using conventional connections would require the impossible: electrons going through electrons. Marks describes the advantage of using optics: "If you do it optically, photons can go through photons. Light can go through itself, so using light gives you the nice ability to have the natural physics for intense interconnections of the nodes or neurons."

One technology available with the neural network is parallel rather than serial processing. "One neuron doesn't have to wait for what another neuron does; they all kind of do their own thing and come out with a really neat answer."

Reaching "a really neat answer" in neural network parlance is called converging, and Atlas and Marks' APNN outperforms previous thermodynamic models of neural networks in accomplishing convergence efficiently and consistently. The thermodynamic models use an energy reduction approach which Marks says, "doesn't prove uniqueness of convergence, that is, one time the neural network converges to one thing, and another time it converges to something else. So in that sense it's a relatively poor model." Marks elaborates, "Our model of the APNN draws upon a wealth of mathematical theory, including projection onto convex sets, which is a recent field of interest and analysis from which we've been able to borrow."

Besides convergence, the ability of a neural network to generalize is a requirement of any efficient classification network. Marks describes generalization between the two modeling systems, "It's easy to train a classifier to respond to training data. What's important, however, is how it responds to new data. Can it recognize a totally new bush?" A disadvantage of the conventional neural network is that determining how it will respond can only be done empirically. "You actually have to expose it to the new material and see if it responds correctly. However, with the APNN, the math is so well developed that we can predict the manner in which the network generalizes, and we can write down math equations that show whether and in what manner the network generalizes to other than the training data."

The ability to generalize to new data or environments is a problem that conventional computers respond to poorly. Even the recent developments in artificial intelligence, such as expert systems, have this problem. "Neural networks offer the theoretical potential to control and design the specifics of generalization," according to Atlas. "However large amounts of data from many real-world environments are needed to test and refine this theory."

Training a network by example requires incredible amounts of time to pass through the data, and the problem with conventional neural nets is that they can forget the earliest data by the time they are exposed to the final data. This forgetting requires repetitive passes through the training data. However, repetitive passes are not required for the APNN, because it has an elephant-quality memory. It never forgets. A single pass through the training data is sufficient.

Improved memory within the actual computer architecture is another advantage of the APNN. The associative memory capability of the artificial neural network could allow the APNN to identify a black and white picture (similar to a digitized picture) of the Mona Lisa, given only her smile. "We have a matrix of neurons," explains Marks, "that can take on gray levels. In this matrix every neuron is connected

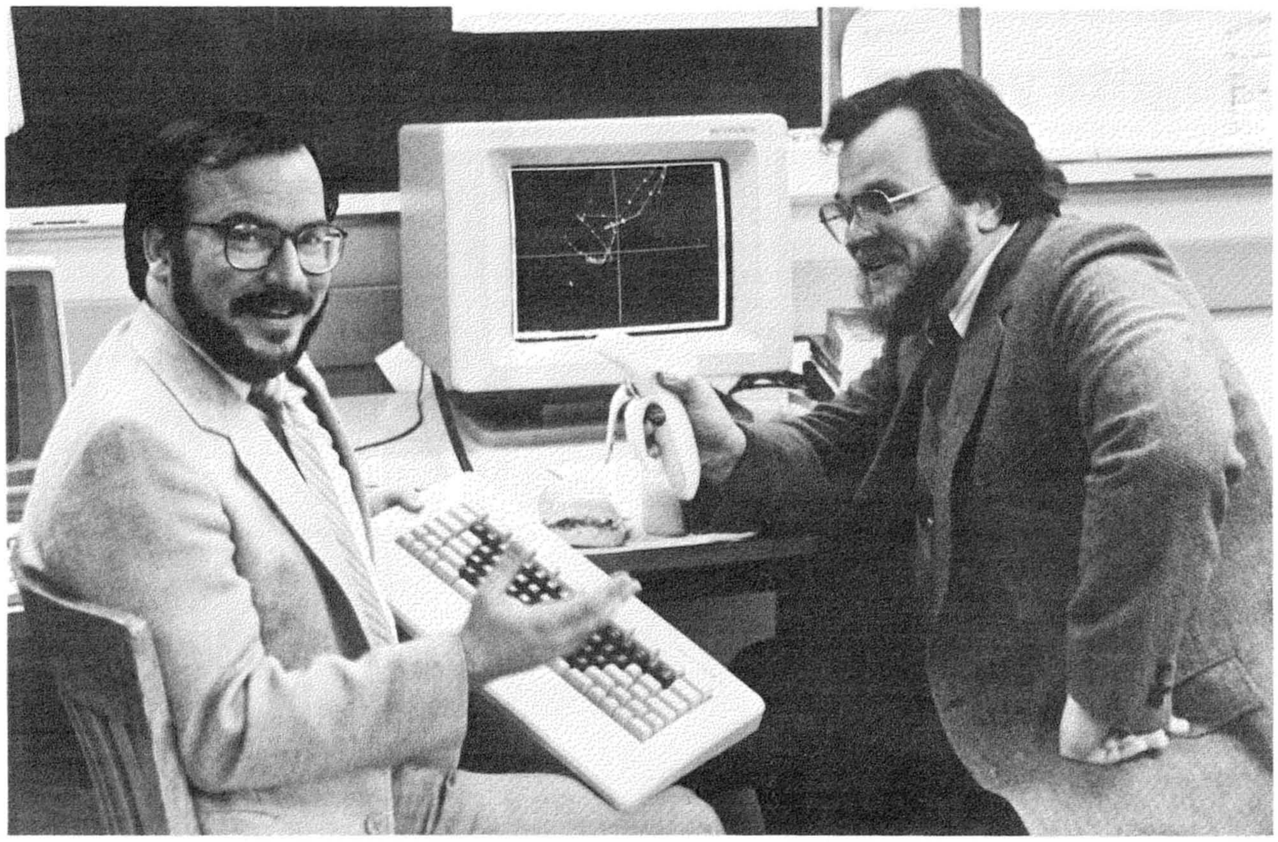

Photo David Spengler

Working lunches led to neural network research partnership between Les Atlas and Robert J. Marks

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Department of Energy Professorship to Aksay

by Keith Robison

A memorandum of understanding was recently signed between the University of Washington and the U.S. Department of Energy's Pacific Northwest Laboratories (PNL). Designed to encourage closer co-operation between the two institutions, this agreement establishes new jointly-funded professorships, graduate fellowships and research contracts. The first of the new professorships, for which the DOE will provide $50,000 in annual support, has been awarded to Ilhan Aksay, professor of materials science and engineering.

His selection as the first PNL Professor is in recognition of Aksay's strengths as a researcher, and his ongoing work with Battelle Memorial Institute, which runs PNL for the Department of Energy. Aksay has been working with the laboratory in the development of its new Molecular Sciences Research Center and has played a major role in starting three interdisciplinary programs through the lab. According to Aksay, the professorship will allow increased access to Battelle's facilities and research, freeing the lines of communication between the lab and the UW, thus improving the research efforts of both. In short, the new arrangement will make it easier for him to continue the kind of cooperative work he has been doing for some time.

Ilhan Aksay receives professorship Photo David Spengler

Aksay, a UW faculty member since 1983, teaches and conducts research in the science of processing ceramics (see *Trend* article, Autumn 1986). As director of the Advanced Materials Technology Program of The Washington Technology Center, Aksay is investigating new techniques for making ceramic materials. The designing of ceramics, he says, is being reduced to smaller and smaller scales, down to the level of locating individual atoms within a ceramic composite, in order to control precisely the composition of the materials. This control will enhance the materials' electrical properties and prevent their premature failure. In 1987, Aksay received the Richard M. Fulrath Award from the American Ceramic Society in recognition of his contributions to the microdesigning of ceramics using colloidal techniques.

Aksay graduated from the University of Washington in 1967 with a B.S. in ceramic engineering. By 1973, he had completed his M.S. and Ph.D. at the University of California, Berkeley. After working at the Xerox Webster Research Center from 1973 to 1975, Aksay taught at the Middle East Technical University in Ankara, Turkey for five years. He then spent two years as a visiting associate professor in UCLA's materials science and engineering department before coming to the UW.

In addition to the new professorship, the agreement between PNL and the UW provides for two $15,000 graduate fellowships—one in materials science and the other in chemistry. The first has been awarded to Bradley L. Thiel, a graduate student. Thiel's work on the electron microscopic characterization of superconducting ceramics has already resulted in several joint publications with the PNL researchers. The winner of the fellowship in chemistry is Brad Tenge, who plans to graduate in the spring of 1989. He is conducting research on the use of fiber technology in analytical chemistry.

Another result of the agreement will be a number of new research projects on campus. According to Deborah Illman, associate director of the UW Center for Process Analytical Chemistry (CPAC), the Battelle Institute is taking steps to collaborate closely on CPAC research. The center's focus on developing chemical sensors and analytical monitors for chemical manufacturing processes is of interest to Battelle in its nuclear operations.

"We have signed a kind of umbrella agreement which covers all the eventualities of our working with Battelle," Illman said. "It spells out such things as what would happen if an invention came out of the joint work." She added, "We're particularly pleased to work with Pacific Northwest Laboratory because of their proximity and because they have tremendous resources and people."

The department of civil engineering is also conducting Battelle-funded research on the design of systems that monitor the transport of contaminants in surface water and ground water. The results of the research will be useful to the DOE in managing sites where radioactive waste is stored.

The comments of Gene Woodruff, dean of the UW Graduate School, seem to mirror those of everyone involved: "Battelle and the University have always had a special and close relationship. We all believe this memorandum of understanding will further strengthen those ties."

Neural networks *from page 4*

to every other neuron, and each neuron can assume a value that relates to a gray level. So, having been given a picture of the Mona Lisa, the gray levels of that picture are imposed on the neurons and the information is stored in the interconnects," (these interconnects correspond to the synapses that connect the neurons in the biological brain) "and remarkably, if the network is then given only the Mona Lisa's smile, the APNN could then extrapolate the entire face of the Mona Lisa."

The future of the APNN, is being extended to some real world applications: A *speaker-independent* system of speech recognition is being developed by Atlas and his team of graduate students. Using a large data base containing many words from many speakers, the team plans to have a demonstration system ready in two years. In order to make the system commercially acceptable, it is necessary to keep the rate of recognition errors to a minimum. It is also essential that the remaining errors be as "natural" as possible. "Human voice interaction is not error-free either," Atlas explains. "A key problem with conventional recognizers is that their errors are not at all like natural human errors. We feel that the APNN has the potential to behave as a human does, which would include the errors that naturally occur in human speech recognition." Other applications of the APNN include efficient routing of computer links and an automatic system to identify irregularities in electrocardiograms (EKG's).

Funding for Atlas and Marks' APNN comes from a variety of sources: The National Science Foundation, The Office of Naval Research, Physio Control Corp. and the Washington Technology Center. Although a considerable amount of research remains to be done, based on the available funding and the incredibly high level of interest in the field, Marks and Atlas are optimistic that neural network computers will be commercially available in the near future.

Continuing Education Courses

	May
AHERA Inspectors Training	2-4
AHERA Management Planners Training	5-6
Ground Safety Management	9-20
Cold Regions Engineering	12-16
Asbestos Certification Course	24-27
	June
AHERA Inspectors Training	6-8
AHERA Management Planners Course	9-10
Mobile Hydraulic Troubleshooting	6-10
Designing On-Line Documentation	9-10
System Safety Management	13-24
AEA/UW Engineering Management	19-24
	July
Surface and Colloid Science	11-17
System Safety Analysis	18-28
	August
International Combustion Symposium	14-19
System Safety Analysis	22-31

For further information, call (206) 543-5539.