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COMPUTER RECREATIONS

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COMPUTER RECREATIONS

On the spaghetti computer and other analog gadgets for problem solving

by A. K. Dewdney

Mention computers these days and one thinks invariably of digital machines. All but forgotten are their analog cousins, the electromechanical devices that once ruled the computational scene. Before World War II major laboratories employed elaborate analog computers with names such as the continuous integraph and the differential analyzer. The machines exploited electrical or mechanical analogies to mathematical equations; a variable in an equation would be represented by some physical quantity, such as a voltage or the rotation of a shaft. Analog computers could be applied to equations that arise in many fields: ballistics, aerodynamics, the analysis of power networks and so on.

The analog machines could not compete with the digital computers developed during World War II and immediately after. Analog computers seemed to be capable of solving only certain kinds of problems, chiefly those defined by differential equations, and even then with less than perfect accuracy. In contrast, it quickly became apparent that digital computers could be programmed to solve an infinite variety of problems with very high accuracy. Slowly the analog machines faded into the background until by the mid-1960's they were barely mentioned in books on computing.

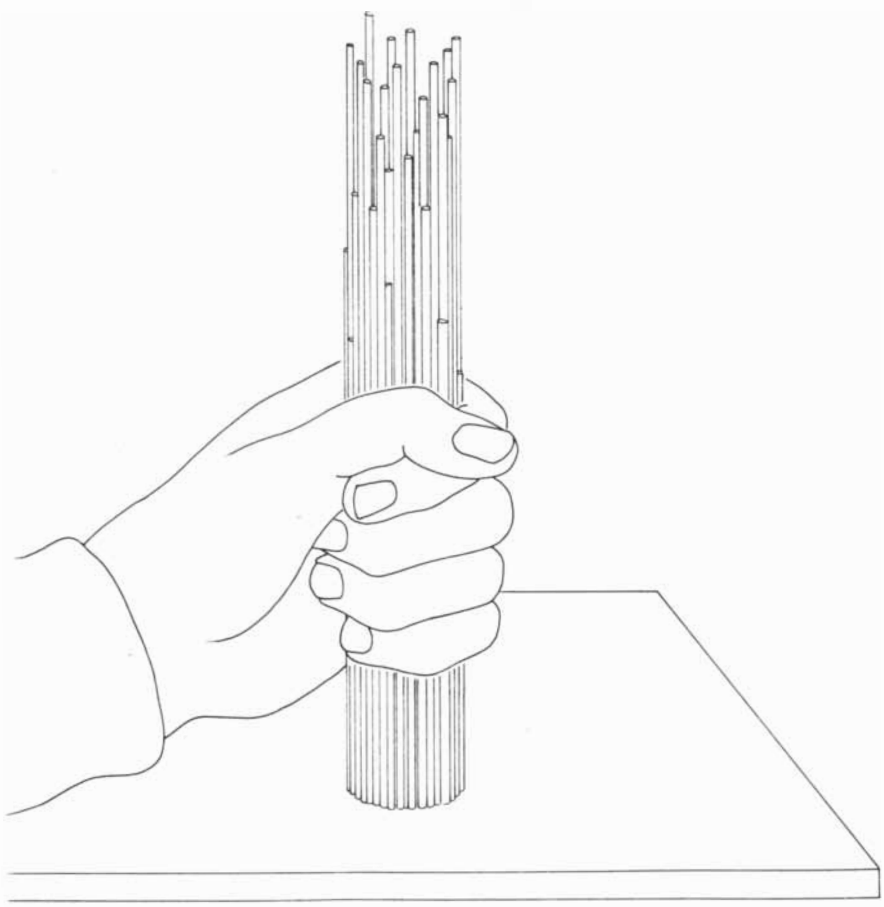
Although the successors of the great analog machines of the 1920's and 1930's are still in use (and under continuing development) in a few laboratories, no one seriously expects analog computers to spring to the forefront again. The digital revolution cannot be turned back. It is also true, however, that a revolution sometimes blinds us to the charms of an earlier milieu.

The essential delight of an analog computation lies in the notion that one is getting something for nothing. A problem that would require hours of computation by hand (or even by a digital computer) is solved by merely observing a physical system as it comes rapidly into equilibrium. In the most dramatic cases the process seems wellnigh instantaneous, and we have a gadget that computes.

Consider the SAG computer, or Spaghetti Analog Gadget. This device, in the configuration I have tested, is able to sort up to 700 numbers in order of decreasing magnitude. Sorting is a common task in digital computing, and algorithms for doing it have been highly refined, but the time needed to sort a list of numbers still grows somewhat faster than the size of the list. With SAG one must spend a little time setting up the machine for the particular list of numbers and a little more time reading out the results, but the actual sorting appears to take no time at all.

Here is how SAG works. For each number in the sequence to be sorted trim a piece of uncooked spaghetti to a length equal to the number. Naturally, appropriate units of measurement must be adopted. Now take all the pieces of trimmed spaghetti in one hand and, holding the bundle vertically and somewhat loosely, bring it down on a table rather sharply. The momentum of the individual rods ensures that all of them have one end resting on the table. In order to obtain the sorted sequence from the resting bundle, one has only to remove the tallest rod, then the tallest of the remaining rods and so on until the bundle is exhausted. As each rod is removed it is measured and the number is recorded.

It is important to distinguish three phases of the sorting operation; I call them the preprocessing, the analog and the postprocessing phases. In the preprocessing phase the spaghetti is measured and trimmed; in the analog phase a simple mechanism sorts the rods; in the postprocessing phase the rods are removed one at a time, yielding the sorted sequence. All the gadgets described here require pre- and postprocessing. Indeed, so did the early analog computers, and



The spaghetti computer sorts a bundle of numbers in descending sequence

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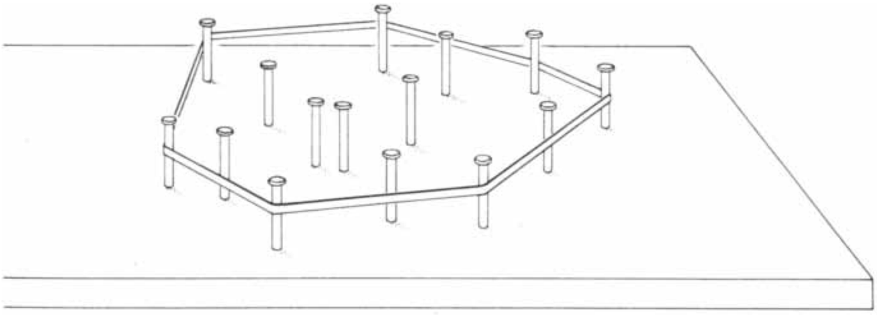
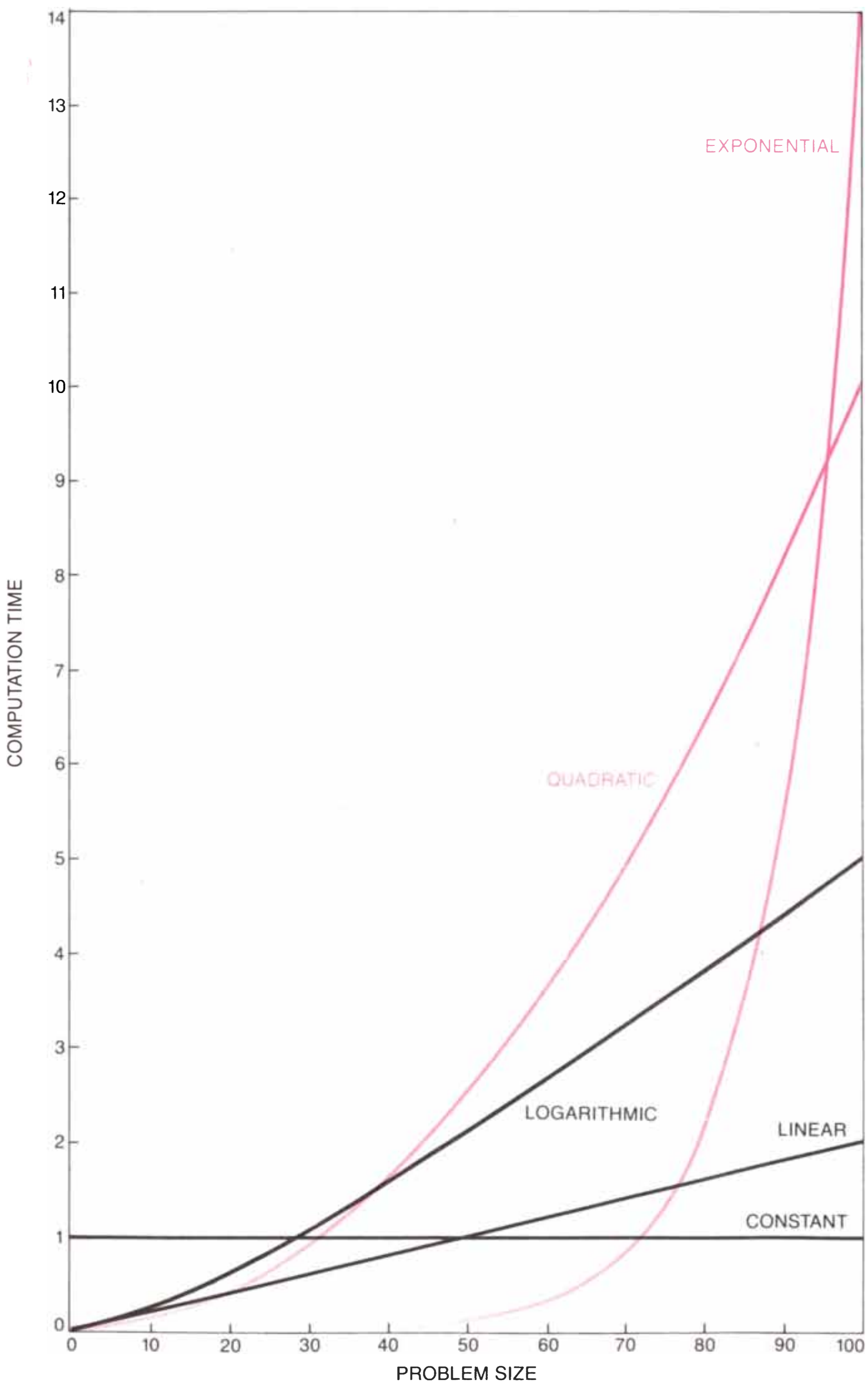


Finding the convex hull of a set of points in the plane



Several possible functions relating computation time to problem size

much research and development was invested in speeding up these phases.

There will be those who say, "SAG may be able to sort 700 numbers, but what about 7,000 or seven million?" The only reasonable way to deal with questions of this kind is to mention SUPERSAG, a modified fork-lift truck capable of picking up seven million pieces of carefully trimmed (extralong) uncooked spaghetti and slamming them sideways against a brick wall.

There will be others who say, "I can sort 700 numbers faster than SAG can. I'll do it all with pencil and paper and I'll finish before the spaghetti is even trimmed!" Sadly for SAG, this remark is probably true. Suppose it takes one minute to read a number from the unsorted sequence, measure a piece of spaghetti to that length, cut it and insert it into the bundle. Suppose further it takes 10 seconds to remove and measure each piece of spaghetti after the (one-second) slamming operation. It will then take SAG more than 13 hours to sort the 700 numbers, with all but one second of the time being spent in preprocessing and postprocessing. The challenger, on the other hand, sorts the sequence by scanning it, selecting the largest number on each pass, recording it and stroking it off the sequence. It takes him a tenth of a second to scan each number, and thus he needs $(700 + 699 + \ldots + 2 + 1)/10$ seconds to sort the sequence. This works out to 175 minutes 15 seconds, a clear victory for the challenger. Will the wonderful, all-at-once quality of the analog phase be completely undone by the lengthy pre- and postprocessing phases? Not quite.

Suppose the human sorter becomes cocky and challenges SUPERSAG to a seven-million-number sorting duel. SUPERSAG would need some 15 years, whereas the challenger would not finish for almost 74,000 years! SUPERSAG's superiority can be explained by examining the way the speed of a computation depends on the size of the problem. The slamming of the spaghetti against the wall is said to be a constant-time operation: it is essentially independent of the size of the bundle. The pre- and postprocessing phases are linear-time operations: they grow longer in simple, linear proportion to the size of the sequence of numbers. The human sorter's task grows much faster. He must inspect each remaining member of the sequence on each pass through it. Even though the sequence gradually shrinks, the total number of inspections goes up as the square of the size of the sequence; the sorting is said to take quadratic time. Sooner or later a linear-time procedure is bound to beat a quadratic-time one.

Even with its lengthy pre- and postprocessing phases, a large enough SAG machine could outsort a modern digital

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How an idea in yesterday's funny papers can become tomorrow's front page headlines.

Dick Tracy's wrist radio used to belong strictly in the Funnies.

But a revolution in electronics is moving ideas like these onto Page One.

Thanks to a semiconducting compound called gallium arsenide that's being used to make super microchips by the people at ITT.

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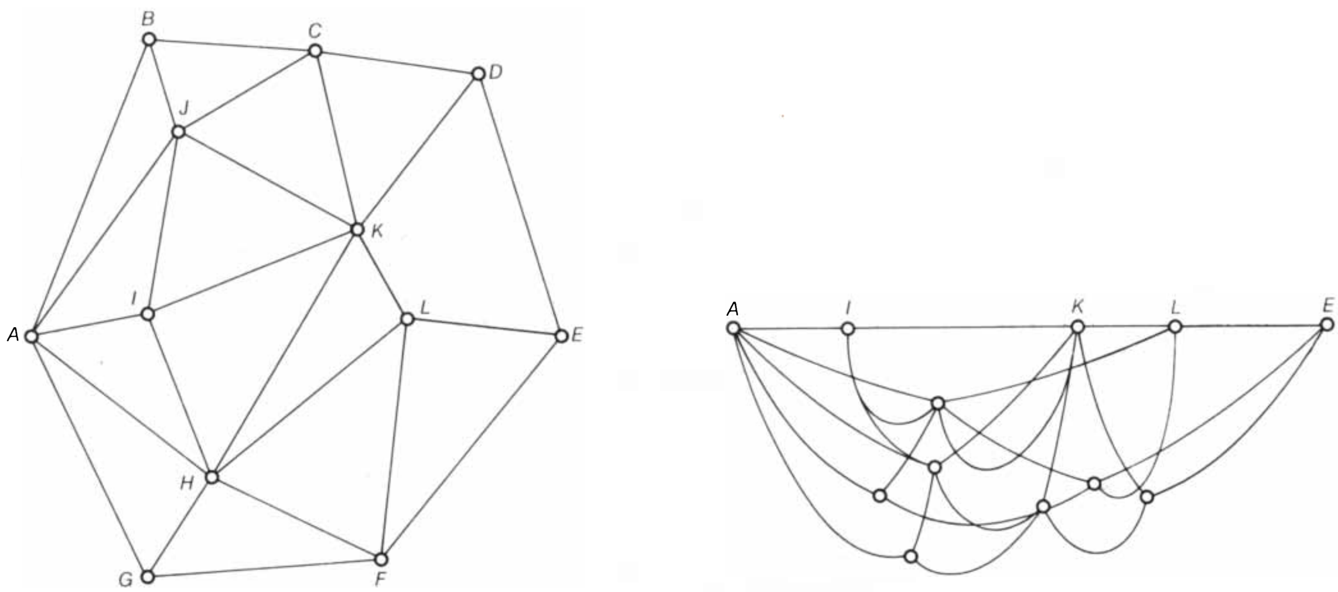
computer employing the fastest sorting algorithms. These require on the order of $n \log n$ steps, where n is the size of the sequence and log represents the logarithm function. Linear time is certainly superior to this in principle, but one shudders to imagine the size of the spaghetti gadget needed to win such a contest. SUPERDUPERSAG would have to be constructed in space and slammed against the moon.

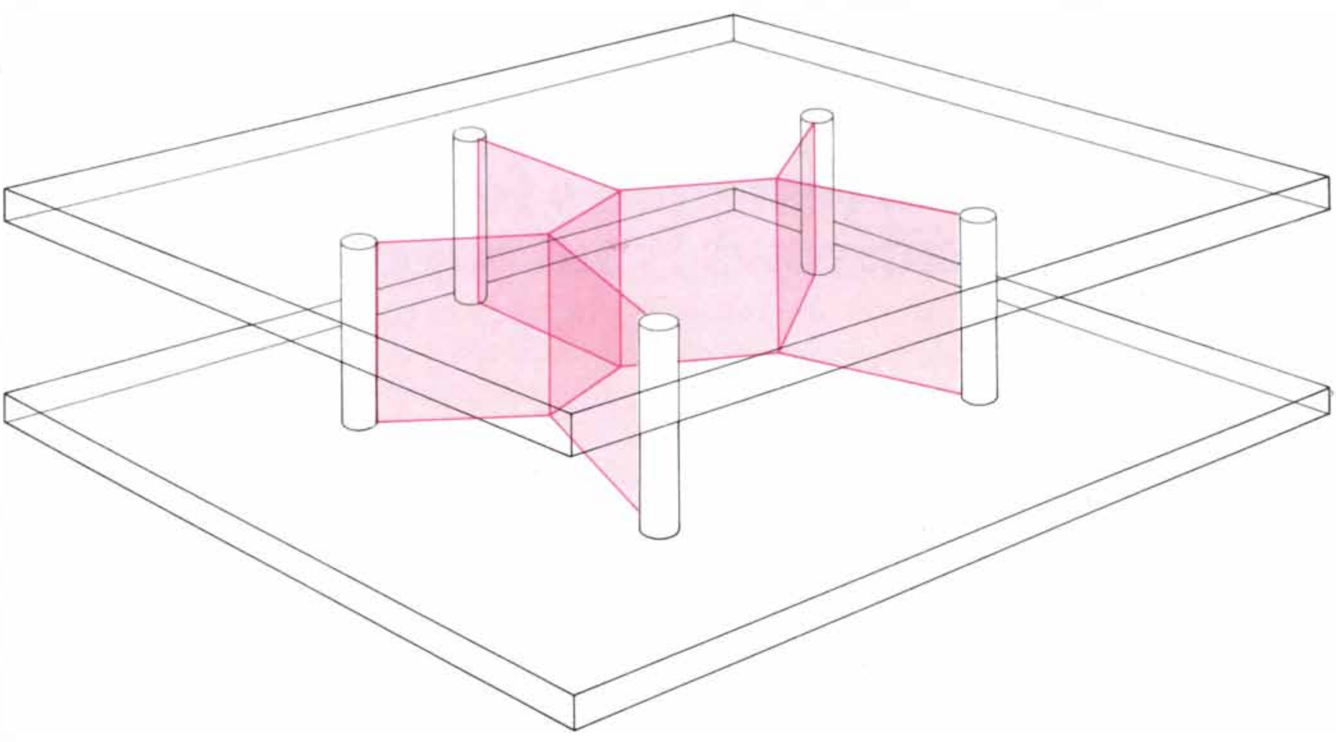
The next gadget in my collection computes the convex hull of n points in the plane. The convex hull is just the smallest convex region containing all n points. It is entirely defined by its boundary, a polygon that has one of the points at each vertex. The gadget that computes the boundary is made from a large board, some nails and a rubber band. I call it RAG, short for Rubber Band, Nails and Board Analog Gadget. It would have been nice to include "nails and board" in the acronym, but one would end up with a grotesque name such as RUNBAG.

To set up RAG simply drive n nails into the board at positions corresponding to the n points in the plane. Then pick up the rubber band, stretch it into a large circle surrounding all the nails and release it. The rubber band will snap into place, precisely defining the polygonal boundary of the convex hull.

Here again a linear amount of work precedes the analog operation of releasing the rubber band. It will take a certain number of seconds to determine the position of each nail and then to drive it into the board. Once the rubber band has been released, noting the ver-



An analog device for finding the shortest path between two vertexes in a graph



A soap-film solution to the minimum Steiner-tree problem for five points in the plane

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What's the difference between the wagons from Renault, Volvo, and Mercedes? On the one hand, all three are engineered to carry a load in a very un-wagonlike manner. They come equipped with rack-and-pinion steering, front and rear anti-sway bars and sophisticated engines with 2 litre-plus displacement. And they carry an impressive list of luxury credentials at no extra cost. Features like AM/FM stereo, rear wiper/washer with defogger, ergonomically-designed seats and even air conditioning. But, while all three cars have much in common, there is one thing you'll carry in the Volvo and Mercedes that you won't in a Renault: larger payments. The front wheel drive Renault Sportwagon: the affordable European at **$9,595.** Manufacturer's suggested retail price. Tax, license, destination charges, metallic clearcoat paint ($150), optional equipment extra. **Sold by American Motors. Safety belts save lives.**

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texes of the convex hull takes somewhat less than linear time. Only the nails touched by the rubber band need to have their position recorded.

The fastest digital algorithm known for finding the convex hull requires on the order of n log (log n) steps. This is so close to being linear that perhaps only a RAG machine the size of the solar system would be able to compete with a digital computer running the algorithm.

The function of a third gadget is to find the shortest path joining two vertexes of a graph. In this context a graph is a network of lines, or edges, joining the points called vertexes. In some graphs the edges can have different lengths, and it is this kind of graph that serves as input to STAG, an analog gadget that uses string to represent graphs. Specifically, each vertex is represented by a small brass ring. If two vertexes are joined by an edge in the graph, the corresponding rings are connected by a piece of string cut to the right length and supplied with a hook at each end.

To find the shortest path between the vertexes u and v in a graph, pick up the network by the rings u and v, holding one ring in each hand. Then pull the network taut. Instantly the shortest path stands out as a sequence of taut strings at the top of the network; all the strings representing edges that are not in the shortest path remain more or less slack [*see upper illustration on page 22*]. If the rings are labeled with the names of the vertexes they represent, one can now read off the labels along the shortest path.

If the size of a graph is measured by n, the number of vertexes, both pre- and postprocessing require at most a linear number of steps. The analog phase of the computation is as usual virtually instantaneous. The fastest digital algorithms known for the problem take on the order of n^2 steps.

It has been mildly irritating to include the pre- and postprocessing phases in analyzing the relative speeds of these gadgets, but honesty compels me to include them as part of the overall operation. How else could one specify a problem or interpret the gadget's output?

Some gadgets require no processing at all because they are incorporated into a system that uses the results directly. Two examples that come to mind are the needle-sorter once widely used in libraries and a trick for balancing a plate of food on one finger. In the needle-sorter a set of cards with notches and holes along one edge serves to show which books are due on a given day. The cards are stacked and a long needle is inserted into the hole corresponding to that day. When the needle is lifted, only the cards with holes at that position come with it. The notched cards slip off the needle and remain in the stack.

The balancing trick was shown to me by mathemagician Ronald L. Graham of AT&T Bell Laboratories. Graham begins by holding aloft a plate of food on a thumb and two fingers, widely spaced. As he draws the three digits together the plate's center of gravity remains between them because the digit supporting the least weight slides most easily. The final intrusion of another finger supports the center of gravity well enough to balance the plate. Graham warns beginners to practice the trick carefully before demonstrating it at Thanksgiving dinner.

Up to now I have applied gadgets only to problems that already have a reasonably fast algorithmic solution. Such problems are said to have polynomial-time complexity, because the number of steps needed to solve a size-n instance of a problem can be expressed as (or at least is bounded by) a polynomial function of n. For example, the solution time might be proportional to n itself, to n^2, to n log n or to n^{27}. There are other problems, including some of practical importance, for which no polynomial-time algorithm is known; the best algorithms seem to require an amount of time that grows exponentially with the problem size. Typically the solution time is proportional to 2^n, a function that increases faster than any polynomial. For a large instance of such a problem, or even for one of moderate size, the time needed is exorbitant. Why not try to solve some of these difficult problems with a gadget?

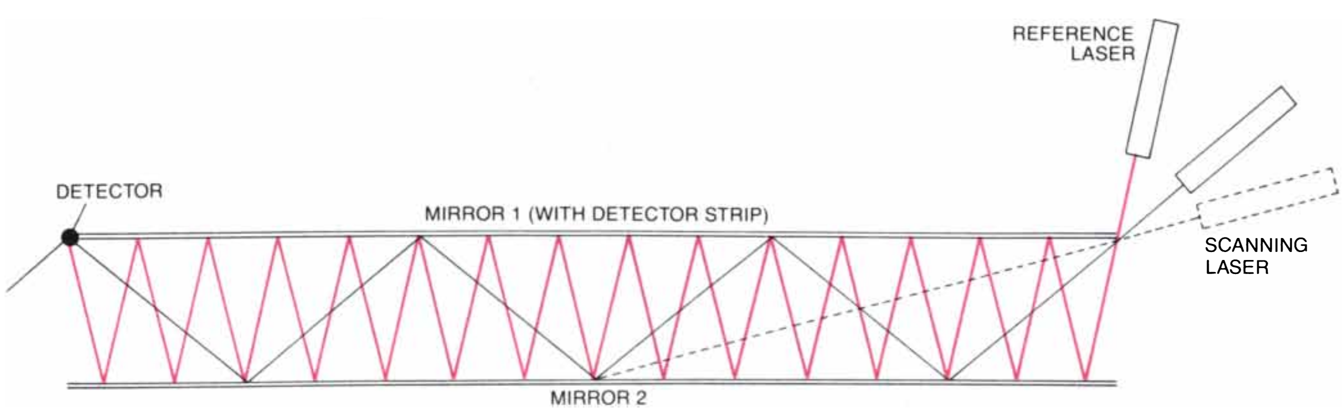
One candidate problem is to find the longest path joining two points in a graph, which turns out to be much harder than finding the shortest path. Indeed, the problem is said to be NP-complete, a property that appears to condemn it to eternal algorithmic intractability. (Readers who would like to know more about NP-completeness, and who do not mind an occasional bit of mathematical notation, are urged to consult the excellent book *Computers and Intractability: A Guide to the Theory of NP-Completeness,* by Michael R. Garey and David S. Johnson of AT&T Bell Laboratories.)

On occasion a little force must be brought to bear on a problem. Take the network of strings that was stretched taut to solve the shortest-path problem. When you pull on it even harder, first one of the strings breaks, then another. Eventually, just before the network falls into two pieces, all the strings that remain intact are taut. You have solved the longest-path problem.

Or have you? The method is effective for some networks but not for others. Readers may enjoy discovering examples of both kinds of graph. At each stage in the stretching where more than one string is taut, assume the worst about which one breaks.

Perhaps one should have known better than to attempt a snappy analog solution to an NP-complete problem. The theory of computability, however, says only that an NP-complete problem is hard for a digital computer to solve; there is nothing to indicate that it should not yield to analog methods. Therefore let us try again.

The minimum Steiner-tree problem asks that n points in the plane be connected by a graph of minimum overall length. The task is virtually the same as



The Laser Analog Gadget demonstrates that 15 is not a prime number

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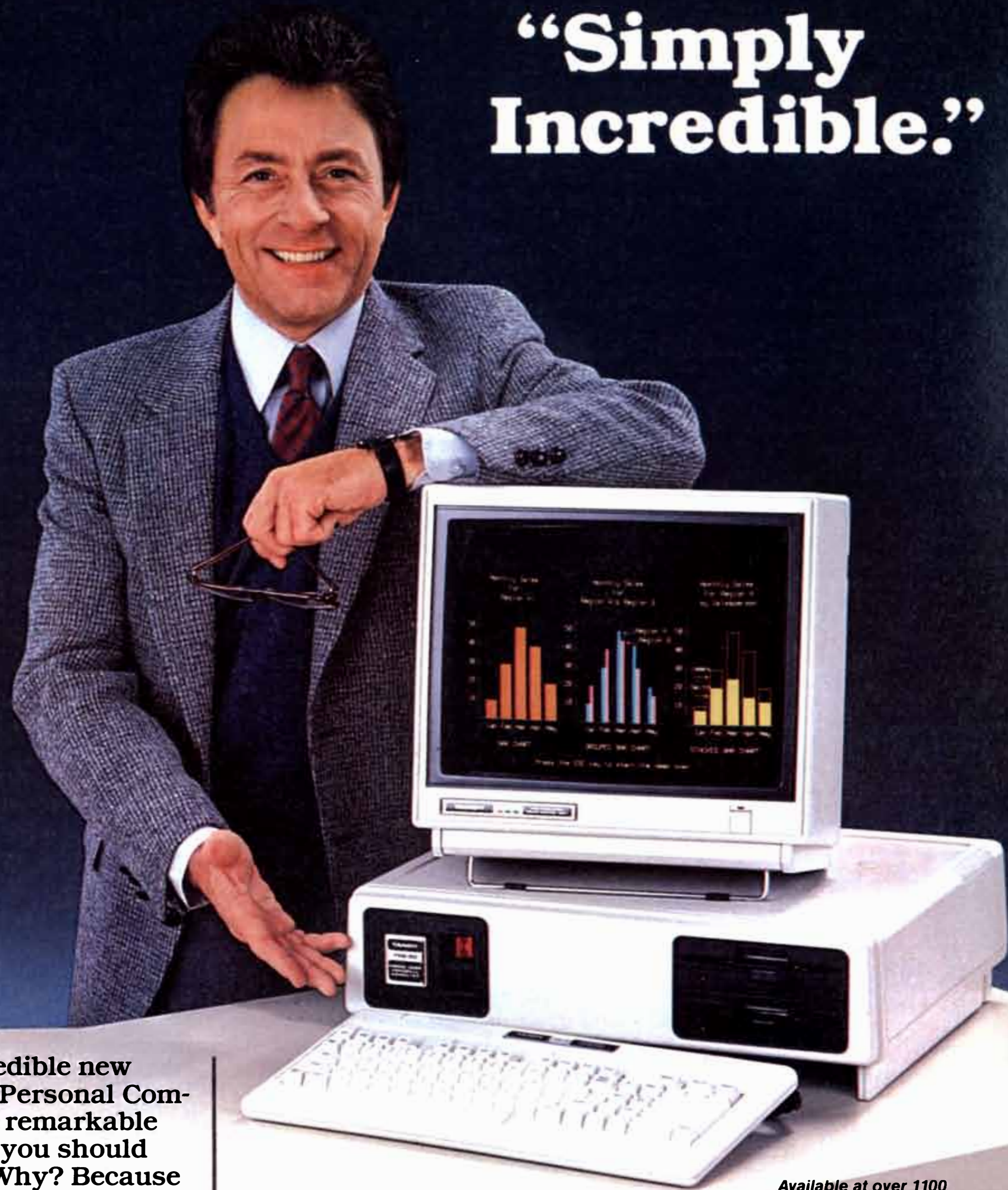

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that of connecting n towns by a system of roads whose total length is a minimum. One is allowed to take as vertexes of the graph not only the n original points but additional ones as well, which represent crossroads in the countryside, so to speak. It is not hard to see that the minimum graph must be a tree: a graph without closed loops. It turns out, moreover, that any additional vertexes in the minimum tree are joined to three other vertexes by edges making angles of 120 degrees with one another [*see lower illustration on page 22*].

The minimum Steiner-tree problem is *NP*-complete, and there is no algorithm known for it that requires fewer than 2^n computational steps (where n is the number of vertexes). Nevertheless, there is a strange device I call the Bubble Analog Gadget that seems to find a soap solution to the problem. Attach two parallel sheets of rigid transparent plastic to a handle and insert pins between the sheets to represent the points to be spanned. Now dip the gadget into a soap solution and withdraw it. There before your eyes is a soap film connecting the n pins in a beautiful Steiner-tree network.

Joy at the appearance of this solution is premature, however. How can one be certain that the tree generated is the one of minimum length? As it happens, the soap film always creates the shortest possible network for a given topology, but there may be another topology in which a still shorter tree could be formed. Depending on the configuration of pins and on the angle at which the gadget is withdrawn from the solution, the length of the film network may or may not be the absolute minimum. Once again an attempt to solve an *NP*-complete problem by analog methods has come to nought.

One of the most famous computational problems is to decide whether a given integer N is composite or prime. (If it has factors other than N and 1, it is composite; otherwise it is prime.) There is a very fast analog solution to this problem based on LAG, the Laser Analog Gadget. Set up two parallel mirrors, *M1* and *M2*, and two lasers so that both lasers bounce light back and forth between *M1* and *M2*, as is shown in the illustration on page 24. The angle of one laser is adjusted so that its light bounces N times from each mirror and finally strikes a detector at the end of *M1*. The second laser is placed in such a way that its beam is initially coincident with that of the first laser, but the second beam is subsequently swept through a range of angles.

As the angle of the second beam changes it periodically strikes the detector at the end of *M1*. The mirror *M1* also has a detection strip running its length, so that whenever two beams strike the same point, the coincidence can be detected. A simple electronic circuit monitors both the detector at the end of the mirror and the detection strip. If they report a simultaneous coincidence, the circuit turns on a light. The signal indicates that the number is not prime but composite. For there to have been a double coincidence the second laser must have bounced its light n times off the mirror *M1*, and n must also divide N evenly.

When speaking of the difficulty of deciding whether a number N is composite or prime, one must be careful about measuring the size of the problem. If the size is defined simply as N, there are digital algorithms that can solve the problem in polynomial time. It is generally considered fairer, however, to state the size as $\log N$, because this is the length of the string of digits needed to represent N. By this measure no one knows whether the composite-prime decision problem is *NP*-complete or not. Based on the success of the LAG computer and the failure of other analog gadgets in solving intractable problems, might one conjecture that the problem is not *NP*-complete?

Throughout the foregoing discussion I have dodged the important issue of the feasibility of constructing gadgets such as SAG, RAG, STAG, BAG and LAG. Although each of the gadgets can be built and persuaded to work, after a fashion, on small problems, it would be silly to suggest that one construct them with serious computations in mind. Yet, considered in the context of an ideal world in which ideal materials are available, each gadget works, by definition, exactly as described. It is a fascinating question to pursue (in this ideal realm) just what analog computations are possible.

I would be interested in hearing from readers with other gadgets to describe. As things stand, I do not know who invented either of the first two gadgets described here; they are part of computer-science folklore. The string gadget seems to have been invented by Marvin L. Minsky and Seymour A. Papert of the Massachusetts Institute of Technology. The bubble gadget I found in Cyril Isenberg's wonderful little book *The Science of Soap Films and Soap Bubbles*. The laser gadget is my own invention.

The laser gadget reminds me of a little problem readers might enjoy pondering. There is a square box in the plane and its interior walls are lined with perfectly reflecting mirrors. In the ideal realm mentioned above it would be possible to remove the point at one of the corners and to shine a one-dimensional beam of laser light into the box through this vanishingly small hole. The resulting gadget computes something quite profound about the angle of the beam. The answer depends on whether the light ever emerges from the box, but what is the question?

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"The State of Connecticut has earned a national reputation for the resources we offer to advanced-technology industry—and for the variety and high quality of such industry we have developed and attracted," says Bill O'Neill.

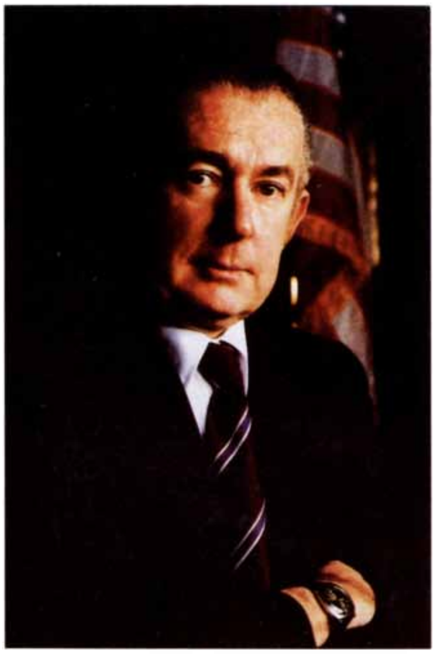
In September of 1982, Governor O'Neill announced Connecticut's high-technology policy and appointed a High Technology Council to identify strengths and develop plans to "retain and enhance Connecticut's place as a leader in the field." As the preliminary report was filed, Connecticut already provided features such as a positive business and tax climate; a broad-based industrial infrastructure; substantial formed capital, from both state sources (the Connecticut Product Development Corporation and the Connecticut Development Authority) and private sources; plenty of accessible, high-quality educational facilities; a skilled labor pool; a strategic geographic location; scenic and diverse "quality of life" factors; and, as the governor suggests, a tradition of innovation.

The Council's final report was issued in January. By that date Connecticut had attracted nearly 650 high-tech companies employing more than 148,700 workers. Connecticut ranked among the top three states in America in the percentage of manufacturing jobs in advanced technology, the number of industrial research laboratories per capita, the number of patents granted per capita and the number of engineers per capita. These were some of the strengths on which the Council would build.

Since Eli Whitney's day, the taciturn Connecticut Yankees who work at, manage or seek to attract advanced-technology firms have tended to be modest about their accomplishments. They are too busy getting on with business.

In a quiet grove overlooking the Trap Falls Reservoir in Shelton, the advanced-technology center of ITT was built. There, 700 or more scientists, engineers, programmers and technical and support personnel work on new circuits and systems for telecommunications, very-large-scale integrated circuits and dramatic increases in computer power.

The Connecticut site was selected largely because it is close to New York, Boston, Washington and the research laboratories of many leading universities and so provided the amenities that



Connecticut Governor William A. O'Neill is the state's top manager —and chief salesman.

technologically creative people seem to need. Shelton is symbolic of what has been happening in Connecticut, although corporate growth in advanced technology is occurring across the state's 5,000 square miles.

"The 'new Connecticut' is a balanced blend of strong, growing industries, aided by the fast-developing communications field and other high-tech areas," says Don Klepper-Smith, corporate economist at Southern New England Telephone Company (SNET). "The communications industry now employs approximately 25,000 in the state, about 1.4 percent of the manufacturing work force." After more than a century of service to Connecticut industry and consumers, SNET entered the newly unregulated marketplace in January, 1983.

At the same time, SNET guided its core business, the basic Connecticut Telephone Business, through a number of changes and achieved the best financial year in its recent history. Revenues reached nearly $1.2 billion.

SNET president and CEO Walter H. Monteith, Jr., emphasizes that "while our new developments have received the most media coverage, we remain fully committed to providing service to 1.3 million Connecticut customers." To meet large Connecticut businesses' need to move vast quantities of voice, data and video images over the same circuits, SNET has pioneered in the installation of state-of-the-art fiber optic transmission. By the end of this month, a $15 million fiber optic route, providing high-quality digital transmission in a cost-effective way, will be in service from Stamford to Hartford, the corridor along which Connecticut's large businesses are clustered. This network will reach 60 to 70 percent of SNET's customers.

SNET's initial unregulated venture was its Sonecor Systems division. The firm has a carefully planned strategy, described by Monteith. "We believe that to move too slowly amid tumultuous change and intense competition in the communications industry represents a greater risk than any other we would encounter." In September of 1983 Sonecor Systems introduced the first information management system that completely integrates computer and communications technology. The Sonecor System 2001 is designed for firms with 200 to 22,000 users.

To date, there are about 25 of these systems on order or in place. Two of SNET's first customers were Olin Corporation in Stamford and Stanley Works in New Britain. A 2001 will also provide communications for New Haven's Science Park. A second key 1983 development was LightNet, a joint venture with the CSX Corporation, the nation's largest transportation and natural resource company. LightNet combines SNET's experience with fiber optic technology with 5,000 miles of CSX Railroad right-of-way.

Another important SNET offering is cellular mobile radio service, which is a series of short-range radio transmitters covering geographic "cells." This advanced technology makes high-quality phone service also highly portable. SNET has received its first construction permits from the FCC for the Hartford and New Haven areas and expects to be in business before the end of 1984.

Monteith, summing up SNET's passage into a new competitive era, says, "We have *relearned* that as our company moves into the future, we cannot move away from the fundamentals that have given Southern New England Telephone its strength. We enter into new ventures with the full understanding that our first responsibility is to Connecticut. We go forward with the same commitment to quality that has characterized our business for the past century."

In Connecticut, innovation is a tradition. But even Connecticut Yankee ingenuity can benefit from financing to turn that spark of genius into reality. In Connecticut, help for the entrepreneur can come from CPDC—the Connecticut Product Development Corpo-

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ration, the first state agency of its kind in the nation.

Through specially tailored programs, CPDC helps Connecticut entrepreneurs meet the ever increasing costs of designing, developing and marketing new products and processes. CPDC Risk Capital Financing can cover the costs of developing a new product or process from initial concept through fabrication of a prototype. CPDC Innovation Development loans provide low-cost working capital to get products manufactured, marketed and distributed.

CPDC is a not-for-profit state agency; it does not require equity participation or a management position in exchange for financing. Risk Capital investments by CPDC are repaid by limited royalties on successful sales of financed products. Innovation Development loans are direct loans made by CPDC at below-market interest rates. Either or both programs may be utilized.

New products equal new jobs. Since its formation in 1973, CPDC has played a key role in the state's aggressive efforts to expand Connecticut's job base through economic diversification. CPDC is the centerpiece of Governor O'Neill's high-technology strategy for the 1980's: keep Connecticut industry competitive, growing and important for new technologies.

Millions of CPDC dollars have made possible new Connecticut products as diverse as computer programs and bathroom scales, robot cutting instruments and car-top ski carriers, all resulting in hundreds of new jobs.

As of mid-1984, CPDC has delivered good performance to match its economic promise. Royalty income more than equals CPDC's operating-overhead expenses and is drawn from a score or more of developed products on the market. The corporation is enjoying an ever growing flow of new applications from companies that have learned that being in Connecticut is advantageous.

George Martin, president of OWL Electronic Laboratories of Old Saybrook, approached CPDC with a proposal for a new project two years ago. His firm was then four years old. "The members of CPDC's board of directors were all people in business or finance or the universities," Martin recalls. "In their regular jobs, they're subject to rules and influences that don't affect them at CPDC. Our proposal was weighed in a straightforward manner and the arrangement has worked out well for all of the parties involved."

David Coffin, chairman of Dexter Corporation of Windsor Locks, is the seventh-generation descendant of the founder of the firm; Dexter was founded in 1767 and is the oldest company listed on the New York Stock Exchange.

Harold V. Fleming is Dexter senior vice president for corporate development. "We work closely with the state," he says, "to review ideas and seek out new technologies appropriate for Dexter Corporation. We'll go anywhere to look at a promising commercial idea." Stiles Twitchell, a Yale graduate, reports to Fleming as manager of technical development. "We're in frequent contact with the Connecticut Product Development Corporation," Twitchell states. "They know us as an excellent prospective resource and we are always ready to talk with them."

The Connecticut Development Authority (CDA) is in its 11th year of developing public financing for private-sector job-generating investments.

Announcing a revolutionary advance in energy conservation:

Teamwork.

Consider America's first computerized energy audit program, provided by Northeast Utilities as a service to Connecticut businesses statewide. In the last two years, more than 3,500 businesses have used it to cut their energy costs. And that's just the beginning.

In Connecticut, NU works with businesses and towns to create programs that:

- provide builders and designers of new buildings with recommendations that can reduce energy use by nearly half
- assist municipalities in energy management
- and even help cities and towns improve the efficiency of street lighting.

Conservation. It brightens the bottom line for business. And it's easy when we all work together.

NORTHEAST UTILITIES
NU
THE CONNECTICUT LIGHT AND POWER COMPANY
WESTERN MASSACHUSETTS ELECTRIC COMPANY
HOLYOKE WATER POWER COMPANY
NORTHEAST UTILITIES SERVICE COMPANY
NORTHEAST NUCLEAR ENERGY COMPANY

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Chaired by commissioner of economic development John J. Carson, CDA has arranged approval of $1.5 billion for 1,100 projects, which have created or retained nearly 125,000 jobs. CDA's excellent performance of its task is exemplified by Connecticut's jobless rate—one-third lower than the national average, and eighth lowest in the country.

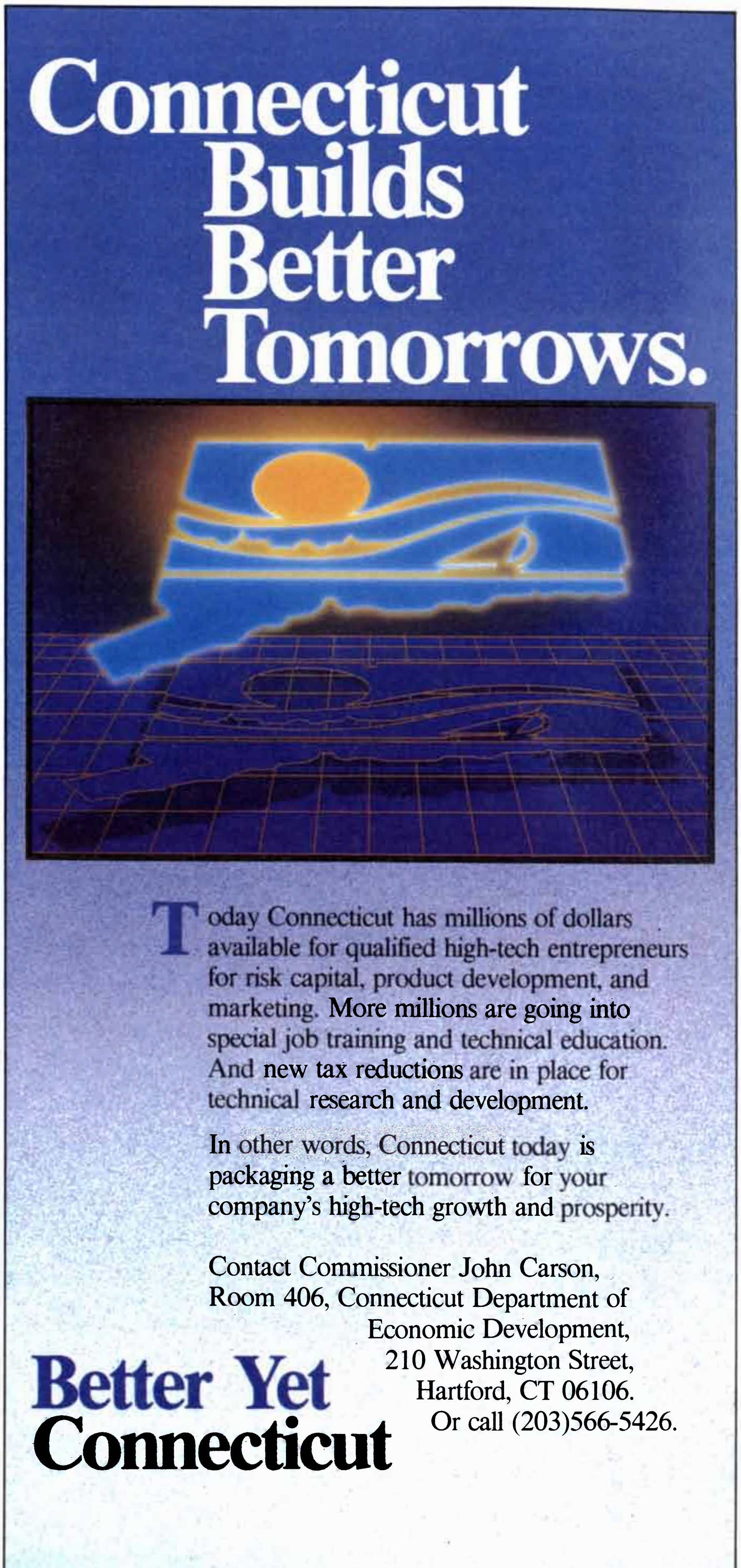
"Though the support of Connecticut's financial community may not be highly visible to the public, its commitment behind the scenes has made the whole job-creating process work," says CDA executive director Richard Higgins. "Connecticut's banks and insurance companies ... are, in many cases, the purchasers of CDA bond issues, and in other cases they are the lenders extending mortgage credit or construction, interim or matching-fund program financing."

TIE/communications has expanded in 12 years from a Greenwich garage to sales of nearly $300 million as a manufacturer of advanced-telecommunications equipment. Gerald Poch, president of its subsidiary Technicom International, attributes CDA's "aggressive assistance" as a key factor in TIE's corporate growth. Gerber Scientific employed CDA partial financing to add nearly 200 people to its work force in Manchester and South Windsor in just seven years. During the single year ending June 30, 1983, CDA financing programs for over 50 Connecticut companies totaled in excess of $400 million and 18,500 jobs.

Zygo Corporation, based in Middlefield, started up in the bedroom of a house on Wesleyan University's nearby campus. The company designs, manufactures and markets high-performance, laser-based, noncontact electro-optical measuring instruments and systems. Zygo president Paul Forman describes his company's beginnings:

"Our funding came partly from Wesleyan, partly from Canon in Japan and later from the Connecticut Development Authority." Zygo leases its 100,000-square-foot Middlefield facility under a net lease with CDA.

Most business and industry in Connecticut is electric-powered by Northeast Utilities, a holding company based near Hartford. The United Illuminating Company services the Bridgeport-New Haven coastal area. NU has concentrated heavily on proper management of the power needs of Connecticut industry; the utility has standing plans to use fuel cell technology, its existing and successful nuclear facilities and conservation to ensure that the state's present and future



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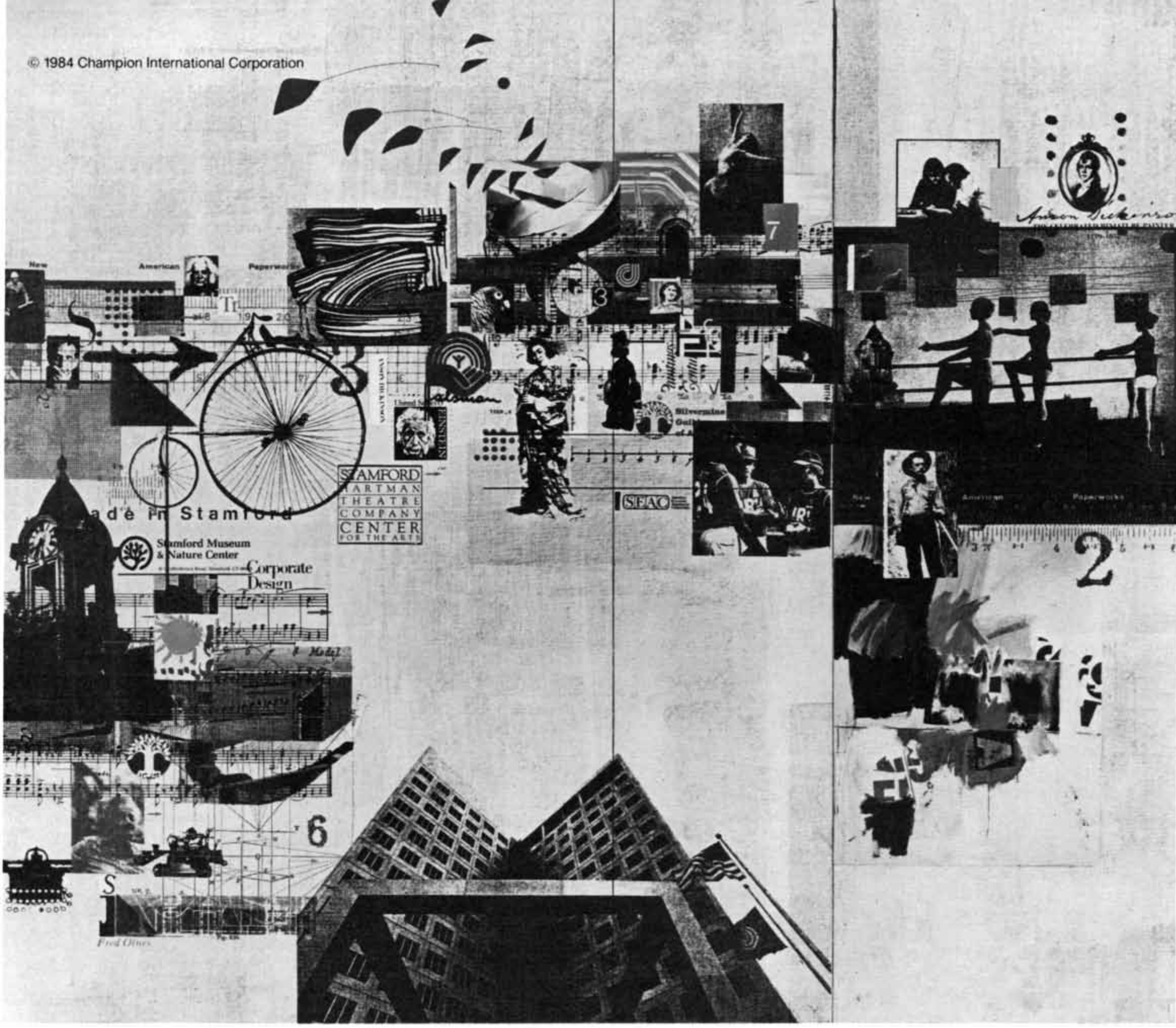

Why should a forest products company be concerned about the quality of life in Fairfield County?

Although it's a long way from our forests, mills, and plants, Fairfield County is home to the 700 Champion people who work at our corporate headquarters in Stamford–and to their families and friends. In Fairfield County, and in all communities where Champions live and work, contributing to a healthy, vital social and cultural environment is, we believe, more than a nine-to-five job.

So Champion and Champion people are involved: in social services, in education, in community organizations, in the arts.

While we recognize that our first obligation is to remain a strong and profitable producer of building materials, paper, and packaging, we also believe a company's responsibilities include how the whole business is conducted, every day. In our complex and demanding world, that means corporations must strive to rise above the bottom line and consider thoughtfully the impact of their actions: on the communities where they operate and on the society as a whole.

The economic future of the nation–including Fairfield County–depends on strong and responsive business enterprises. And, in turn, the long-term viability of business is linked to how well it meets all its responsibilities to the society of which it is part.

That's why our company and our people are concerned about the quality of life in the communities where they live and work. Champion and Champions: Planting seeds for the future in Fairfield County.

Champion

Champion International Corporation

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Stamford, Connecticut 06921

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electric power needs will be met.

"I am interested in fresh, new ideas," says NU's young (44) chairman, Bill Ellis. "There is no inertia at Northeast when it comes to applying industrial methods to utility operations."

Chairman Ellis is also president of the Connecticut Economic Development Corporation, a consortium of industry leaders who work to keep Connecticut at the forefront of American economic growth.

"For technological growth to continue in Connecticut," says Lane DeCamp of General Electric's GEVENCO venture-capital unit, "the fundamentals must be there. Connecticut tends to attract the kind of advanced-technology firm that needs the state's triad of adequate financing, excellent management and access to markets."

GEVENCO is the largest of the fraternity of Connecticut venture-capital firms.

Bob Sorenson is chairman and CEO of Norwalk-based Perkin-Elmer and also a member of Governor O'Neill's High Technology Council. "Our company depends not on what we have been but on what we can become," Sorenson says. "Advancing the frontiers of technologies is the name of our game." Perkin-Elmer's Connecticut facilities extend from the manufacture of analytical instruments to computerized chemistry to optics for NASA's space telescope.

The Connecticut Technology Institute at the University of Bridgeport has been established to help incubate new advanced-technology industry. Both Perkin-Elmer and the High Technology Council were instrumental in building CTI, the only such facility in Fairfield County.

CTI is an attempt to provide a critical mass of personnel, research grants, financing, ideation and product development.

CTI's Technology Council includes 100 of the state's senior scientists and encourages the free flow of information about what is on the frontier of development between the laboratory, the classroom and the private sector.

Paul Phelpo, project director of the U.S. Congressional Office of Technology Assessment, says New Haven's Science Park "has all the best features .... In fact, if there's anything that's unique about it, it's the degree to which all of the parties to the game are participating." In Connecticut, cooperation among industry, academia and government is looked on as good business sense, with the Park as one case in point.

An interested and powerful coalition was assembled from among strong organizations already working within the state. The Science Park Development Corporation was created with two important goals: to create a center for high-technology economic activity and expansion, and to upgrade disadvantaged surrounding New Haven neighborhoods. Governor O'Neill, the Connecticut Office of Economic Development and New Haven mayor Biagio DiLieto hammered out a system of tax-based incentives that created an "enterprise zone" in the area. A $5 million venture-capital pool was formed. Yale University, which adjoins the new Park, contributed its own human and financial resources.

Scientific instruments are important to Connecticut's economy. Perkin-Elmer optics technology made NASA's space telescope possible.

Yale made its Office of Cooperative Research available. Companies associating themselves with the new Park have access to Yale's research, libraries, student interns, laboratories and faculty. Linkages to advanced-technology industry are likely to prove substantial given the university's strength in computer science, medicine and the physical sciences. Says Mayor DiLieto, "The dynamism and creativity demonstrated by the entrepreneurs who will develop their businesses here represent the highest ideals of our free-enterprise system."

Olin Corporation, one of three dozen major international corporations headquartered in Connecticut, is responsible for much of what Science Park will become. Olin faced a problem common to other industrial leaders: departure

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Quality of Life

"Quality of life" is often cited by Connecticut companies recruiting managerial and technical personnel. Visitors find themselves surrounded by 300 years of living history amid some of New England's stunning scenery, ample recreational opportunities and a diversified cultural atmosphere. Along the Sound, one can spend days exploring Mystic Seaport with its *Charles W. Morgan*, last of the great wood whaling ships. There is live theater year-round at the Hartman in Stamford, the Long Wharf in New Haven, the Westport Playhouse and more.

The Berkshire foothills in northwest Connecticut offer excellent skiing and golf. One can spend the night at historic Under Mountain Inn near Salisbury, where enterprising Yankees hid naval supplies for the King's Rangers before the Revolution, and then canoe along the Housatonic.

One can walk the trails through the Mianus Gorge Reservation in northern Stamford and see woodlands that have remained untouched for three centuries.

"Of all the beautiful towns it has been my fortune to see, this is the chief," said Hartford resident Mark Twain. The capital city's huge insurance industry and several colleges and universities support a wide range of restaurants, opera, ballet, the Wadsworth Atheneum art museum, a symphony orchestra and acres of parkland.

"I was drawn first to the miles of rivers and streams, the glowing forest pools, and the meandering marshes and coastal inlets," writes photographer Steve Dunwell in *Connecticut—A Scenic Discovery*, whose cover photograph of the *Charles W. Morgan* appears above. Connecticut's coastline gives access to Manhattan's Broadway theatre district, less than an hour's drive from Stamford, and to the America's Cup races in Newport, Rhode Island, an equal distance from eastern Stonington.

One night during the War of 1812, British forces moved up the Connecticut River, pausing for their officers to dine comfortably at the Griswold Inn. Having paid their bill, they then set fire to the elements of the American navy anchored in Essex Harbor.

Save only for that last act, a Connecticut Yankee might duplicate both the trip and the dinner this very weekend.

from a community with which it had shared three-quarters of a century of life and work. The solution came from Olin's resourceful chairman and president, John Henske. A Yale graduate and former manager of the New Haven operation, Henske was determined to move honorably and responsibly.

So Olin donated all its land and buildings to the Science Park Development Corporation. Olin will maintain and secure the property until the Park can assume such tasks and has also loaned the Development Corporation $500,000 to renovate and adapt the complex.

Henry Chauncey, Jr., former secretary of Yale and president of Science Park Development Corporation, says, "We are very pleased that the Sonecor Systems division of Southern New England Telephone Company will install its new telecommunications system in the Park. This will give entrepreneurs and established firms access to a modern telecommunications system."

Says Hugo Kranz, Jr., of Data-Graphics, another Park tenant, "We left Houston and chose Science Park to start up our company for three reasons: a university setting would encourage the interactive computer graphics technology in which we are interested, New Haven would provide a competitive operating cost advantage long term, and Connecticut would be an enjoyable place to live."

Science Park offers a variety of opportunities that demonstrate the O'Neill administration's commitment to strengthening the state's competitiveness in luring and nurturing advanced-technology industry and offering additional benefits to the high-technology firms already in place. Besides several million dollars for site improvement, the state Office of Economic Development has made marketing aid available. The state benefits as development attracts more and larger companies to the greater New Haven area.

"The relationship to Yale is key to our success," says Chauncey. "Virtually all of our embryo companies have some relationship to Yale—a faculty member, a laboratory, students—some sort of working together."

A. Bartlett Giamatti, president of Yale, agrees. "Science Park is a tremendously exciting venture that will help to revitalize the center of our city," he says.

The Rogers Corporation, founded in 1832 in Manchester, applies polymer chemistry and process technology to meet needs in electronics and other industrial markets for engineered

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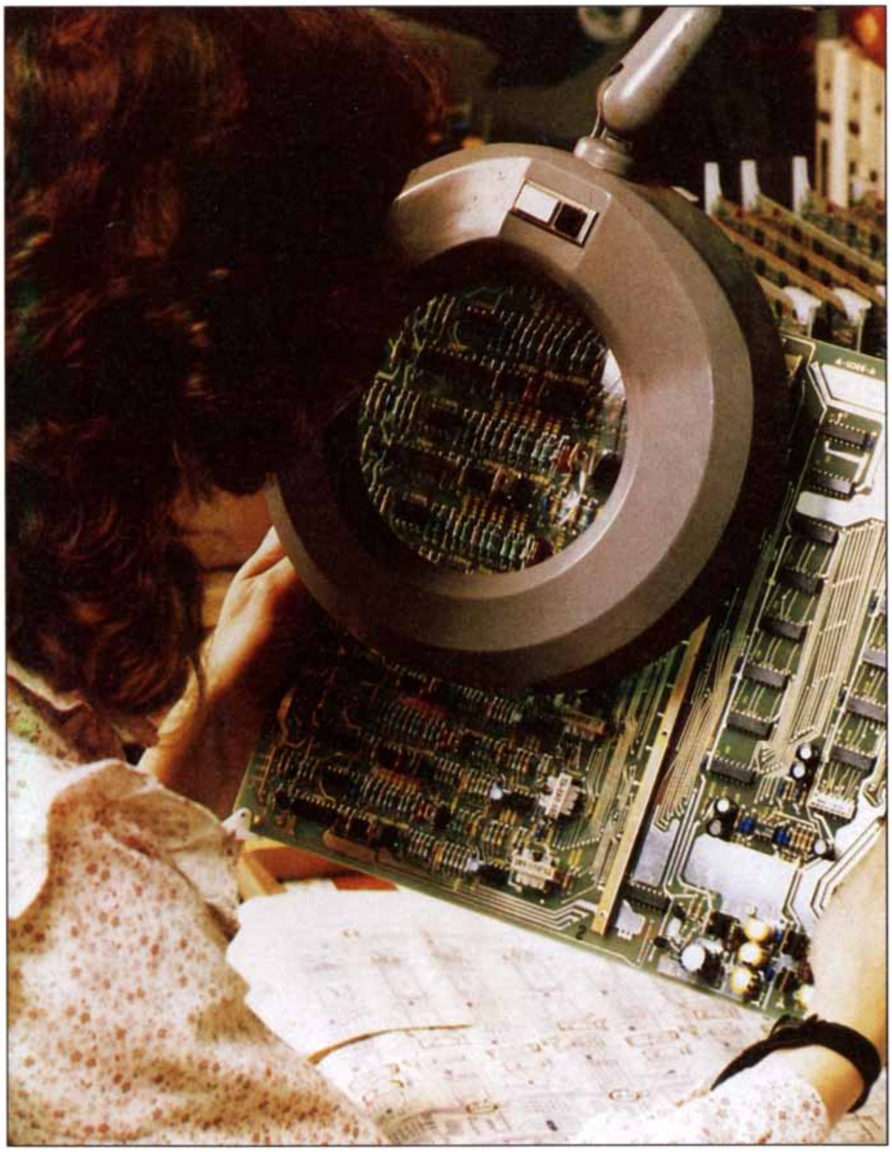

Connecticut's skilled people make advanced technology work. Above: Production under way at TIE/communications, Shelton.

"There's obviously a broad awareness of the 'megalopolis' that stretches from Boston to Washington, but not so many people know there's a gap right in the middle of it," states Russ Meyerand, vice president for technology at United Technologies Corporation. "That gap is Connecticut, and there's room here for a lot of growth, activity and expansion."

United Technologies, based in Hartford, has become one of the world's largest companies, with over $14 billion in 1983 sales and over 190,000 employees worldwide. UTC's Pratt & Whitney division in East Hartford is a major state employer in the technologically sophisticated aero-engine industry. Norden Systems develops radar and guidance products in Norwalk. Hamilton-Standard manufactures astronaut space suits in its complex near Bradley International Airport. Otis Elevator is headquartered in Farmington. The famous Sikorsky helicopter is manufactured adjacent to the Merritt Parkway in Stratford. A new Building Systems division, merging the technologies of UTC's Otis people-movers and Carrier temperature-control operations, develops "intelligent buildings."

"High technology is in fact the common denominator of all we do," Meyerand states. A physicist himself and holder of 20 patents, Meyerand rapid-fires his firm's broad commitment to applied and basic research, in cooperation with academia and through UTC's own East Hartford Research Center. "We have a number of professional people who are adjunct professors at local colleges and universities. We're close to UConn's Institute of Materials Sciences. We've funded 10 science fellowships in Wesleyan's teaching program. I'm on the executive committee at the Hartford Graduate Center, which started several years ago as an extension of Rensselaer Polytech in New York but now has become a separate institution."

The United Technologies Research Center employs well over 1,000 scientists and engineers in four key areas: electronics and electro-optics, materials technology, power and industrial systems technology and manufacturing technology, particularly industrial lasers. The Research Center was founded in 1929 in support of UTC's aircraft operations and has since paced the company's expansion and diversification. The Center's charter is clear: conduct basic and applied research that will help to guide the corporation's technological future.

The Center resembles an engineer-

materials and components. Rogers maintains a number of cooperative research programs with leading universities; a Rogers director, Leonid V. Azaroff, is also director of the Institute of Materials Science at the University of Connecticut, 20 miles from Rogers' corporate headquarters.

UConn's Institute of Materials Science represents a successful example of Connecticut Yankee ingenuity. "The mission of the Institute," writes Azaroff, "is to foster quality graduate programs in the materials sciences and to provide graduates suitably trained to meet the needs of Connecticut's materials-based industries.... Twenty-one chief scientific officers of Connecticut's leading technological corporations serve on the advisory board."

UConn has come a long way since its founding as a land-grant college in 1881. Some 24,000 students now populate UConn's main Storrs campus and regional campuses at Avery Point in Groton and at Hartford, Stamford, Torrington and Waterbury.

UConn president John DiBiaggio, a member of Governor O'Neill's High Technology Council, reflects on the university's role as a catalyst in Connecticut: "To really take advantage of our resources, we need more rapid technology transfer, a hand-in-glove process. I believe we will see the period of time between research and application abbreviated. There is incredible potential at UConn and I feel very positive about the new ways it's beginning to be used."

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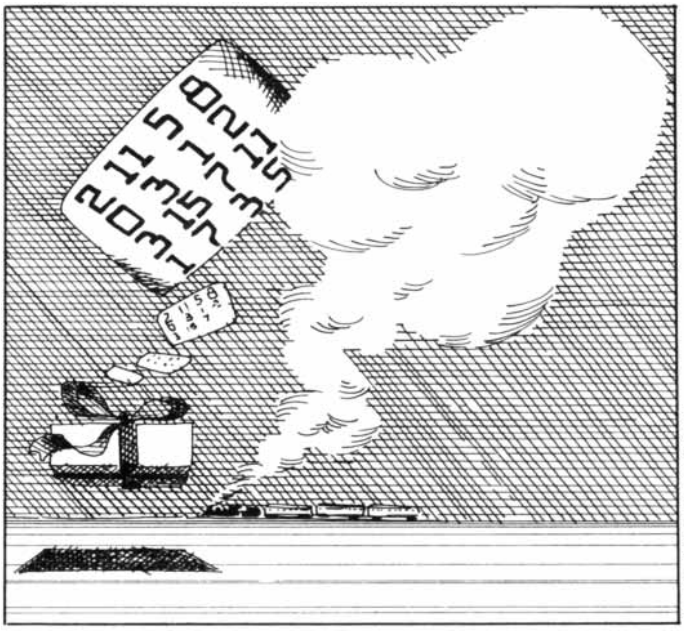
CAN YOU SAVE THE TRAINS?



An Equal Opportunity Employer

A smoke bomb has been set to explode in Grand Math Railway by the evil Numerians. However, they have left instructions for you to defuse it.

On a computer screen appears the number array above, and a message: "Pick any combination of four numbers in both different rows and different columns. There is an arithmetic operation which, with any four such numbers, produces the same 3-digit result. What, doomed one, is this operation?"

This puzzle is part of our continuing effort to attract problem-solvers. We're United Technologies, a worldwide company that's ambitious, innovative and growing. We operate on the leading edge of technologies such as microelectronics, aerodynamics, lasers, fiber optics, composite materials, and metallurgy. During the remainder of this decade, we plan to spend an average of $1 billion annually on R&D at our Research Center, Microelectronics Center and operating units to keep us out in front. Our operations include Pratt & Whitney, Otis, Carrier, Norden, Mostek, Sikorsky, Building Systems, Lexar, Inmont, Hamilton Standard, Essex, Elliot, and Automotive.

If you're an engineer or scientist interested in solving problems and growing with us, please write to Mr. Ray Lambert, United Technologies, Hartford, CT 06101. He'll send you more information about United Technologies — and, if you like, he'll also let you know whether your answer to our puzzle is correct.

UNITED TECHNOLOGIES

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ing campus at a large university. Huge wind tunnels facilitate aircraft and engine design. Elsewhere, metals are tested against extremes of heat and stress. Diesel-engine research and experimentation, laser spectroscopy, computer-aided manufacturing and robotic automation, advanced ceramics and metals composites, and energy and communications systems for buildings are all subjects of ongoing research.

Five years ago, Meyerand received the Eli Whitney Award from the Connecticut Patent Law Association in recognition of his scientific achievements. United Technologies is the true successor to inventor Whitney in Connecticut. Through its R&D facilities, its manufacturing and other sites across the state and chairman Harry J. Gray's constant focus on well-managed technology, the Whitney tradition continues strongly in the 1980's.

Ridgefield, in upper Fairfield County, is a small, classically picturesque New England town. In late 1977 Ridgefield attracted Dr. Harvey Sadow, president of Boehringer Ingelheim, an American specialty pharmaceutical and health-care company. Sadow became involved in Connecticut education by renovating and occupying the columned, red-brick former Ridgefield High School as Boehringer Ingelheim's headquarters. By 1979 the company had completed a research center for the discovery and development of products to diagnose and treat disease on 193 acres of land at the Ridgefield-Danbury town line. At present some 225 chemists, pharmacologists and other scientific personnel staff the center, along with over 600 personnel at Boehringer Ingelheim's manufacturing and headquarters facilities.

Sadow encourages his people to undertake university research and service. Dr. Kurt Freter, head of the firm's chemistry department, is also adjunct professor of chemistry at Wesleyan. Other employees share their expertise with students at Fairfield University, Western Connecticut State and schools in nearby New York.

"Advanced technology in Connecticut is logical," says Dr. Sadow. "It's here because of the people—they're the attraction."

Fairfield County has displaced Chicago as the second most popular area for corporate headquarters in America. GE, Xerox, Olin and Champion International are among 20 of the largest U.S. industrial corporations headquartered in Greenwich, Stamford and surrounding towns.

Albert Phelps, Jr., owner-developer of Merritt 7 Corporate Park in Norwalk, has been part of Fairfield's growth for years. Merritt 7's strategic location 35 miles northeast of New York City has attracted firms such as IBM, GE and Merrill Lynch. The Park adjoins the Merritt Parkway.

"Every productive facility or amenity has been built into Merritt 7," Phelps says. "Business needs a lot of things beyond office space."

Champion International Corporation, one of the nation's largest paper and forest product companies, is headquartered in Stamford at One Champion Plaza, designed by the renowned architect Ulrich Franzen. About 40,000 people pass through the Champion headquarters lobby each year—not on company business, but to visit the Whitney Museum of American Art, Fairfield County. This branch of the Whitney is the first to be outside New York and is supported by Champion. "We believe the Whitney project represents the kind of partnership modern corporations need to establish with other institutions in our society," says Champion chairman Andrew Sigler.

The world's first passenger bus was manufactured in Sweden by Scania-Vabus in 1911; soon the latest models will be transporting people in cities across America. "We look to about 200 units per year," says Saab-Scania of America vice president and general manager Rolf Sundeman, "and we'll assemble them here in Orange."

Saab-Scania evaluated many North American locations before selecting Orange. "I received telephone calls while I was still in Sweden," Sundeman recalls. "Some Canadian developers flew over to talk to me.

"But Governor O'Neill assured me we would be both welcome and productive in Connecticut. And this has proved to be so."

New York City, Boston's Route 128, Albany, Long Island and Providence all fall within a 100-mile radius of Hartford's Bradley International Airport. The airport, equipped to handle over 160 scheduled flights daily plus corporate and charter service, benefits from its inland location: it rarely closes due to weather conditions.

Ray Fitzgerald is general manager of the growing Combs Gates service center at Bradley; Combs Gates, a division of Gates Learjet, provides fueling and other ground service for scheduled and private aircraft. "We're expanding to meet increasing demands from corporate and industrial customers," Fitzgerald states. "We maintain the arriving and departing corporate aircraft and service their crews. We've outgrown our current quarters; we're building newer, larger service facilities on the airport grounds nearby."

The Thames River flows from Norwich down to Long Island Sound, through quaint towns such as Uncasville and Gales Ferry and past the tall ship *Eagle* berthed at the U.S. Coast Guard Academy in New London. Across the Thames from New London, Groton's waterfront harbors a different sort of vessel: Trident-class nuclear submarines, built by the Electric Boat division of General Dynamics. EB, with a Connecticut staff of over 20,000, occupies about 100 acres of riverfront. Its first Groton-built submarine was contracted for by the Peruvian navy in 1924.

"New technology is obviously important to us," says assistant general manager Emmett Holt. "We work with universities in Connecticut and across the nation. We assign specific projects to UConn. We've even arranged for the University of New Haven to conduct degree programs on-site here, for our employees."

Pfizer Central Research has just formally opened a 110,000-square-foot, $50 million expansion of its Groton facility adjoining Electric Boat. The worldwide research-based company attained sales of nearly $4 billion in 1983, with research and development well in excess of $200 million at centers in England, France, Terre Haute and the important 137-acre Groton site.

Pfizer's presence in Groton dates to 1948, when Connecticut's economy was adapting to the falloff of war-related industry. Formerly a shipyard, Pfizer's Groton compound now encompasses 75 buildings and employs 3,000 people in the firm's chemical, central research, quality-control and Howmedica divisions. Howmedica makes orthopedic implants.

In the new expansion, 86 biology and chemistry laboratories have been added to Pfizer's Groton complex. Scientists can jog through the campus-like facility at noontime and extend their exercise to the adjacent Avery Point campus of UConn's Marine Sciences Institute.

The presidents of the University of Illinois and the Memorial Sloan-Kettering Cancer Center serve on Pfizer's board. Pfizer president Gerald Laubach, himself a chemistry Ph.D., has encouraged support of chemistry research at New London-based Connecticut College. "The relationship with Pfizer has been a wonderful one for us," says college president Oakes

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Ames. "We hope Pfizer has found benefits here as well."

Connecticut has emerged as a site of preference for a growing number of biotechnical companies and institutions. Richardson-Vicks and Chesebrough-Pond's are both Fairfield County-headquartered firms with sales in excess of $1 billion. Bristol-Myers' world-known Clairol products have been manufactured in Stamford for years. The $3 billion firm is becoming a world leader in pharmaceuticals as well. In December, the architectural design was decided for the firm's new consolidated pharmaceutical research center in Wallingford. The $45 million first stage of the center will house basic research for anti-infective, anticancer and central nervous system therapeutic areas; it will be completed next year.

Wallingford is just 10 miles north of the Yale University School of Medicine, with which Bristol-Myers signed a unique agreement in 1983. For the next five years, Yale scientists will share with Bristol-Myers researchers their insights into the mechanism of cancer cell development and spread. "We want to develop some entirely new approaches," says Dr. Alan Sartorelli, chairman of Yale's department of pharmacology and director of Yale's Comprehensive Cancer Center. "We have many new leads."

Connecticut technology means submarines, electronic computing equipment, optics, industrial controls, telecommunications, surgical appliances, office machines, scientific instrumentation, guided missiles, guidance technology, helicopters, chemicals, fiber optics, semiconductors, photo equipment, control instrumentation and ophthalmic equipment, made by Connecticut-based companies whose names are a kind of litany of technology leadership. Burndy (electrical connectors), Olin (industrial chemicals), Pitney Bowes (mailing devices and office machinery), Alderson Research (medical equipment), Bunker-Ramo, Vitramon, Frigitronics, Branson Ultrasonics, Notsuko America, Samarius, Kaman, Emhart, GE, General Digital, Loctite, Data Switch, Gerber Scientific, Ex-Cell-O, Mite, Combustion Engineering, Union Carbide, Colt, Surgicot, Echlin, Sigma Instruments, American Cyanamid, Unholtz-Dickie, General Data-Com, Unimation, Holgrath, Arrow Hart, Boehringer Ingelheim, Qualitron, Canberra, Bicron Electronics—some are household words, others are known only in limited fields.

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Science Park's New Enterprise Center is ready for you:

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- 24 Hour Security
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- Video Conferencing
- Receptionist
- Computer Rentals
- Health Plan
- Research Libraries
- High Speed Facsimile
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- Copy Center
- Phone Answering
- Credit Union
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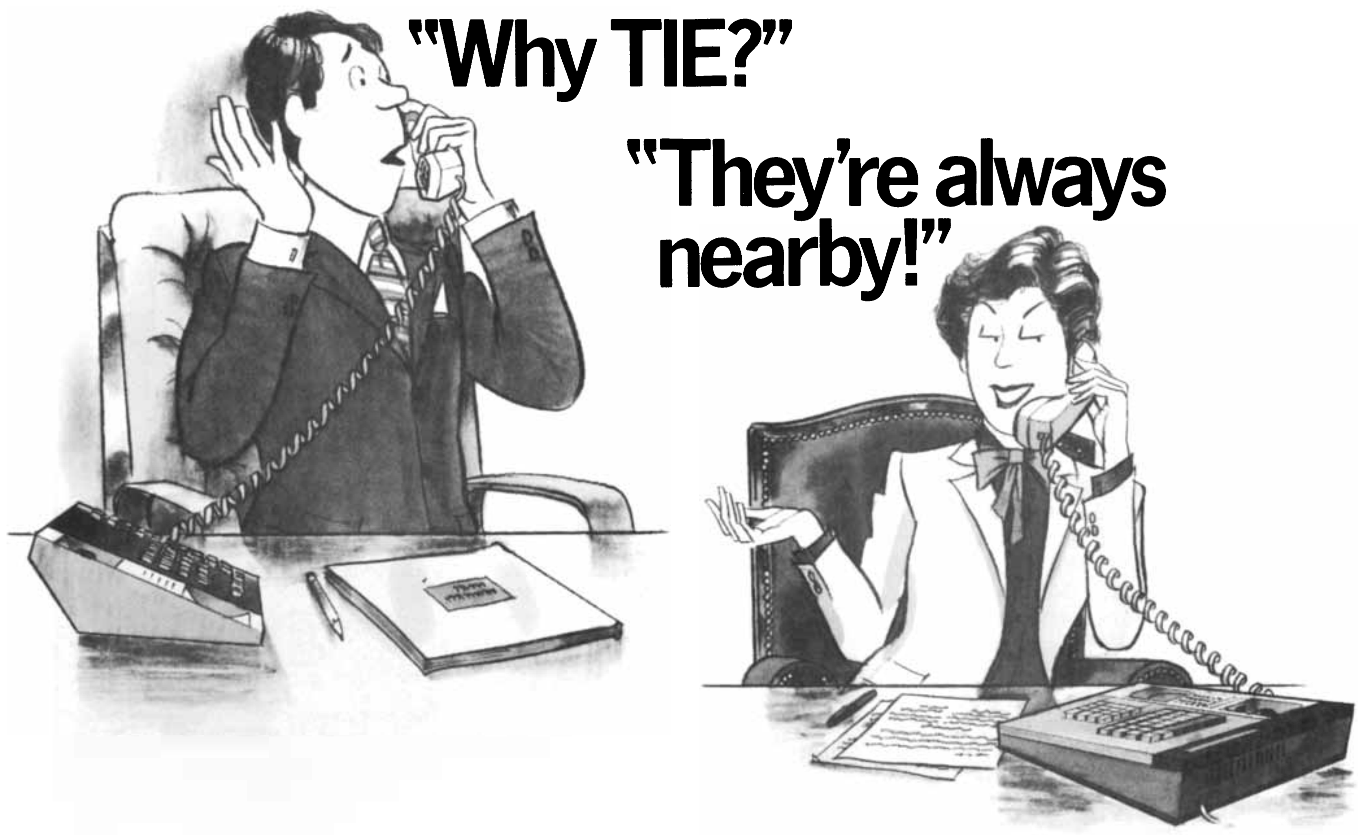

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