

MATHEMATICAL GAMES

How to build a game-learning machine and then teach it to play and to win

by Martin Gardner

I knew little of chess, but as only a few pieces were on the board, it was obvious that the game was near its close. . . . [Moxon's] face was ghastly white, and his eyes glittered like diamonds. Of his antagonist I had only a back view, but that was sufficient; I should not have cared to see his face.

The quotation is from Ambrose Bierce's classic robot story, "Moxon's Master" (reprinted in Groff Conklin's excellent science fiction anthology, *Thinking Machines*). The inventor Moxon has constructed a chess-playing robot. Moxon wins a game. The robot strangles him.

Bierce's story reflects a growing fear. Will computers someday get out of hand and develop a will of their own? Let it not be thought that this question is asked today only by those who do not understand computers. In recent years Norbert Wiener has been viewing with increasing apprehension the day when complex government decisions may be turned over to sophisticated game-theory machines. Before we know it, Wiener warns, the machines may shove us over the brink into a suicidal war.

The greatest threat of unpredictable behavior comes from the learning machines: computers that improve with experience. Such machines do not do what they have been told to do but what they have *learned* to do. They quickly reach a point at which the programmer no longer knows what sort of circuit his machine contains. Inside most of these computers are randomizing devices. If the device is based on the random decay of atoms in a sample radioactive material, the machine's behavior is not (most physicists believe) predictable even in principle.

Much of the current research on learning machines has to do with computers that steadily improve their ability to play games. Some of the work is secret—war

is a game. The first significant machine of this type was an IBM 704 computer programmed by Arthur L. Samuel of the IBM research department at Poughkeepsie, N.Y. In 1959 Samuel set up the computer so that it not only played a fair game of checkers but also was capable of looking over its past games and modifying its strategy in the light of this experience. At first Samuel found it easy to beat his machine. Instead of strangling him, the machine improved rapidly, soon reaching the point at which it could clobber its inventor in every game. So far as I know no similar program has yet been designed for chess, although there have been several ingenious programs for nonlearning chess machines [see "Computer v. Chess-Player," by Alex Bernstein and Michael de V. Roberts; *SCIENTIFIC AMERICAN*, June, 1958].

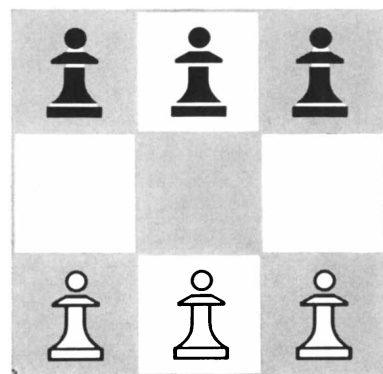
Recently the Russian chess grand master Mikhail Botvinnik was quoted as saying that the day would come when a computer would play master chess. "This is of course nonsense," writes the American chess expert Edward Lasker in an article on chess machines in last fall's issue of a new magazine called *The American Chess Quarterly*. But it is Lasker who is talking nonsense. A chess computer has three enormous advantages over a human opponent: (1) It never makes a careless mistake; (2) it can analyze moves ahead at a speed much faster than a human player can; (3) it can improve its skill without limit. There is every reason to expect that a chess-learning machine, after playing thousands of games with experts, will someday develop the skill of a master. It is even possible to program a chess machine to play continuously and furiously against itself. Its speed would enable it to acquire in a short time an experience far beyond that of any human player.

It is not necessary for the reader who would like to experiment with game-learning machines to buy an IBM 704. It is only necessary to obtain a supply of empty matchboxes and colored beads. This method of building a simple learning machine is the happy invention of

Donald Michie, a biologist at the University of Edinburgh. Writing on "Trial and Error" in *Penguin Science Survey 1961*, Vol. 2, Michie describes a tick-tacktoe learning machine called MENACE (Matchbox Educable Naughts And Crosses Engine) that he constructed with 300 matchboxes.

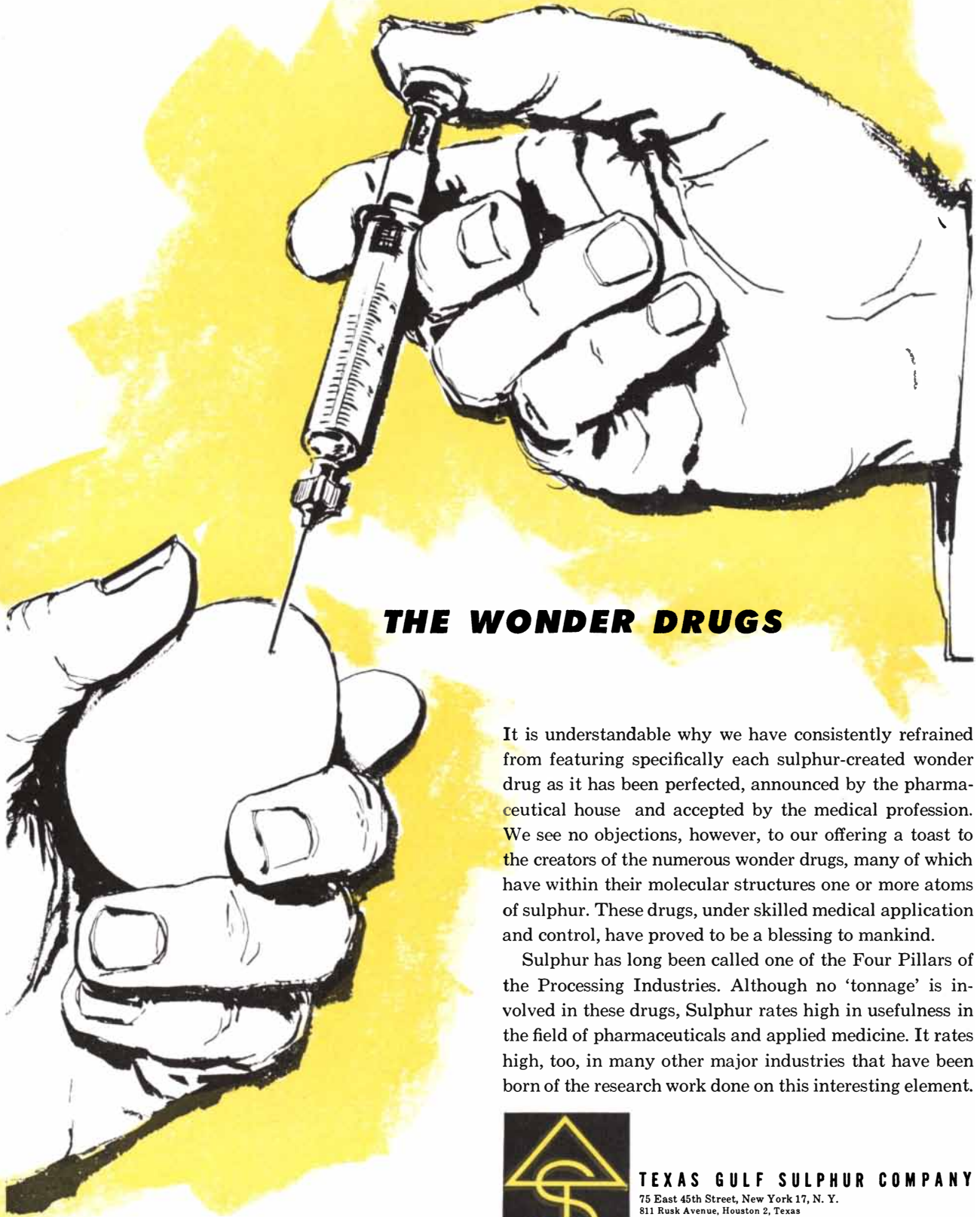
MENACE is delightfully simple in operation. On each box is pasted a drawing of a possible ticktacktoe position. The machine always makes the first move, so only patterns that confront the machine on odd moves are required. Inside each box are small glass beads of various colors, each color indicating a possible machine play. A V-shaped cardboard fence is glued to the bottom of each box, so that when one shakes the box and tilts it, the beads roll into the V. Chance determines the color of the bead that rolls into the V's corner. First-move boxes contain four beads of each color, third-move boxes contain three beads of each color, fifth-move boxes have two beads of each color, seventh-move boxes have single beads of each color.

The robot's move is determined by shaking and tilting a box, opening the drawer and noting the color of the "apical" bead (the bead in the V's apex). Boxes involved in a game are left open until the game ends. If the machine wins, it is rewarded by adding three beads of the apical color to each open box. If the game is a draw, the reward is one bead per box. If the machine loses, it is punished by extracting the apical bead from each open box. This system of reward and punishment closely parallels the way in which animals and even humans are taught and disciplined. It is obvious that the more games MENACE plays, the more it will tend to adopt winning lines of play and shun losing lines. This makes it a legitimate learning machine, although of an extremely simple sort. It does not make (as does Samuel's checker machine) any self-analysis of past plays



The game of hexapawn

SULPHUR helps to create headline products



THE WONDER DRUGS

It is understandable why we have consistently refrained from featuring specifically each sulphur-created wonder drug as it has been perfected, announced by the pharmaceutical house and accepted by the medical profession. We see no objections, however, to our offering a toast to the creators of the numerous wonder drugs, many of which have within their molecular structures one or more atoms of sulphur. These drugs, under skilled medical application and control, have proved to be a blessing to mankind.

Sulphur has long been called one of the Four Pillars of the Processing Industries. Although no 'tonnage' is involved in these drugs, Sulphur rates high in usefulness in the field of pharmaceuticals and applied medicine. It rates high, too, in many other major industries that have been born of the research work done on this interesting element.



TEXAS GULF SULPHUR COMPANY

75 East 45th Street, New York 17, N. Y.
811 Rusk Avenue, Houston 2, Texas

Sulphur Producing Units: Newgulf, Texas • Moss Bluff, Texas
Fannett, Texas • Spindletop, Texas
Worland, Wyoming • Okotoks, Alberta, Canada

that causes it to devise new strategies.

Michie's first tournament with MENACE consisted of 220 games over a two-day period. At first the machine was easily trounced. After 17 moves the machine had abandoned all openings except the corner opening. After the 20th game it was drawing consistently, so Michie began trying unsound variations in the hope of trapping it in a defeat. This paid off until the machine learned to cope with all such variations. When Michie withdrew from the contest after losing eight out of ten games, MENACE had become a master player.

Since few readers are likely to attempt building a learning machine that requires 300 matchboxes, I have designed hexapawn, a much simpler game

that requires only 24 boxes. The game is easily analyzed—indeed, it is trivial—but the reader is urged *not* to analyze it. It is much more fun to build the machine, then learn to play the game while the machine is also learning.

Hexapawn is played on a 3×3 board, with three chess pawns on each side as shown in the illustration on page 138. Dimes and pennies can be used instead of actual chess pieces. Only two types of move are allowed: (1) A pawn may advance straight forward one square to an empty square; (2) a pawn may capture an enemy pawn by moving one square diagonally, left or right, to a square occupied by the enemy. The captured piece is removed from the board. These are the same as pawn moves in chess,

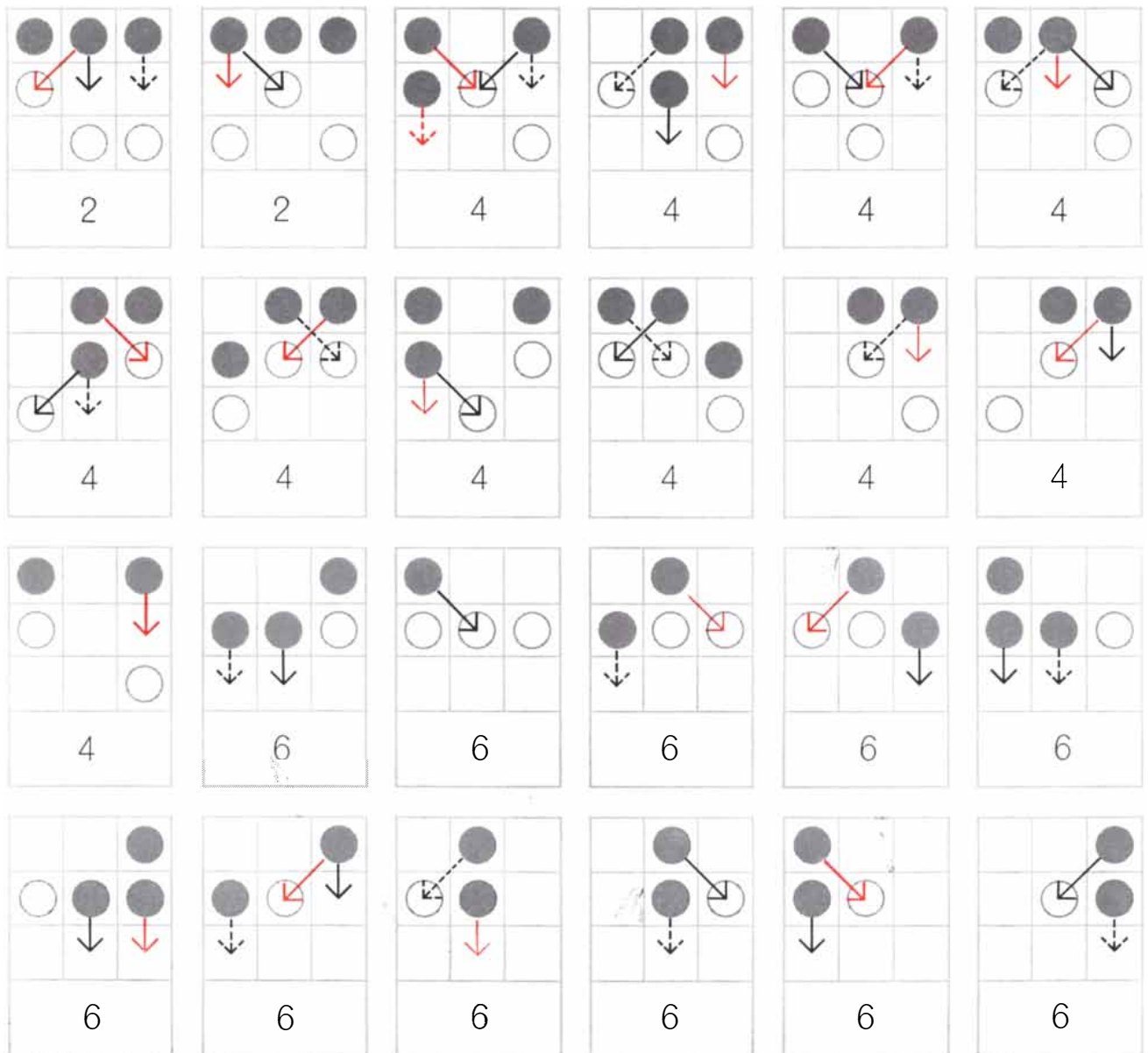
except that no double move, *en passant* capture or promotion of pawns is permitted.

The game is won in any one of three ways:

1. By advancing a pawn to the third row.
2. By capturing all enemy pieces.
3. By achieving a position in which the enemy cannot move.

Players alternate moves, moving one piece at a time. A draw clearly is impossible, but it is not immediately apparent whether the first or second player has the advantage.

To construct HER (Hexapawn Educational Robot) you need 24 empty matchboxes and a supply of colored beads. Small candies that come in different



Labels for HER matchboxes



ON TARGET!

Air Force Skybolt is expected to be one of America's most powerful deterrent weapons. This air launched ballistic missile will save billions in taxes by extending the useful life of our B-52 and British Vulcan II bombers.

The Douglas Skybolt gives an aggressor reason to pause. It is being developed as a missile with nuclear capability that can be launched from a mobile hiding place in the sky a thousand miles from its target.

To date, several successful tests have been made and the aircraft-to-missile compatibility has been demonstrated. With modifications, Skybolt can also be used with supersonic aircraft of the future.

In developing this weapon system, Douglas has again proved its ability to create weapons that are practical and powerful deterrents... the best safeguards of the peace.

DOUGLAS

MISSILE AND SPACE SYSTEMS • MILITARY AIRCRAFT • DC-8 JETLINERS • RESEARCH AND DEVELOPMENT PROJECTS • GROUND SUPPORT EQUIPMENT • AIRCOMB® • ASW DEVICES

NIKON OPTICAL COMPARATORS



for accurate inspection and measurements of

Electron micrographs
Ultracentrifuge & Electrophoresis
Photo Data
Delicate Specimens

A steadily increasing number of hospitals, pharmaceutical, bio-chemical and industrial laboratories are using *Nikon model 6 Optical Comparators* for accurate studies, analyses and evaluations of visual data obtained in various test and research procedures.

While most applications reported deal with inspection and measurement of electron photomicrographs, ultracentrifuge and electrophoresis plates and films, and even delicate specimens in petri dishes, new applications are constantly arising, growing out of the almost unlimited facilities offered by this versatile instrument.

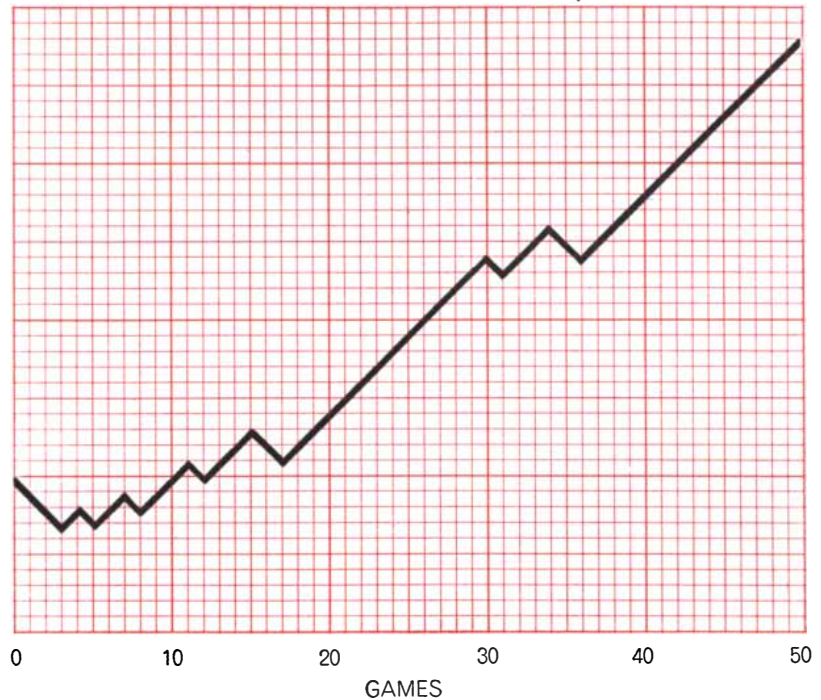
The *Nikon 6 Optical Comparator* is essentially a precision macro-projector with a magnification range from 10X to 100X—extendable to 500X. It provides surface as well as sub-stage or diascopic illumination. Any specimen, substance or transparency placed on the stage appears on its screen as a bright, clear, magnified image. Magnification accuracy permits specimen measurements to 2-micron increments.

For complete details, write to Dept. SA-3,



NIKON INC., INSTRUMENT DIVISION,
 111 Fifth Avenue, New York 3, New York

ROBOT BECAME PERFECT PLAYER
 AFTER LOSING 11 GAMES



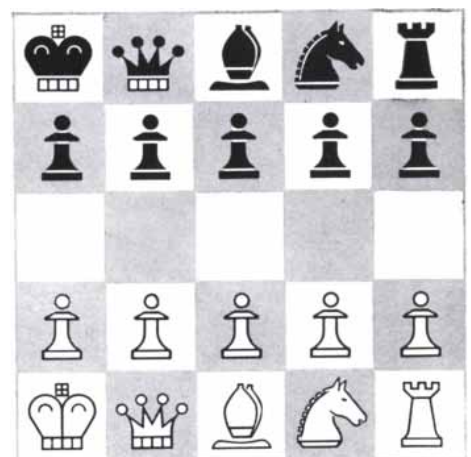
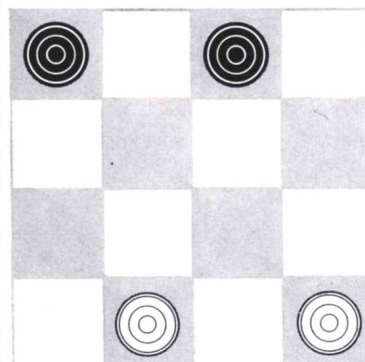
Learning curve for HER's first 50 games (downslant shows loss, upslant a win)

colors work nicely. (I used five five-cent boxes of jubes.) Each matchbox bears one of the diagrams shown in the illustration on page 140. The robot always makes the second move. Patterns marked "2" represent the two positions open to HER on the second move. You have a choice between a center or an end opening, but only the left end is considered because an opening on the right would obviously lead to identical (although mirror-reflected) lines of play. Patterns marked "4" show the 11 positions that can confront HER on the fourth (its sec-

ond) move. Patterns marked "6" are the 11 positions that can face HER on the sixth (its last) move.

Inside each box place a single bead to match the color of each arrow on the pattern. The robot is now ready for play. Every legal move is represented by an arrow; the robot can therefore make all possible moves and only legal moves. The robot has no strategy. In fact, it is an idiot.

The teaching procedure is as follows. Make your first move. Pick up the matchbox that shows the position on the board.



Matchbox machine can be built for simplified checkers (left) but not for chess (right)

You can be sure to play an important part in the exploration of space ...when you join NASA



A factual statement on career opportunities for scientists and engineers from James E. Webb, head of NASA

The exploration of space, for peaceful purposes and the benefit of all mankind, is the most challenging assignment ever given to the American scientific and engineering community.

To the men of NASA, the space program has many objectives: broad scale, rapid advancement of scientific knowledge of space, the moon and planets . . . the creation of a worldwide operational network of weather satellites . . . the establishment of a global satellite system of communications . . . prompt feedback of space technology into our economy . . . and many others. Technological advances through our space effort will bring total benefits exceeding those of any other undertaking in history.

The scientists and engineers who are directly involved in NASA's space program are faced with formidable research and development problems. NASA needs—and seeks—the best

creative scientific and engineering talent our nation has to offer.

We will provide the professional men who join NASA with the tools they need: a truly intellectual atmosphere, a framework for easy communication with colleagues in universities as well as government and industry laboratories, the most advanced equipment available, and the technical and clerical support to let you concentrate on the important aspects of your work.

Still, the greatest personal satisfaction may be found in the scope of the individual assignment and in the end product of the work—breaking out from the world we know into an entire new world and uncovering a flood of new benefits not only for ourselves, but for all mankind.

To scientists and engineers in all disciplines, at all levels:

The dynamic expansion of NASA has created outstanding career positions and opportunities for rapid advancement. Career appointments are available in ten different locales: Washington, D. C.; Greenbelt, Maryland; Mountain View and Edwards, California; Hampton and Wallops Island, Virginia; Cleveland, Ohio; Huntsville,

Alabama; Cape Canaveral, Florida; and Houston, Texas.

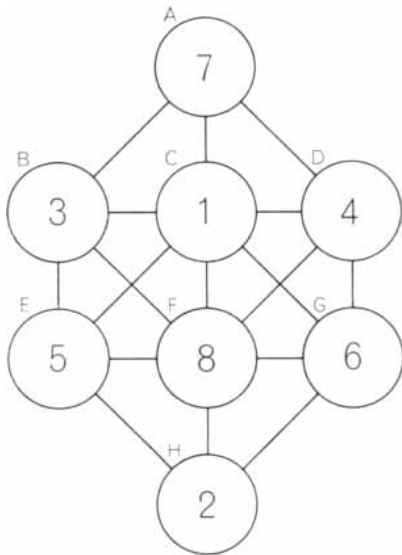
Find out how you may contribute to the American space effort. You need send only one resume—it will be reproduced and distributed to all NASA facilities for evaluation.

Write to: Director, Professional Staffing, NASA Headquarters, Washington 25, D. C.

AN EQUAL OPPORTUNITY EMPLOYER. POSITIONS ARE FILLED IN ACCORDANCE WITH AERO-SPACE TECHNOLOGY ANNOUNCEMENT 252B.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



Solution to last month's Problem 1

Shake the matchbox, close your eyes, open the drawer, remove one bead. Close the drawer, put down the box, place the bead on top of the box. Open your eyes, note the color of the bead, find the matching arrow and move accordingly. Now it is your turn to move again. Continue this procedure until the game ends. If the robot wins, replace all the beads and play again. If it loses, punish it by confiscating only the bead that represents its *last* move. Replace the other beads and play again. If you should find an empty box (this rarely happens), it means the machine has no move that is not fatal and it resigns. In this case confiscate the bead of the preceding move.

Keep a record of wins and losses so you can chart the first 50 games. The top illustration on page 142 shows the results of a typical 50-game tournament. After 36 games (including 11 defeats

for the robot) it has learned to play a perfect game. The system of punishment is designed to minimize the time required to learn a perfect game, but the time varies with the skill of the machine's opponent. The better the opponent, the faster the machine learns.

The robot can be designed in other ways. For example, if the intent is to maximize the number of games that the machine wins in a tournament of, say, 25 games, it may be best to reward (as well as punish) by adding a bead of the proper color to each box when the machine wins. Bad moves would not be eliminated so rapidly, but it would be less inclined to make the bad moves. An interesting project would be to construct a second robot, HIM (Hexapawn Instructable Matchboxes), designed with a different system of reward and punishment but equally incompetent at the start of a tournament. Both machines would have to be enlarged so they could make either first or second moves. A tournament could then be played between HIM and HER, alternating the first move, to see which machine would win the most games out of 50.

Similar robots are easily built for other games. Stuart C. Hight, director of research studies at the Bell Telephone Laboratories in Whippany, N.J., recently built a matchbox learning machine called NIMBLE (Nim Box Logic Engine) for playing nim with three piles of three counters each. The robot plays either first or second and is rewarded or punished after each game. NIMBLE required only 18 matchboxes and played almost perfectly after about 30 games.

By reducing the size of the board the complexity of many familiar games can be minimized until they are within the scope of a matchbox robot. The game of go, for example, can be played on the intersections of a 2×2 checkerboard.

The smallest nontrivial board for checkers is shown at the left in the bottom illustration on page 142. It should not be difficult to build a matchbox machine that would learn to play it. Readers disinclined to do this may enjoy analyzing the game. Does either side have a sure win or will two perfect players draw? (The answer will be given next month.)

When chess is reduced to the smallest board on which all legal moves are still possible, as shown at the right in the bottom illustration on page 142, the complexity is still far beyond the capacity of a matchbox machine. In fact, I have found it impossible to determine which player, if either, has the advantage. The game is recommended for computer experts who wish to program a simplified chess-learning machine and for all chess players who like to sneak in a quick game during a coffee break.

The answers to last month's collection of short problems are given below:

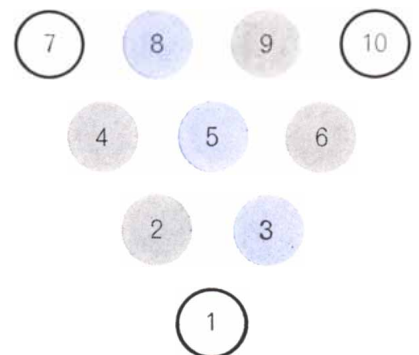
1.

If the numbers from 1 to 8 are placed in the circles as shown in the illustration at the top of this page, no number will be connected by a line to a number immediately above or below it in serial order. The solution (including its upside-down and mirror-image forms) is unique.

L. Vosburgh Lyons, who gave me this puzzle, solved it as follows. In the series 1, 2, 3, 4, 5, 6, 7, 8 each digit has two neighboring numbers except 1 and 8. In the diagram, circle C is connected to every circle except H. Therefore if C contains any number in the set 2, 3, 4, 5, 6, 7, only circle H will remain to accommodate *both* neighbors of whatever number goes in C. This is impossible, so C must contain 1 or 8. The same argument ap-

| | | | | | | | | | |
|--------------------|---|---|---|---|---|---|---|---|---|
| GAMES | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| SERVER | R | M | R | M | R | M | R | M | R |
| WINNER | R | M | R | M | R | M | M | M | M |
| GAMES WITH SERVICE | X | X | X | X | X | X | | X | |
| GAMES V. SERVICE | | | | | | | X | | X |

Chart for Problem 3



Impossibility proof for Problem 4

MILITARY COMMAND TECHNOLOGY... A NEW SCIENCE FOR NATIONAL DEFENSE

Systems that instantly provide the military Commander with the information necessary for decision. Systems to enable the Commander to control all his forces under any conditions.

This is the purpose of Military Command Technology. It is the work carried out at MITRE. It includes command systems, control systems, intelligence systems, warning systems, and support systems. It encompasses a vast network of interrelated, constantly evolving systems that protect our country.

The designer of these systems must be able to visualize how war would be fought. He will work closely with the nation's top policy makers.

He will help solve the problems of military command — nature, deployment, and use of weapons; war-plans; control of forces; missions; logistics; support and intelligence operations. But, most important — he must be able to apply existing and predictable technology to the abstract problems of future military command.

Military Command Technology, in short, is a systems engineering task of overwhelming importance. MITRE has men who can get the job done. And there is room at MITRE for more such men — top professionals who feel they want to serve their country in a vital area. There are key assignments available in system analysis and planning; intersystem integration; general system engineering; initial system design; and research and experimentation. Facilities are at Bedford, Mass.; Washington, D. C.; Colorado Springs.

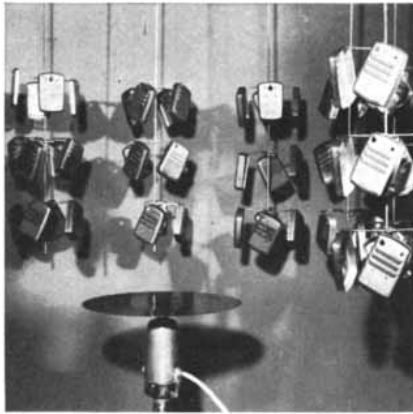
If you feel you can advance this new science, you are urged to write in confidence to Vice President — Technical Operations, The MITRE Corporation, Box 208, Dept. MC26, Bedford, Mass.

THE
MITRE
CORPORATION

MITRE is an independent, nonprofit corporation working with — not in competition with — industry. Formed under the sponsorship of the Massachusetts Institute of Technology, MITRE serves as Technical Advisor to the Air Force Electronic Systems Division and is chartered to work for such other Government agencies as FAA.

An Equal Opportunity Employer

New York Job Painting Shop Cuts Paint and Labor Costs, Improves Quality and Steps Up Production with RANSBURG No. 2 PROCESS



Automatic electrostatic spray painting provides nearly 200% increase in paint mileage over air hand spray in finishing these motor covers. Quality of the work is improved, too, with Electro-Spray.

It's NO WONDER Sam Conoval, president of Carnival Spraying Co., Inc. (industrial finishers located in New York City) is so enthusiastic about Ransburg Electrostatic Spray painting.

At Carnival Spraying, one Ransburg automatic unit is providing a higher quality, uniform finish on a wide variety of painted parts with less materials and lower labor costs. And, with the quality improvement, production is increased more than 500% on some items.

For instance:

- On cast aluminum mail boxes, they formerly painted 1000 units a day by air hand spray using 6 gallons of enamel. Today, they paint 1000 in an hour and a half with only 2 gallons of enamel.
- On another job, toy xylophone bars, they paint over 80,000 pieces a day with Electro-Spray while formerly, 20,000 was a full day's run by air hand spray.
- On steel covers for barbecue grill motors, they formerly used 4 hand sprayers and two packers to turn out 7000 pieces a day. NOW, with automatic No. 2 Process, they can paint over 18,000 a day with only 2 men loading the line, and another unloading and packing. Paint mileage is increased, too. Where they used to use 15 gallons of enamel to hand paint 7000 pieces, today with the same amount of enamel, they paint 20,000 with practically no rejects! That's because the paint goes where it's supposed to go and not up the exhaust stack.

NO REASON WHY YOU CAN'T DO IT TOO

Many manufacturers of painted products are reporting similar savings in paint and labor with increased production. If your volume doesn't justify automatic electrostatic equipment, perhaps the RANSBURG Electrostatic Hand Gun will help cut costs in YOUR finishing department. Write for our new brochure showing other in-plant production photos, savings

figures and detailed information on RANSBURG No. 2 Process Electro-Spray—both automatic and manual.



RANSBURG
Electro-Coating Corp.
 Box 23122, Indianapolis 23, Indiana

Affiliates in AUSTRALIA • AUSTRIA • BELGIUM • BRAZIL
 DENMARK • ENGLAND • FRANCE • FINLAND • GERMANY
 HOLLAND • INDIA • IRELAND • ITALY • NEW ZEALAND
 NORWAY • PAKISTAN • SOUTH AFRICA • SPAIN
 SWEDEN and SWITZERLAND

plies to circle F. Because of the pattern's symmetry, it does not matter whether 1 goes in C or F, so let us place it in C. Circle H is the only circle available for 2. Similarly, with 8 in circle F, only circle A is available for 7. The remaining four numbers are now easily placed.

2.

The problem of the lady or the tiger is merely a dressed-up version of a famous ball-and-urn problem analyzed by the great French mathematician Pierre Simon de Laplace (see James R. Newman's *The World of Mathematics*, Vol. 2, page 1332). The answer is that the young man on his third choice of a door has a probability of 9/10 that he will

choose the lady. The pair of doors concealing two tigers is eliminated by his first choice of a lady, which leaves 10 equally probable possibilities for the entire series of three choices.

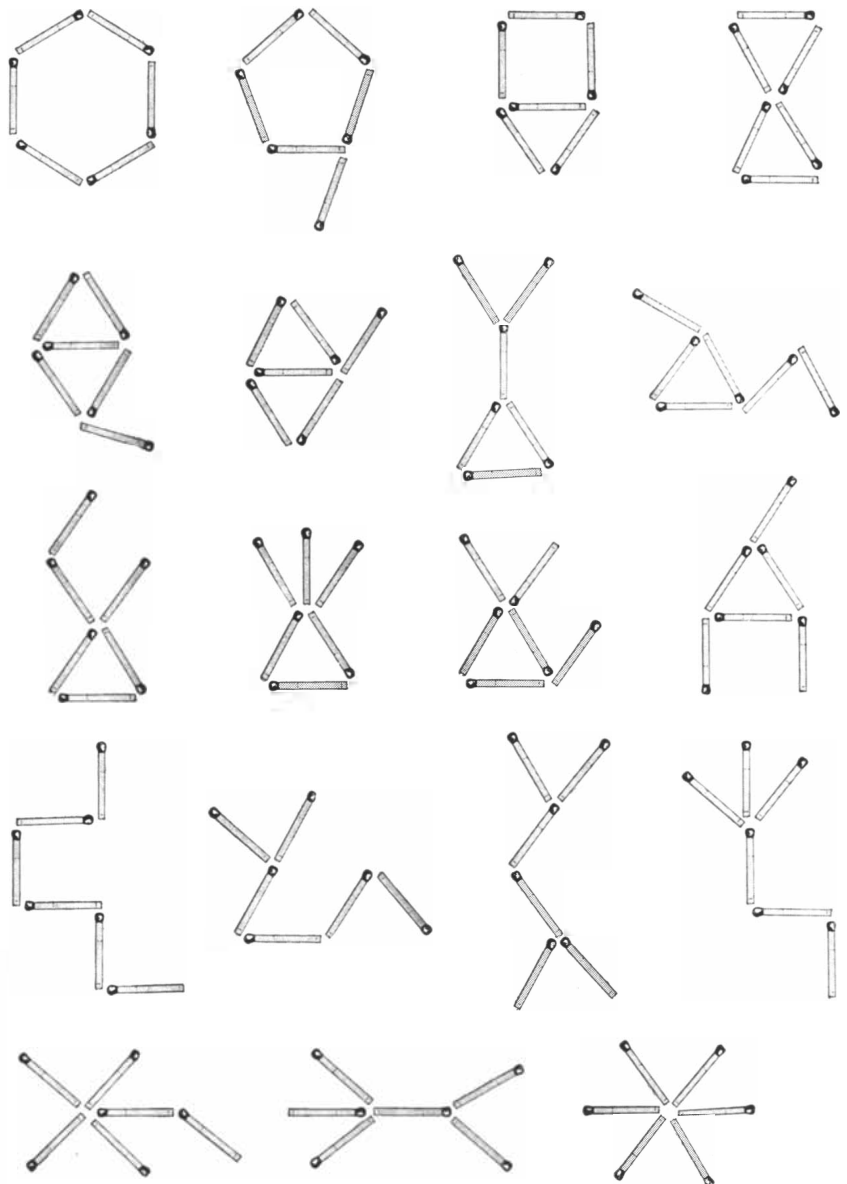
If the doors conceal two ladies:

- Lady 1 – Lady 1 – Lady 1
- Lady 1 – Lady 1 – Lady 2
- Lady 1 – Lady 2 – Lady 1
- Lady 1 – Lady 2 – Lady 2
- Lady 2 – Lady 1 – Lady 1
- Lady 2 – Lady 1 – Lady 2
- Lady 2 – Lady 2 – Lady 1
- Lady 2 – Lady 2 – Lady 2

If the doors conceal a lady and a tiger:

- Lady 3 – Lady 3 – Lady 3
- Lady 3 – Lady 3 – Tiger

Of the 10 possibilities in the prob-



Solution to Problem 5

Original painting by Louise Ganthers, Taos, New Mexico

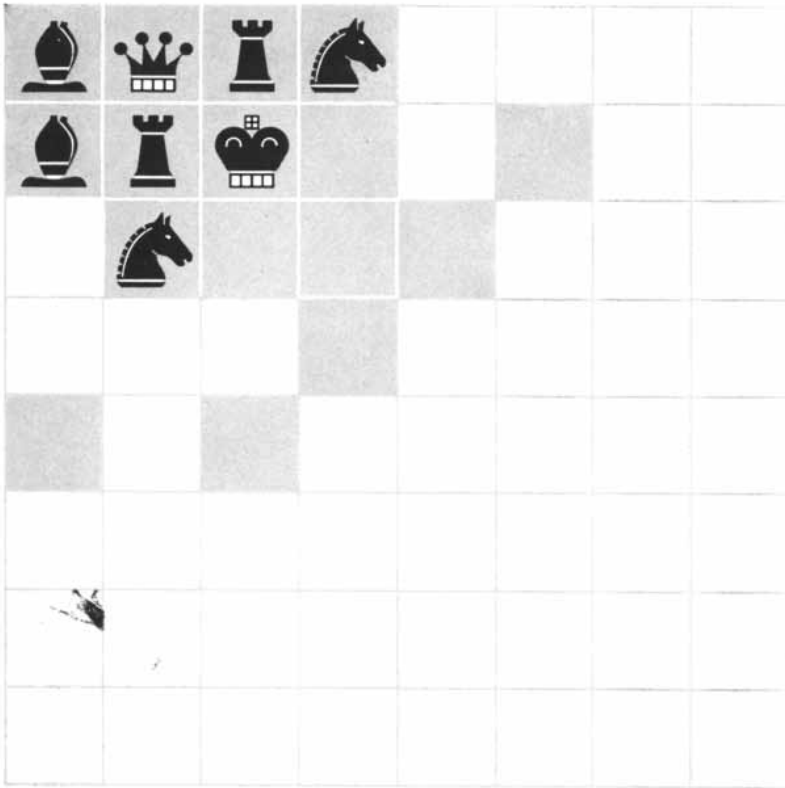


MOLTEN PLUTONIUM and MOBILE FUELS

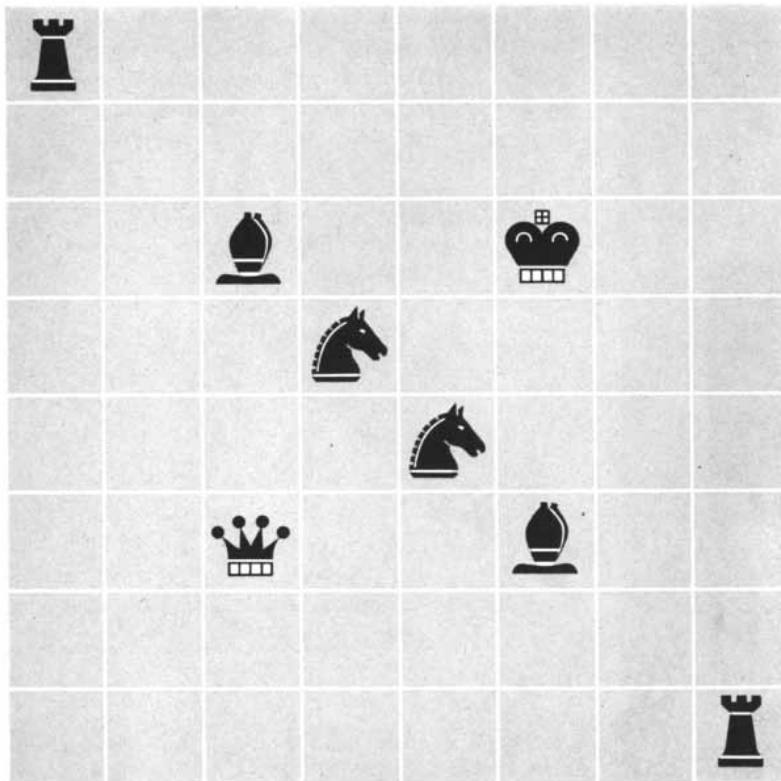
are utilized by Los Alamos Scientific Laboratory in reactor research and development programs. LAMPRE I (Los Alamos Molten Plutonium Reactor) is in operation at a temperature of 500°C, producing 400 kw of heat. Research is in progress with various other forms of mobile fuels. Under construction is a 20 megawatt core test facility for the integral testing of fast reactor fuel concepts.

*Qualified applicants please send resumes to:
Director of Personnel, Division 62-30*





Solution to minimum attack problem



Solution to maximum attack problem with bishops on same color

lem's "sample space," only one ends with a fatal final choice. The probability of the man's survival is therefore 9/10.

3.

Miranda served first. One way to prove it follows:

Tennis players alternate in serving. Assume that Rosemary served first. The set included nine games so she must also have served last. Since Miranda won the set, she must have won the last game. We are told that Miranda won six games to Rosemary's three games and that five games went against service. Of the eight games that remain, therefore, five were won by Miranda, three by Rosemary.

Consider the three that Rosemary won. There are four possibilities:

- A. Rosemary served all three.
- B. Rosemary served two.
- C. Rosemary served one.
- D. Rosemary served none.

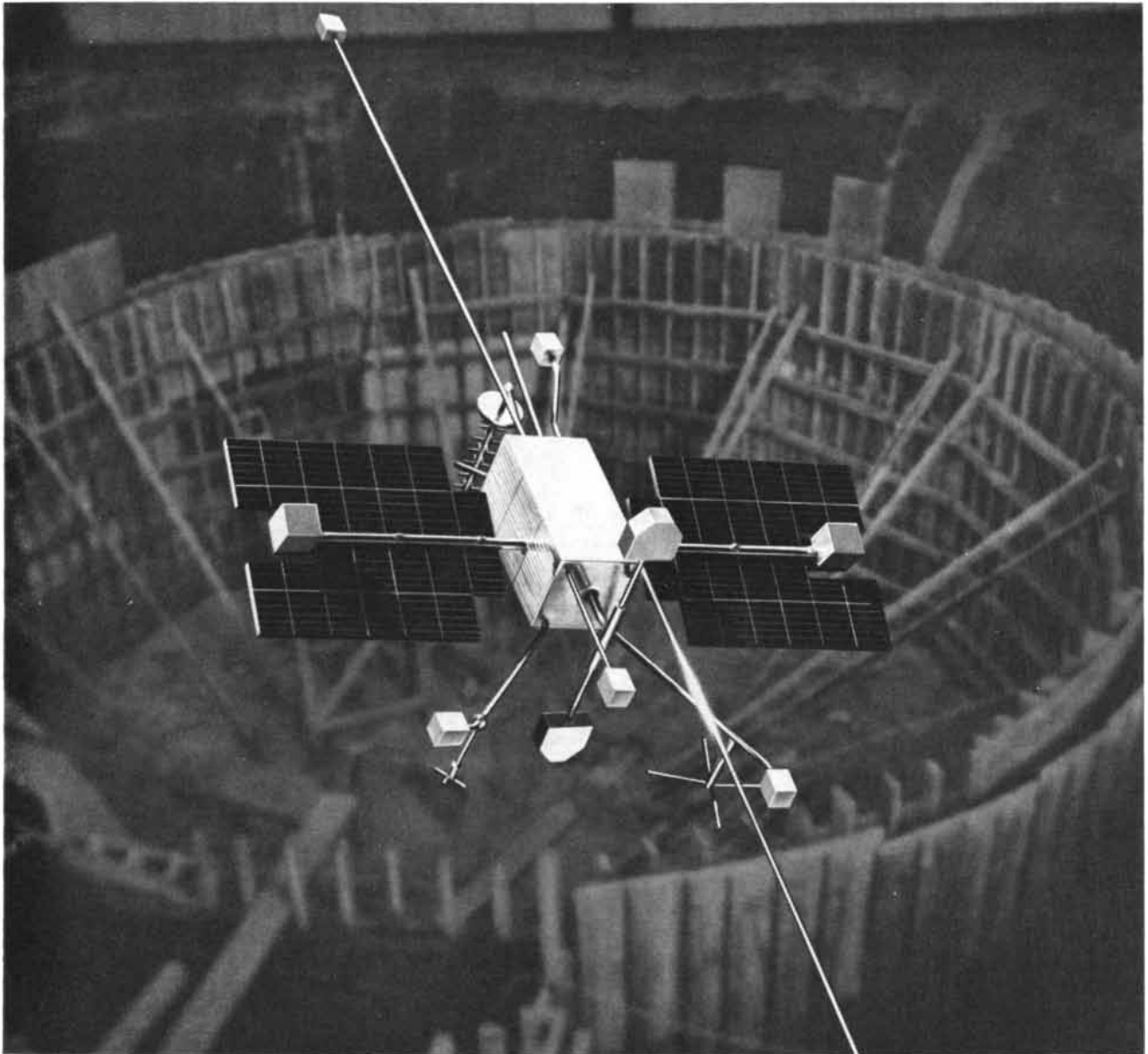
The illustration at the bottom left on page 144 is a chart of the first possibility. Three R's are placed in the third row beneath any three R's in the second row. The remaining blanks of the third row must be filled by M's. This shows only two games won against service; therefore possibility A is eliminated. Similar charts eliminate B (four games against service), C (six games against service) and D (eight games against service). This exhausts the four possibilities, proving that Rosemary could not have served first.

It remains to be seen if the assumption that Miranda served first is consistent with the known facts. By drawing a new chart and following the previous procedure it will be found that all data can be accounted for on the assumption that Miranda served first and that Rosemary served one of her three winning games.

4.

It is not possible to mix bowling pins of two different colors and set up a triangular formation of 10 pins in such a way that no three pins of the same color mark the corners of an equilateral triangle. There are many ways to prove this. The following is typical:

Assume that the two colors are red and black and that the 5 pin [see illustration at bottom right on page 144] is red. Pins 4, 9, 3 form an equilateral triangle, so at least one of these pins must be red. It does not matter which we make red, because of the figure's symmetry, so let us make it the 3 pin. Pins 2 and 6 must therefore be black. Pins 2, 6, 8 form



Today OGO hovers above a crater on earth

Soon a new space chamber 30 feet in diameter will fill this deepening bowl of earth. Here OGO (NASA's Orbiting Geophysical Observatory) will be subjected to conditions of solar heating, vacuum, and vehicle radiation to the cold of outer space. The new space chamber will be the sixth at STL. It will enable engineers and scientists working on OGO, Vela Hotel and other STL projects to test large, complete spacecraft as well as major subsystems. And along with other advanced facilities at STL's Space Technology Center, it will provide unusual scope for engineers and scientists to verify and apply new techniques in design, development and fabri-

cation of spacecraft. STL's expanding space programs have created new opportunities for engineers and scientists in the following fields: Aerodynamics, spacecraft heat transfer; Communication Systems; Electronic Ground Systems; Power Systems; Propellant Utilization; Propulsion Controls; Re-entry Body Evaluation; Systems Analysis; Thermal Radiation; and Trajectory Analysis. All qualified applicants are invited to write Dr. R. C. Potter, Manager of Professional Placement and Development, for opportunities with STL in Southern California or at Cape Canaveral. STL is an equal opportunity employer.



SPACE TECHNOLOGY LABORATORIES, INC.

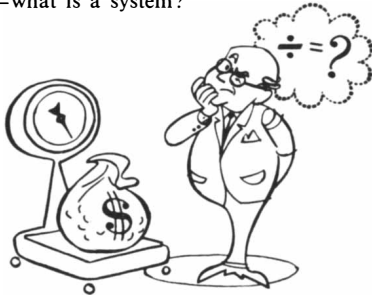
a subsidiary of Thompson Ramo Wooldridge Inc.

P.O. Box 95005-V, One Space Park, Redondo Beach, California • P.O. Box 4277, Patrick AFB, Florida

Los Angeles • Vandenberg AFB • Norton AFB, San Bernardino • Dayton • Cape Canaveral • Washington, D.C. • Boston • Huntsville
IRE Delegates: NYC Interviews March 26-29. Call F. C. Nagel, PLaza 2-8968. Visit STL Booth 1435

You can't beat the system

At Systron we design and build electronic systems. If this is a vague concept to you, it's understandable. Each system is always different from the last, always a new creation even though it uses well-established techniques and components. Because the systems approach is so flexible, because it saves an immense amount of time and labor, it has become an almost indispensable tool for solving complex problems. But —what is a system?

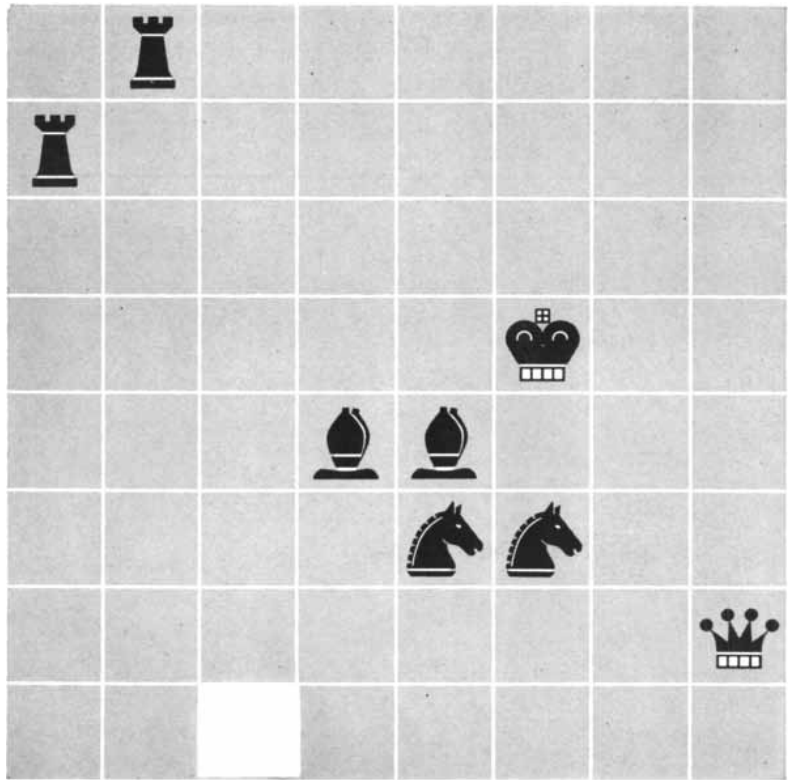


An electronic system is, first of all, hardware—amplifiers, counters, computers, and many other electronic instruments all tied together to perform certain precise measurements. A system can be analog or digital or both. This example will illustrate which is which. Suppose a banker asked us the fastest way to count a big pile of money. We would say weigh it and divide the total by the weight of an individual coin. That is the *analog* method, and although very fast, it is not too accurate. For an accurate count, we would recommend counting the pile coin by coin. That is the *digital* method, not as fast, but highly accurate and, fortunately for depositors, that is the method banks prefer. Digital techniques, of course, are not slow—we can count up to 25,000,000 events per second. In practice, Systron uses both digital and analog techniques, or a mixture of both, depending upon the customer's needs.

Systron produces an extraordinary variety of accurate, high speed systems which provide a printed record of results. A recent example is a high speed 100 channel data acquisition system for measuring temperature, pressure, and vibration in the first stage booster of Saturn, the nation's most powerful missile. Using the same techniques (and often the same instruments) Systron has built systems for testing the tensile strength of fibres, monitoring fuel flow in refineries, testing auto engines, for soil compaction studies in connection with building dams, controlling the production of tin cans, and even for studies of speech patterns. There's virtually no limit for systems applications.

Systron, sophisticated in adapting digital and analog techniques to systems, fulfills a necessary and important role in space exploration and industry. So do Systron-Donner's other divisions, Donner and Greenleaf. You will be hearing more about them later.

SYSTRON-DONNER
Corporation
CONCORD, CALIFORNIA



Solution to maximum attack problem with bishops on different colors

a triangle, forcing us to make 8 a red pin. This in turn makes the 4 and 9 pins black. Pin 10 cannot be black, for this would form a black triangle with 6 and 9, nor can it be red, because this would form a red triangle with 3 and 8. Therefore pin 5, with which we started, cannot be red. Of course, the same argument will show that it cannot be black.

5.

Nineteen topologically distinct networks can be made with six matches, placing them on a plane so that no matches overlap and the matches touch only at their ends. The 19 networks are shown in the illustration on page 146.

6.

The top illustration on page 148 shows how eight chess pieces of one color can be placed on the board so that only 16 squares are under attack. The queen and the bishop in the corner can be switched

to provide a 16-square minimum with bishops on the same color. This is believed to be the minimum regardless of how the bishops are placed.

The bottom illustration on page 148 shows one way to place the eight pieces so that all 64 squares are under attack, obviously the maximum. If the bishops are not permitted on the same color, however, 63 squares is believed to be the maximum. There are many solutions, one of which is shown in the illustration above. The maximum attack problem was first proposed in 1849. With bishops on opposite colors, 83 basically different solutions have been proved possible. The single unattacked square may be in any position except the corner of the board. I am indebted to Edward Early of Stamford, Conn., for having called this problem to my attention.

7.

To find the mileage covered by the Smiths on their trip from Connecticut to



Chart for Problem 7

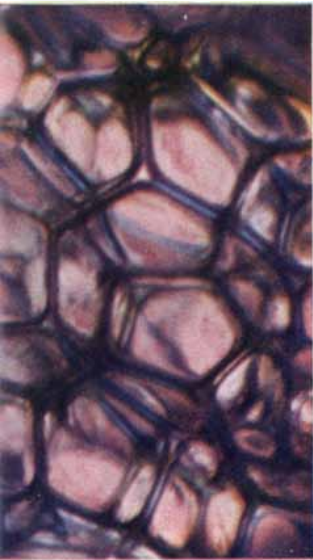


FROZEN FOODS STAY SMACKING-GOOD IN TRAILERS WITH BUBBLE-FILLED WALLS

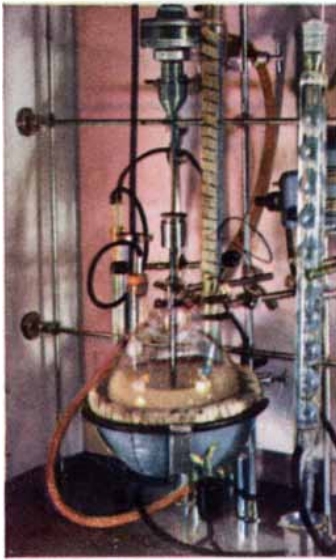
A liquid plastic that expands and solidifies into a rigid foam full of tiny bubble cells is helping manufacturers build "reefers" that haul frozen foods at 0°F, even across Death Valley at high noon.

By developing a practical way of combining urethane polymer with a fluorinated hydrocarbon blowing agent, Glidden chemists have made high-efficiency insulating foam readily available to the transportation and food handling industries.

Glidfoam®, product of Glidden research, is poured into the walls of refrigerated trucks, trailers and railroad cars. It quickly expands to form an airtight solid barrier to heat transfer. Glidden experience with resins and chemicals makes possible Glidfoam recipes which assure desired foam generation, cell size, and aging characteristics.



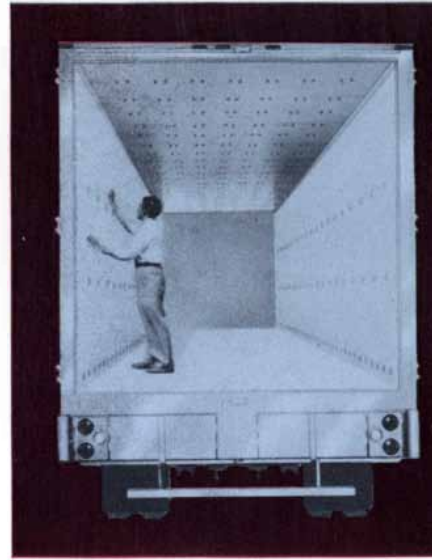
1 Under 50X magnification, rigid Glidfoam shows myriad of individual fully sealed airtight cells which give this moisture-resistant plastic its low density of only 2.0 lbs./cu.ft.



2 Glidden chemists formulate custom recipes of resin, catalysts, blowing agents, and surfactants to meet the specific flow and foaming requirements of each Glidden application . . . reefer bodies, palletized containers and commercial freezers.



3 This transparent mold, simulating double-wall trailer construction, shows how Glidfoam, pumped as a two-component liquid, solidifies into a homogeneous bubble-filled rigid foam of uniform density with no shrinkage at successive pour "knit lines."



4 On a reefer-trailer production line, the temporary form has been removed from the trailer interior for final inspection of the poured Glidfoam after setting. Note that Glidfoam is a sturdy, self-supporting, continuous, thermal barrier that cannot vibrate down and leave uninsulated heat paths at the trailer roof-line.

If your product requires a finish, a coating or a resin, Glidden is ready to work with you. To obtain the formulation best suited to your product and application methods, write or phone:



GLIDDEN

THE GLIDDEN COMPANY • COATINGS AND RESINS DIVISION
900 UNION COMMERCE BUILDING • CLEVELAND 14, OHIO
In Canada: The Glidden Company, Ltd., Toronto, Ontario



Performance — a product of WESTERN's **G**rowth

Remember when the wheels of progress were wood-spoked dust eaters, rimmed with iron? We were there. In 1888. And today, when progress moves at a super-sonic pace, the name Western Gear is written always bigger by those who keep the logbooks on performance. The newest entry to appear in large letters is our new Heavy Machinery Division in Seattle. For years, this facility has produced impressive equipment for the marine and steel industries. It is now a separate division—one of seven which design and produce over 500 products from miniature components to complete systems. Get the complete story. Write for Corporate Capabilities Bulletin 5900. Address Western Gear Corporation, Box 182, Lynwood, California. Or cable WESTGEAR, Lynwood, California. *Growing* someplace? Then it will pay you to know these seven WG symbols which stand for performance.

COPYRIGHT 1962 WESTERN GEAR CORPORATION



WESTERN GEAR CORPORATION
 SEATTLE, WASHINGTON; BELMONT, LYNNWOOD, PASADENA, CALIFORNIA; HOUSTON, TEXAS. OFFICES IN ALL PRINCIPAL CITIES.

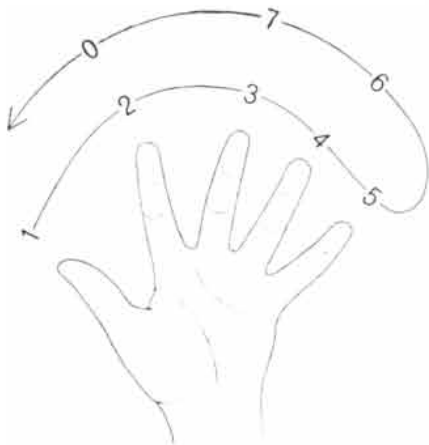
AIRCRAFT AND MISSILE SYSTEMS ■ SUB-SYSTEMS AND COMPONENTS ■ RADAR ANTENNA DRIVES ■ MINIATURE MOTORS AND BLOWERS ■ PRINTING PRESSES ■ A COMPLETE LINE OF INDUSTRIAL POWER TRANSMISSION EQUIPMENT ■ MAJOR PRODUCERS OF LARGE MARINE GEARS AND DECK MACHINERY ■ SYSTEMS MANAGEMENT ANALYSTS AND SPECIALISTS IN EXOTIC PROBLEMS IN RESEARCH AND DEVELOPMENT

Pennsylvania, the various times of day that are given are irrelevant, since Smith drove at varying speeds. At two points along the way Mrs. Smith asked a question. Smith's answers indicate that the distance from the first point to Patricia Murphy's Candlelight Restaurant is two-thirds of the distance from the start of the trip to the restaurant, and the distance from the restaurant to the second point is two-thirds of the distance from the restaurant to the end of the trip. It is obvious, therefore, that the distance from point to point (which we are told is 200 miles) is two-thirds of the total distance. This makes the total distance 300 miles. The bottom illustration on page 150 should make it all clear.

8.

When the mathematician's little girl counted to 1,962 on her fingers, counting back and forth in the manner described, the count ended on her index finger. The fingers are counted in repetitions of a cycle of eight counts as shown in the illustration below. It is a simple matter to apply the concept of numerical congruence, modulo 8, in order to calculate where the count will fall for any given number. We have only to divide the number by 8, note the remainder, then check to see which finger is so labeled. The number 1,962 divided by 8 has a remainder of 2, so the count falls on the index finger.

In mentally dividing 1,962 by 8 the mathematician recalled the rule that any number is evenly divisible by 8 if its last three digits are evenly divisible by 8, so he had **only** to divide 962 by 8 to **determine the remainder**.



How fingers are labeled for Problem 8

To preserve your copies of **SCIENTIFIC AMERICAN**

- ¶ A choice of handsome and durable library files—or binders—for your copies of SCIENTIFIC AMERICAN.
- ¶ Both styles bound in dark green library fabric stamped in gold leaf.
- ¶ Files—and binders—prepacked for sale in pairs only.

*Index for entire year in December issue.**



FILES

Hold 6 issues in each.
Single copies easily accessible.
Price: \$3.00 for each pair (U.S.A. only).
Address your order, enclosing check or money order, to: *Department 6F*



BINDERS

Hold 6 issues in each.
Copies open flat.
Price: \$4.00 for each pair (U.S.A. only).
Address your order, enclosing check or money order, to: *Department 6B*

New York City residents please add 3% Sales Tax

*Supply of back copies of SCIENTIFIC AMERICAN is limited. To replace missing copies, mail request with your order for files or binders.

SCIENTIFIC AMERICAN, 415 Madison Ave., New York 17, N.Y.

CRYOGENICS

SUPER EFFICIENCY

DEWARS

in standard production at CRYENCO

1,000 liter in-plant liquid hydrogen trailer dewar.
High efficiency—1% hydrogen heat leak per day.
Also with supports for liquid N₂.



25 liter liquid nitrogen dewar, for physicians—less than 0.5% N₂ heat leak per day.

Special dewars include: high efficiency 100 liter liquid helium dewars with a liquid nitrogen shield—1% H₂ and 3% N₂ heat leak per day; an 8,150 gallon liquid helium trailer, now under thermal tests. At CRYENCO, quality is a creed! These efficiency ratings show it. For your standard or special dewars write for CRYENCO Dewars data sheets.

CRYENCO

Cryogenic Engineering Co.
236 W. 48th Ave., Denver 16, Colo.
Low Temperature, High Vacuum
Equipment and Engineering

FREE
50
PAGE
OBSERVER'S
GUIDE

With artificial satellites already launched and space travel almost a reality, astronomy has become today's fastest growing hobby. Exploring the skies with a telescope is a relaxing diversion for father and son alike. UNITRON's handbook contains full-page illustrated articles on astronomy, observing, telescopes and accessories. It is of interest to both beginners and advanced amateurs.

CONTENTS INCLUDE:

Observing the sun, moon, planets and wonders of the sky • Constellation map • Hints for observers • Glossary of telescope terms • How to choose a telescope • Astrophotography

UNITRON

INSTRUMENT COMPANY • TELESCOPE SALES DIV.
66 NEEDHAM ST., NEWTON HIGHLANDS 61, MASS.

Please rush to me, **FREE** of charge,
**UNITRON'S OBSERVER'S GUIDE and TELESCOPE
CATALOG #6-Z**

Name _____

Street _____

City _____ State _____