SPECIAL REPORT

Microprocessors

The amazing micromice: see how they won

Probing the innards of the smartest and fastest entries in the Amazing Micro-Mouse Maze Contest

The stage was set. A crowd of spectators, mainly engineers, were there. So were reporters from the *Wall Street Journal*, the *New York Times*, other publications, and television. All waited in expectancy as *Spectrum*'s Mystery Mouse Maze was unveiled. Then the color television cameras of CBS and NBC began to roll; the moment would be recreated that evening for viewers of the Walter Cronkite and John Chancellor-David Brinkley news shows. The final races of the Amazing Micro-Mouse Maze Contest were beginning at the National Computer Conference in New York, and what was perhaps most amazing was the wide public interest that the competition had evoked almost since its inception.

Publicity was not the chief goal when the micromouse contest was conceived. Nor did *Spectrum*'s editors suspect that more than 6000 entries would be received. A modest announcement of the contest was made in the May 1977 issue of *Spectrum* by Editor Don Christiansen, who first suggested the contest. Later *Computer* magazine became a cosponsor.

A secret maze was constructed, and the show went on the road, with time trials at the National Computer Conference in Anaheim, Calif., Personal Computing '78 in Philadelphia, WESCON in Los Angeles, and ELECTRO '79 in New York City. The challenge was to employ microprocessor technology to design and construct a self-contained "thinking mouse" that could solve a maze and, in subsequent trials, avoid its earlier mistakes. A loophole in the rules, however, let strictly mechanical, "nonintelligent" mice enter, too.

At the finals in New York's Sheraton Centre, three engineers—two from Battelle Northwest and one from WED Enterprises—teamed up to score a sweep as two of their entries took prizes for fastest and smartest mouse, respectively. Four other micromice solved *Spectrum*'s maze, and two won prizes. Of the 15 micromice entered, only six managed to solve the maze at least once. Cattywampus, a smart micromouse, did not solve the maze but won a prize for "the most ingenious design."

Mice that could learn

Learning by exploring was, in essence, the algorithm used by Moonlight Express (Fig. 1) as it negotiated the maze in record learning time. Designed and built by Art Boland and Ron Dilbeck of Battelle Northwest Laboratories, Richland, Wash., and Phil Stover of WED Enterprises, Glendale, Calif., it was an improved version of the Moonlight Special, a smart micromouse that had demonstrated its learning prowess at previous time trials of the contest as well as at the finals.

Roger Allan Associate Editor

The major difference between the Express and the Special was in their foward speeds: the Express had stepping motors with four times the torque used on the Special. Top motor speeds of 52.07 cm/s for the Express vs 20.32 cm/s for the Special were made possible. In addition the motor-drive circuitry for the Express was strengthened to handle the increased load of the new motors, and the Special's gear train was entirely eliminated.

Some of the hardware used in the Special—for example, interrupt logic—was eliminated by the use of IC devices that were exclusively from the Z-80A family of components (the Express was based on the Z-80A microprocessor, as was the Special). This represented only a slight modification of the earlier electronic circuitry in the Special (Fig. 2).

A distinguishing feature of the Special was that it looked like a real mouse. Everything else—the optical-sensor arrangement, battery supply, and the high-level software—were the same in the Express as in the Special.

The Moonlight Express and Special were equally intelligent. Both went through the maze on their first runs, exploring paths and mapping nodes (or three-way crossings) into their memories. Both solved the maze on each of their second and third tries, traveling the shortest possible maze routes, from entrance to exit.

Doing it with logic

Not all micromice at the finals contained microprocessors. Dudley and Mushka, two Canadian entries, managed to solve the maze with simple IC logic (Fig. 3). Both had been built from the same basic design, and each solved the maze on its last run in 252 and 94.74, s respectively. Dudley was entered by David Schaefer of NCR, Waterloo, Ontario, and Roger Sanderson of the University of Waterloo. Mushka, which won the runner-up smart prize, was entered by Bob Norton of Hamilton, Ontario, and John Ditner of the University of Waterloo.

The original designs for Dudley and Mushka (Fig. 4) called for a 1602 microprocessor, a Model 2758 EPROM with 1 k × 8 b of memory, a peripheral interface adapter IC, and three infrared sensors. The sensors were to detect the presence of walls around the mouse and to allow it to negotiate the maze without touching the walls. A software algorithm that would have provided the mouse with learning capability on successive trials was to be included. All of this was scrapped at the last minute, however, in favor of a simpler logic circuit due to insufficient time before the finals to do this.

Each mouse used two 3-V hobby dc motors to drive left and right wheels. Front and right switches activated a pair of one-shot multivibrators and three OR gates. Normally the mouse's left wheel was driven forward to the right. When the

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right switch hit the right wall, the right motor was powered forward and the left pulsed for a few milliseconds for reverse motion. The left motor then was turned on for forward motion, while the right motor was stopped. This sequence continued, causing the mouse to move forward while bumping into the right wall at intervals. For intersections, where a right turn was needed, the mouse simply followed the right wall forward. In the case of a left turn, the front switch was activated when the mouse bumped into a forward wall, turning the right motor forward and reversing the left motor long enough to make a 90-degree turn to the left.

The total parts outlay was approximately $50 for each mouse. Power was provided by two battery packs, each containing four Size A Ni-Cd rechargeable batteries. One battery pack was for the motors and one for the logic. The choice of following the right wall was arbitrary.

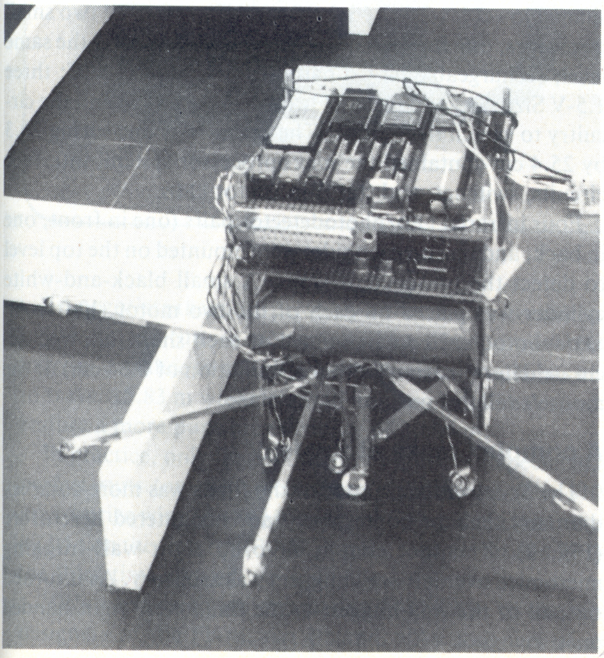
Smart mouse undone by speed

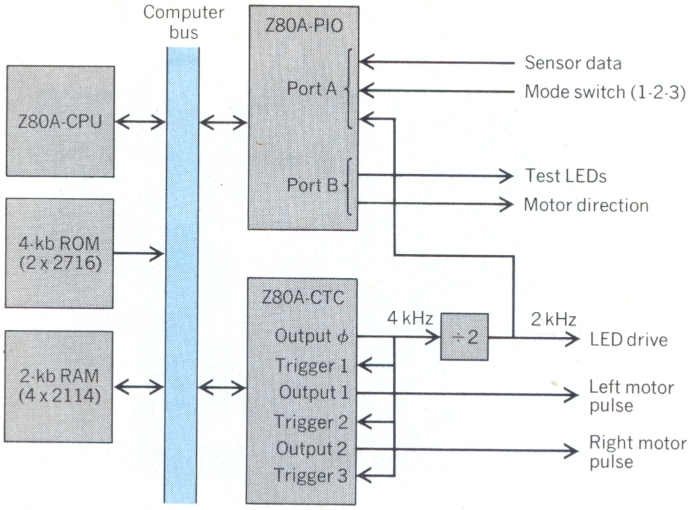
Cattywampus was one of the smarter mice. Its only problem was its poor speed control. Because it used ordinary dc motors instead of stepper ones, it would roar down the maze's opening straightaway, with no control, until it slammed into a wall, whereupon it would get stuck and be unable to negotiate a turn.

Designed and built by Michael Sipser, a graduate engineering student at the University of California at Berkeley, and Howard Katseff of Bell Laboratories, Holmdel, N.J., Cattywampus (Fig. 5) won the "most ingenious design" award despite the fact that it couldn't solve the maze on its three official tries. It was one of the earliest entries in the contest, having participated at the first time trial in Anaheim, in June 1978, when Mr. Katseff was also doing graduate work at Berkeley.

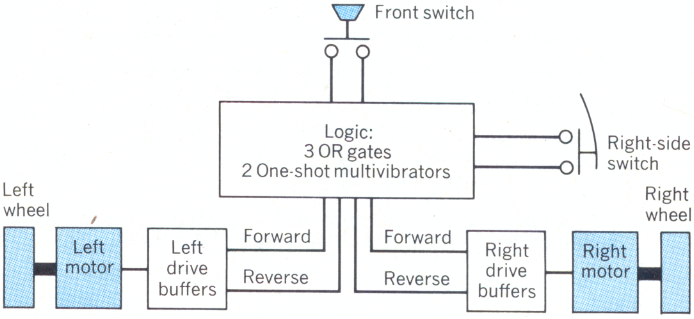
Despite its unsuccessful performance, this smart mouse was based on a 6802 microprocessor (Fig. 6) with a learning algorithm: two phases that governed its locomotion, EX-

[1] Moonlight Express, improved in speed over its predecessor, the Moonlight Special, won the prize for fastest smart mouse. It solved *Spectrum*'s maze in consecutive runs of 100.88, 31.36, and 31.16 s. Like the Moonlight Special, the Express was based on a Z-80A microprocessor. Its five appendages carried optical elements to guide it through the maze.



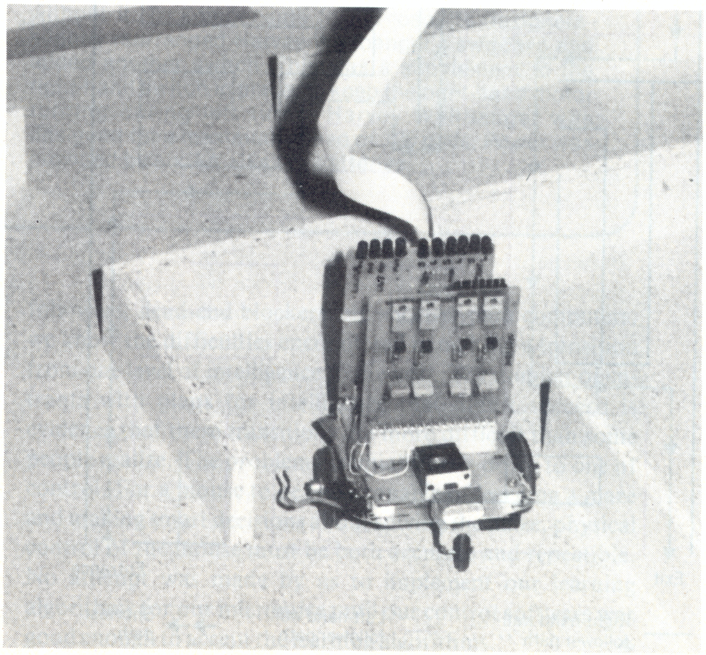


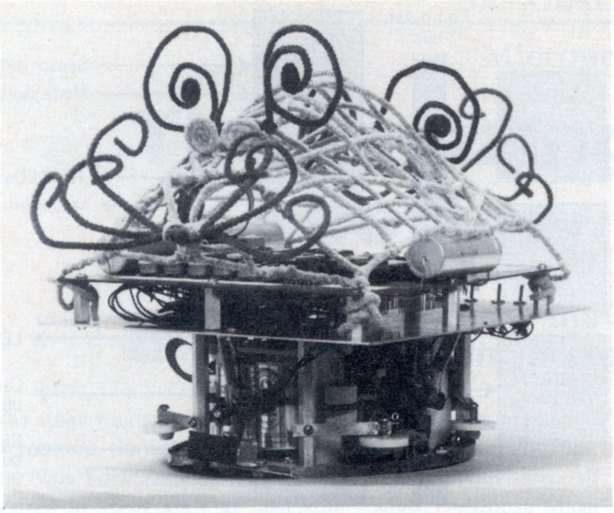
[2] Moonlight Express used Z-80A family components. Sensor data was available from the five optical pairs employed, after passing through ac amplifier/filter and comparator circuits. Motor drive pulses were passed through phase-generator and driver circuits to power a pair of stepping motors.



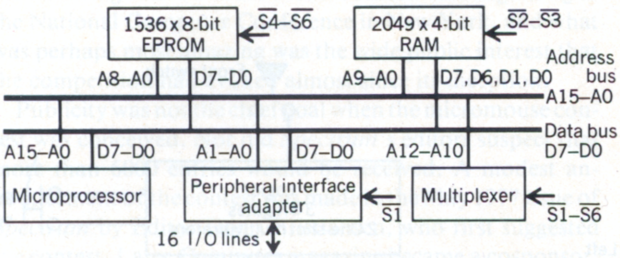
[3] This simple circuit composed only of logic elements propelled Dudley and Mushka. These two micromice solved the maze on each of their third runs at the finals, with Muskha winning the runner-up smart prize.

[4] The original version of Dudley and Mushka used a 1602 microprocessor. It is shown here in development with an emulation cable in a test maze.



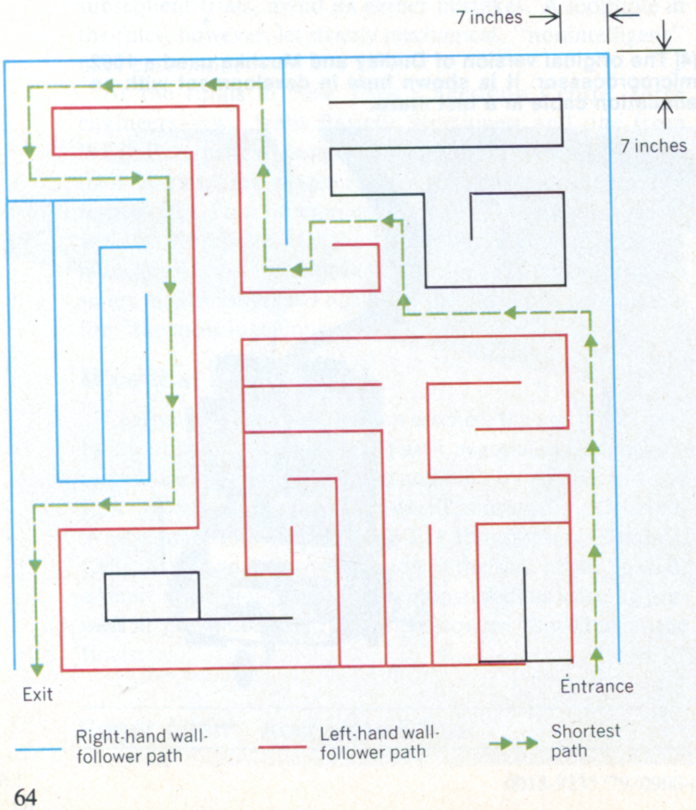


[5] Cattywampus didn't solve *Spectrum*'s maze but won the "most ingenious design" prize. It had a 6802 microprocessor. The pipe-cleaner strands on the cover were not functional.



[6] Cattywampus's microprocessor system included 1536 bytes of 8-b EPROM and 2048 bytes of 4-b RAM.

[7] The maze used in the finals. Note that right-wall huggers would take much less time than left-wall huggers to solve the maze. The layout was arbitrary. All walls were built on 17.78-cm centers according to the contest rules.



I. Box score of the final race, in order of running

Mouse	Designers/ handlers	Run 1, seconds	Run 2, seconds	Run 3, seconds
Dudley	David Schaefer, Roger Sanderson	Aborted	Aborted	252
Mikey	Michael Rigsby	Aborted	Aborted	Aborted
Mini	Anelle Rigsby	Aborted	Aborted	Aborted
Mushka	Bob Norton, John Ditner	Aborted	Aborted	94.74
Theseus	Dave Ziffer, Scott Pector, Robert Matz	Aborted	Aborted	Aborted
Charlotte	Earl Kalbfleisch	Aborted	Aborted	Aborted
Moonlight Special	Art Boland, Ron Dilbeck, Phil Stover	66.98	50.70	50.38
Moonlight Flash	Art Boland, Ron Dilbeck, Phil Stover	30.04	30.62	29.78
Moonlight Express	Art Boland, Ron Dilbeck, Phil Stover	100.88	31.36	31.16
Harvey Wall-banger	Gary Gordon, Gary Sasaki, Ken MacLeod	41.68	40.42	39.96
Mazey	Tony Rosetti, Peter Rowe, Steve Allen	Aborted	Aborted	Aborted
Kimbot	Mark Kantrowitz	Aborted	Aborted	*
Wampus II	David Block	Aborted	*	*
Catty-wampus	Howard Katseff, Michael Sipser	Aborted	Aborted	Aborted
Microbot	James Hamblen	Aborted	Aborted	Aborted

* Run not taken

PLORE and RETRACE. The former was in effect when the mouse was directed to continue moving straight along the maze corridor until it entered territory that it had visited previously, whereupon the RETRACE phase took over. While the mouse was in the EXPLORE phase, it continually remembered all of the paths it had traversed. When it entered the RETRACE phase, the shortest path to the nearest unvisited territory was computed, and it was directed to it. Then the EXPLORE path took over again.

A two-level design

Cattywampus was built on two levels. The football-shaped lower level was 15.2 cm wide. It contained two small dc motors, one for each of two wheels that were on the same level; rechargeable Ni-Cd batteries (six 1.5-V Size C; three 1.5-V Size AA, and two 9-V transistor batteries) and the circuitry to switch the motors. The upper level measuring 20.3 by 25.4 cm contained the microprocessor system, interface circuits, switches, and status-indicator LEDs.

Four infrared LED/photodetector pairs (one in front, one in back, and one on each side) were mounted on the top level to detect the presence of walls. A small black-and-white cylinder was placed on each of the two motor shafts. An LED/photodetector pair, aimed at each shaft, allowed accurate determination (within a resolution of 0.64 cm) of the mouse's relative position in the maze.

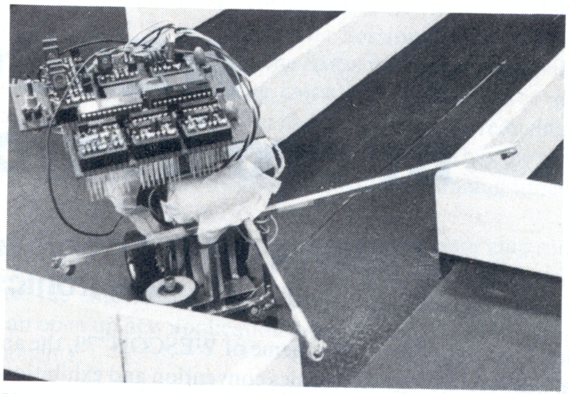
A complex maze at finals

The *Spectrum* maze used at the finals was more complex than any that the contestants had encountered heretofore (Fig. 7). The fact that it favored right-wall-hugging micromice over left-wall huggers was arbitrary. As it turned out, all of the wall huggers at the finals were right-handed ones.

The battle of the wall huggers

It was at the third time trial in Los Angeles last year that the Battelle team of Art Boland, Ron Dilbeck, and Phil Stover (Mr. Stover is now with WED Enterprises), decided to build a wall hugger. They had designed the Moonlight Special, the smartest micromouse observed, but at the time trial the team of Gary Gordon, Gary Sasaki, and Ken MacLeod of Hewlett-Packard, Santa Clara, Calif., introduced Harvey Wallbanger (below). This right-wall-hugging mouse, with no electronic intelligence, made up with speed what it lacked in brains. It traversed the *Spectrum* maze in the third time trial in 41 s on its first run.

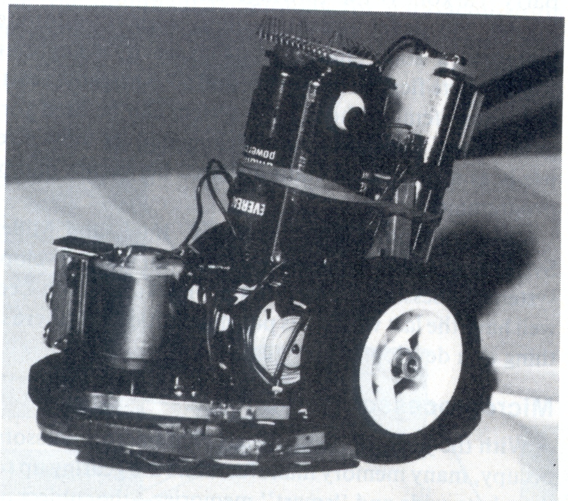
Thus was born the Moonlight Flash, (right) an optical right-wall-hugging micromouse entered by the Battelle team. Moonlight Flash won the grand prize of $1000 with a first run of 30.04 s, beating out Harvey Wallbanger, whose first run was clocked at 41.68 s.



Moonlight Flash, a right-wall-following micromouse, won the top prize by completing its first run at the finals in 30.04 s. It used an 8748 microprocessor and three optical sensor/receiver pairs to provide it with some intelligence. Though limited, this intelligence helped it negotiate turns smoothly, a time-saver that provided the winning margin.

Although the Moonlight Flash was not considered "intelligent," compared with the Moonlight Special and Moonlight Express—two other micromice designed by the same team—it did incorporate an 8748 microprocessor and memory that gave it just enough intelligence for the winning margin. For example, three forward optical sensors mounted on extended arms were used to provide "look ahead" capability to cut corners where possible. The microprocessor and optical sensors optimized the Moonlight Flash's turns at corners to cut down on running time. Whereas an ordinary wall hugger would make a turn at a corner, often slowing in the process and sometimes bouncing off walls, the Moonlight Flash did not require contact with the walls while rounding the corners and did not slow down.

Harvey Wallbanger was the first wall-hugging micromouse to solve *Spectrum*'s maze in less than one minute (at the third time trial in Los Angeles). It had no intelligence and followed the right wall. It won the runner-up fastest mouse prize with a first-try run of 41.68 s in the finals.



Another feature of the winner that was not used at the finals (insufficient time prevented the incorporation of this feature) was dead-end blocking. With it, the mouse would have been able to sense ahead dead ends and mousetraps and avoid them. Moonlight Flash was designed to operate from two small dc motors to achieve a top speed of 63.5 cm/s. Power was provided by three sub-C Ni-Cd rechargeable and four AA batteries.

Harvey Wallbanger operated on four wheels: two main ones driven by two small dc hobby motors, one on the left and one on the right; a swivel wheel in front; and a horizontal wheel mounted on the front right and driven by a third small hobby dc motor to hug the right wall. Two contact switches, one in front and one on the right side, made up the rest of the main components.

Shortly before the finals, it was discovered that the horizontal-wheel's motor was burned out. A search for a replacement was fruitless, and it was decided to do without it. To compensate for its loss, its designers slightly rearranged Harvey Wallbanger's switches and added another switch. This was a supplement to the right-hand switch in place, to keep the right-hand motor turning during left turns. Harvey Wallbanger was designed for a maximum speed of 100 cm/s. Power was provided by six AA alkaline batteries.

To negotiate the maze perfectly—that is, to solve the maze in the shortest run—a mouse would have had to travel but 8 m from entrance to exit. Right-wall huggers would have had to travel 15.83 m while left-wall huggers would have had to endure a more punishing distance of 30.05 m.

In practice, only the Moonlight Express and Special made perfect runs (on their second and third trials). The $1000 grand-prize winner, the Moonlight Flash, solved the maze in 30.04 s on the first run, 30.62 s on the second run and 29.78 s the third time around.

"It's been quite an experience," said one of the three designers of the Flash, Art Boland. "As designers of wall followers, dead-end blockers and shortest-path computers, we know the difficulties encountered in making a transition from one level of intelligence to the next. The number of entrants with plans for intelligence that didn't succeed is evidence that these transitions are more difficult than some people realize. The problem essentially boils down to one of control. For a mouse to be truly capable of learning a maze and making smart decisions about solving the maze, physical control of the mouse must be both accurate and repeatible. No attempt was made by us to implement our learning algorithms for our micromice until our control software was good enough to accept the learning algorithms."

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