A CRAY RESEARCH, INC. PUBLICATION

CRAY CHANNELS

Volume 3, Number 2

ANNOUNCEMENT!
CRAY-2 technology unveiled

FEATURE ARTICLES:

Oil reservoir simulation on the CRAY-1

CHECKMATE!—An electronic chess champion

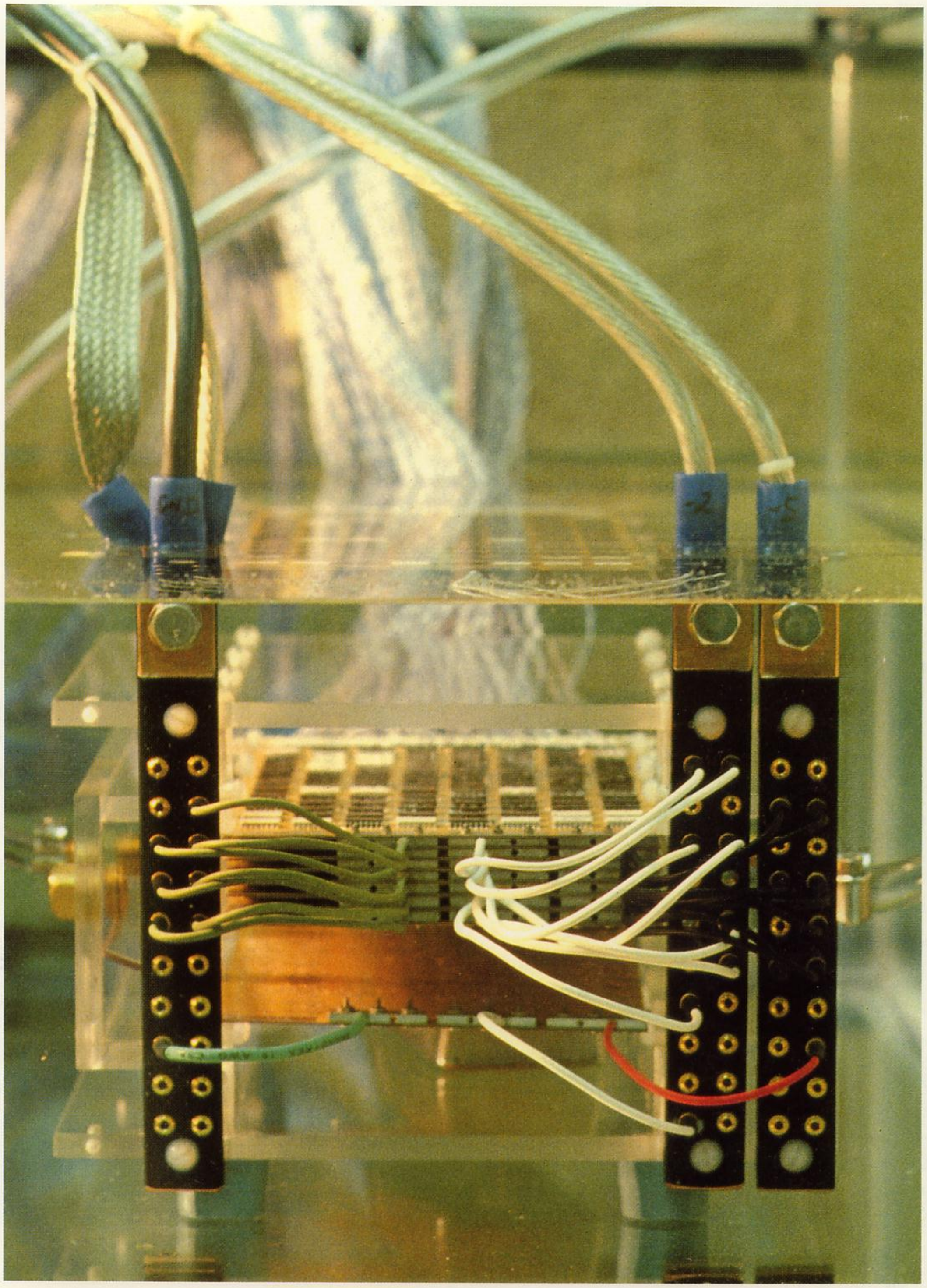
REGULAR COLUMNS:

Corporate register

Applications in depth

Scientific applications package highlight

User news



From the editor's desk

This issue of **CRAY CHANNELS** promises interesting reading for all. Our feature article describes oil reservoir simulation on the CRAY-1—a close look at the complexity of the problem and the dollars and resources hanging in the balance.

Our second feature article is a continuation of the coverage of computer chess begun in the last issue. In part two of this two-part feature, we learn more about the chess program that Cray Research helps support by providing computer time for development. The program's designer evaluates his work and describes what real tournament action is like, including his victory at the Mississippi State Closed Chess Championship, a computer chess first.

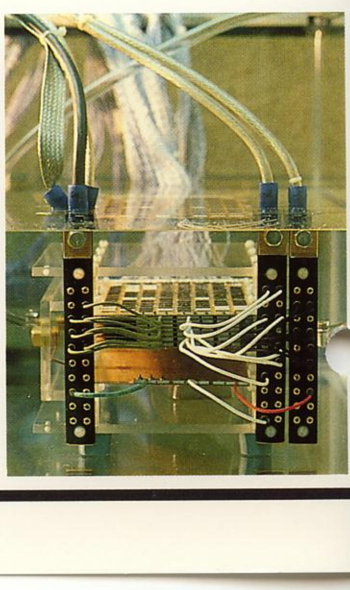
As before, the issue also contains our regular features to keep you up-to-date on product and company news.

In response to your favorable comments, we've expanded the "User news" section of the magazine. And we'd like to extend our invitation to CRAY users to notify us about activities at your sites—**CRAY CHANNELS** readers appreciate hearing about CRAY computer users!

— T.M.B.

About the cover

A technological breakthrough



Shown on our cover is a module of the prototype CRAY-2 computer currently under development by Cray Research. Cray's new technology involves the immersion of the computer in a clear, inert fluorocarbon liquid to provide cooling for the system. Because of the efficiency of this cooling method, components can be packaged in greater density.

For purposes of display, the module shown here was immersed in the coolant in a small aquarium. For further details and additional photographs, see the related story on page 12. (Photo credit: Jill Antolak)

CRAY CHANNELS

CREDITS
Editor Tina M. Bonetti
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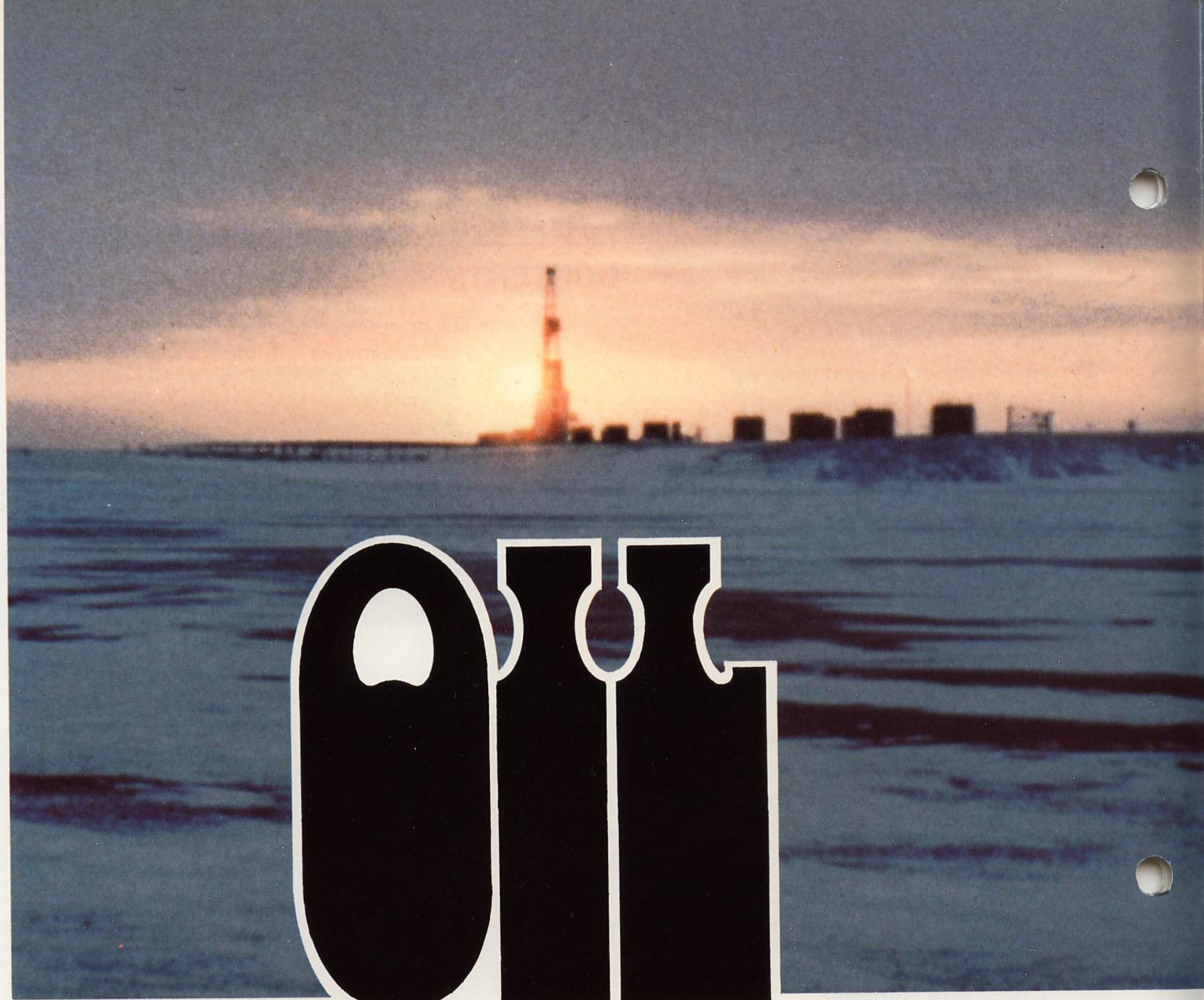
Requests for copies of **CRAY CHANNELS** may be addressed to the Publications Department of Cray Research at the above address. If you have a feature article or news item to submit for publication, please contact the editor of **CRAY CHANNELS** either by mail or by telephone at (612) 452-6650.



Reservoir Simulation on the CRAY-1

Introduction

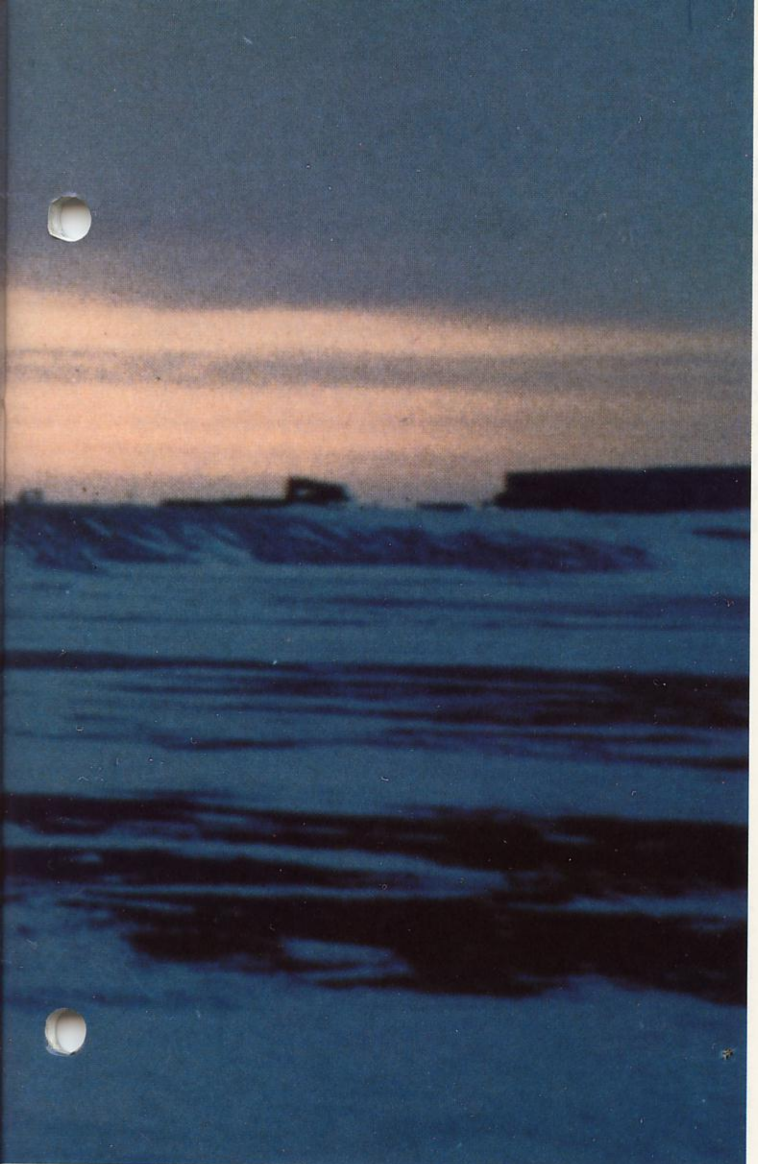
In recent years, scientists and engineers have been able to simulate many different physical phenomena using mathematical models. One area where simulation has become extremely important is in the petroleum industry. In light of the growing concern over our dwindling sources of oil, the biggest challenge to the petroleum industry today is to maximize total recovery.

The earliest oil reservoir modeling took place in the late 1950s. The models in use at that time were much simpler than those in use today. Reservoir simulation models have evolved over the past twenty years with the development of increasingly powerful computer systems. Now, the sophisticated oil reservoir simulations on the CRAY-1 enable major oil companies to test their alternatives before committing resources to a project. On the larger fields, where the stakes are higher, reservoir simulation has become a routine practice.

The simulation problem

For any given reservoir, many different methods of extraction are possible. The petroleum engineer has the difficult job of determining which method will maximize recovery over time, and a mathematical model run on a large-scale computer is usually the tool of choice. A reservoir model solves the set of equations that describe the physical processes taking place in the reservoir in terms of background assumptions and operating constraints. By studying the effect of the various recovery methods, a petroleum engineer can estimate approximate total recovery.

The first step for the engineer in modeling a reservoir is to establish a basic description of the reservoir. The



Photograph of Prudhoe Bay field courtesy of ARCO Oil and Gas Company.

primary depletion method, where little or no reinjection is done, is used to obtain a first approximation of the reservoir's content. Following the testing of primary depletion methods, a more complicated secondary recovery method is considered. The standard secondary recovery method involves water flood recovery.

Once a secondary water flood method has been selected, a tertiary recovery process may also be examined. Tertiary methods involve the injection of other types of fluids into the reservoir. Tertiary recovery methods have become extremely important to the oil industry in maximizing recovery from a reservoir.

Reservoir simulation enables an engineer to "experiment" on a field by trying out alternative methods of recovery. The goal of simulation is to determine output quantities and costs for each of a variety of recovery methods. By analyzing the alternatives, the most attractive development methods for a field can be identified before any actual production work is undertaken.

What is a reservoir model?

Most models are based on a two- or three-dimensional grid system. Each node in the grid system represents an actual location in the reservoir, and each node carries with it data for a variety of physical attributes. Values for gas, water, and oil content for each location in the reservoir are stored in the computer in matrix form. A typical model today includes several thousand grid points, placing great demands on a computer system. The CRAY-1, with up to four million words of central memory, has enabled the representation of larger, more complicated models than were possible in the past.

Even a one percent improvement in recovery brought about through modeling offset by many orders of magnitude the cost of simulations.

In addition, each reservoir model consists of sets of partial differential equations that express conservation of mass and/or energy. A model also includes basic "laws" that describe the physical characteristics in the reservoir, such as heat conduction (Fourier) or fluid flow (Darcy). To simulate the physical characteristics of a large model, the computer must perform repetitive mathematical operations on large matrices. These calculations must be performed with high precision to minimize the effect of roundoff error. The CRAY-1 answers this need well, providing outstanding performance on matrix calculations.

Improving the model through history matching

For many fields, a production history is available. This history data can be used to calibrate the model. By comparing the production history of the reservoir with the model's simulated behavior, engineers can determine what adjustments must be made to the model to bring it into agreement with actual observed behavior.

The quality of the history match depends to a great extent upon the quality and amount of data available. For example, if forty years of production history exists on a field and a ten-year prediction must be made, the engineer can be fairly confident of the simulation results. However, on a newer field, fewer records exist, and the resultant history match is not nearly as complete.

Although history matching is time-consuming, it allows the engineer to have more confidence in simulation results. By minimizing the difference between the model and historical record, the engineer can fine-tune a model. The history match is thus the engineer's best way to test how good a model really is.

Determining the input for the model

In initializing a model, the engineer must provide a description of the reservoir. A variety of data is taken on the field and assigned node by node in the representation. Input data for a simulation model usually includes:

- Reservoir rock properties (for example, porosity, permeability)
- Reservoir dimension measures
- Initial reservoir pressure and temperature
- Locations of oil/water and gas/oil interfaces
- Locations of gas caps
- Fluid property correlations (for example, density, viscosity, compressibility) as functions of composition, pressure, and temperature
- Relative permeability relationships
- Phase equilibrium relationships
- History information

Given this information, the engineer can determine approximate volumes of the oil, water, and gas in place in the reservoir.

Model output

The output provided by a reservoir simulation model usually consists of pressures and fluid saturations at each of the grid points throughout the reservoir. Grid point data is expressed at each of a sequence of time levels from start to finish of the production period. Temperature, concentration and pressure data are often provided for each grid point. Due to the extensive amount of output data, some method of aggregation is employed to simplify further analysis.

Interpreting the simulation results

By analyzing the output, the engineer can predict a maximum efficiency rate for production. This provides an indication of the speed at which oil may be recovered without hindering total production. The analysis of the model yields an estimate of the expected total production.

Based on the results of final simulation runs, engineers can make recommendations to management about how the field should be developed. Says John Killough, Research Director of Mathematical Development at ARCO Oil and Gas Company, "Often, the simulation results simply reinforce management positions. Sometimes, though, it's not as clear—some decisions are so close, that unless you have a model for guidance, you simply don't know which way to go. Certain decisions, such as selection of a pattern, are very difficult to make from gut feel alone."

An important decision that reservoir modeling can help address is how older fields should be developed differently. A company may decide to reopen abandoned wells or to use newer techniques on an older well in order to extract additional oil. Studying the feasibility of such moves is possible using a history-matched reservoir model.

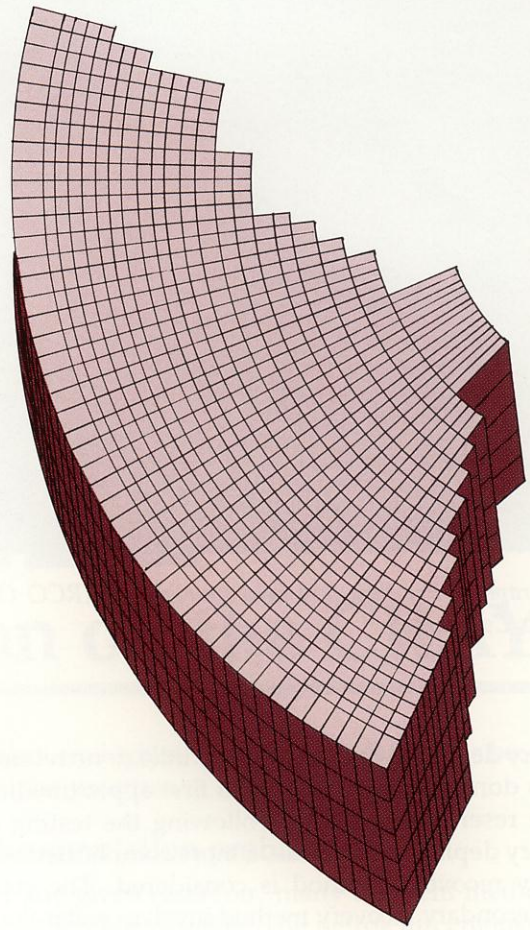


Figure 1. A sample reservoir simulation model

A sample model

Figure 1 illustrates a sample reservoir simulation model that John Killough and his co-workers use for predicting performance of the Prudhoe Bay field. The sample is a black-oil model, which is the simplest type of model because it does not take into account phase behavior relationships.

The black-oil model has become a workhorse model for newly-discovered or young fields. Three basic levels of sophistication exist for the formulation of a black-oil model:

- IMPES, which solves implicitly in pressure, explicitly in saturation;
- Sequential semi-implicit, which solves implicitly for pressure and for saturations; and
- Fully implicit, where the three sets of simultaneous equations are coupled and solved together.

The IMPES formulation is much more efficient in terms of computer time, so in cases where it is possible to use a simpler model, IMPES is generally chosen. The sequential semi-implicit formulation is more stable than IMPES at only a slight increase in computer time; hence, it is often chosen if the possibility for instabilities exists in the simulation. The sample model's formulation is of this latter variety.

"...For most reservoir simulation code, you'll be lucky to be able to vectorize substantially more than fifty or sixty percent..."

The sample model has an X dimension of 23, a Y dimension of 46, and a Z dimension of 5, for a total of 5290 grid blocks. The model grid is unique in that radial or polar coordinates are used. The total number of wells modeled ranged up to 1,700. A sophisticated program was used to model these wells and to include the constraints of the field facilities on the reservoir simulation model.

The total volume of oil in the Prudhoe Bay field is in excess of twenty billion barrels, so that even a one percent improvement in recovery brought about through modeling offset by many orders of magnitude the cost of simulations.

Advantages of the CRAY-1 in reservoir modeling

The CRAY-1 exhibits a number of strengths that make it ideal for reservoir simulation-type problems. Perhaps the greatest advantage of the CRAY-1 is its extremely fast cycle time of 12.5 nanoseconds. This fast cycle time allows the CRAY-1 not only to be fast for vector operations, but also to be extremely fast in scalar mode as compared to other types of scalar processors. Says John Killough, "For most reservoir simulation code, you'll be lucky to be able to vectorize substantially more than fifty or sixty percent, so scalar speed still dominates the CPU time in any reservoir model."

Another advantage is that the CRAY-1 has a 64-bit word (48-bit mantissa). This word size minimizes roundoff error, allowing for greater precision. Yet another strength of the CRAY-1 is that it is very efficient on short vector lengths.

As mentioned previously, the CRAY-1 is available with up to four million words of central memory, allowing for the solution of larger, more complex problems. Creative use of the CRAY-1/S expanded buffer memory can allow for simulation of even larger models using non-memory contained datasets. Alternatively, optimal disking and buffering algorithms can be employed.

Finally, the CRAY-1 FORTRAN (CFT) Compiler is an important advantage because most reservoir simulation models are written in FORTRAN. CFT is compatible with many of the existing IBM and CDC FORTRAN compilers. It offers automatic vectorization of DO loops to maximize efficient use of the vector capabilities of the CRAY-1. CFT also provides for more general models, permitting more realistic modeling of the wide variety of oil and gas reservoirs that exist throughout the world.

Acknowledgement

The model presented in this article will be presented by John E. Killough at the Society of Petroleum Engineers International Symposium in Beijing, China, on March 14-22, 1982.

This article was prepared with the kind assistance of John Killough of ARCO Oil and Gas Company and Diane Detig of Cray Research, Inc.

Further Readings

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Sequential Semi-Implicit Method

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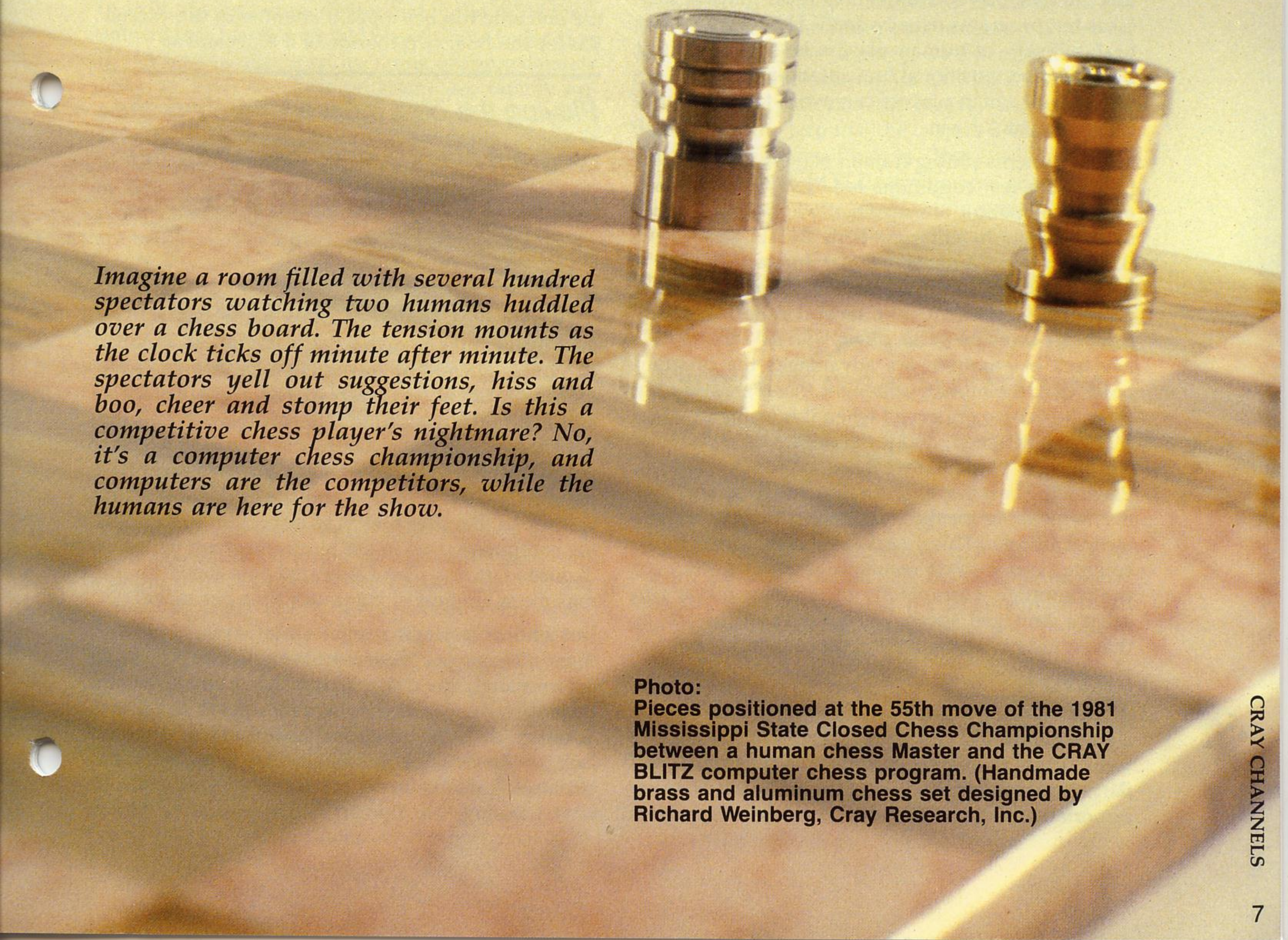
CHECKMATE— An electronic chess champion

Robert Hyatt
University of Southern Mississippi, Hattiesburg

Part two of a two-part series



Imagine a room filled with several hundred spectators watching two humans huddled over a chess board. The tension mounts as the clock ticks off minute after minute. The spectators yell out suggestions, hiss and boo, cheer and stomp their feet. Is this a competitive chess player's nightmare? No, it's a computer chess championship, and computers are the competitors, while the humans are here for the show.

Photo:
Pieces positioned at the 55th move of the 1981 Mississippi State Closed Chess Championship between a human chess Master and the CRAY BLITZ computer chess program. (Handmade brass and aluminum chess set designed by Richard Weinberg, Cray Research, Inc.)

Improvements in computer hardware and software design over the years have enabled computer chess programs to become more competitive with top human chess players. CRAY BLITZ's recent tournament victory in Mississippi is evidence of this fact—never before has a computer chess program won a state chess championship. And while no one can predict when a computer will become world chess champion, very few people will deny that one day the computer will be unbeatable.

Testing a program under competition

Developers of computer chess programs have two choices for testing a program under competition. They can enter open chess tournaments, where most, if not all, of the opponents are human. Alternatively, they can participate in computer chess championships, where only programs are allowed to enter. These two types of tournaments provide very different tests for computer chess programs of today.

The most notable difference between strong computer chess programs and strong human players is that human players sometimes make tactical mistakes but programs usually don't. However, the tactical fallibility of human players is generally offset by the deeper positional understanding humans exhibit, so if human players can avoid tactical errors, they will usually win.

In tournaments pitting human players against computers, the test conditions are ideal: the strengths of one competitor are matched by the weaknesses of the other. In entering both BLITZ and CRAY BLITZ in tournaments against human players, I have demonstrated that the computer is indeed a formidable opponent. The tactical expertise of the computer chess program, along with its "Mr. Spock"-like lack of emotion, are advantages the program holds over the human opponent. A program simply doesn't become unnerved when it is losing or when it is being attacked, and it never gets careless when it is ahead (a particular weakness of human players). Playing the best moves it can find, the program plays evenly, waiting for the human opponent to make a tactical mistake. This mistake is almost always forthcoming, and it often results in another victory for the computer. Fortunately, the human player can salve a damaged ego by thinking about the moves that would have beaten the computer, had they been played.

A chess game between two computers seems to be a non-optimal test condition, because the strong and weak points of the two programs may be quite similar. It is for this reason that luck generally plays an important role in deciding the victor of a contest between two programs. In an extended (multi-game) match, the better program will triumph, because play over a number of games should eliminate the factor of luck (or at least reduce it). Unfortunately, tournament play precludes two opponents meeting more than once.

Computer chess competitions

Each year, the Association for Computing Machinery (ACM) organizes and sponsors a tournament to measure progress in computer chess. An impressive array of computers participates: last year's tournament included two CRAY-1 computers, several AMDAHL 470/V7s and 470/V8s, and a Control Data Corporation CYBER 176. Rarely is that much computing power concentrated in one small room, especially to play chess! In addition to the yearly ACM tournament, a world computer chess tournament is held every three years to determine the best computer chess program in the world.

Computer chess tournaments are great crowd pleasers. Because computers don't mind noise, the spectators can actively participate by booing, hissing, applauding, and suggesting moves. As interest in the outcome reaches a peak, attendance can exceed 500 for the final two rounds of a tournament.

Playing the best moves it can find, the program plays evenly, waiting for the human opponent to make a tactical mistake.

Each side in a computer chess game has a fixed amount of time to make a predetermined number of moves. The requirement is usually that 40 moves must be made in two hours, for an average of three minutes per move. Time is measured precisely by two clocks at the tournament site, one for each program. When it is one program's turn to move, that program's clock is started and the opponent's clock is stopped. Because time is so important in a match, the computers used in the tournament are normally dedicated during play. Dedicated time allows for the maximum amount of computer time per move.

In addition to playing regular tournament chess at three minutes per move, the better chess programs are extremely good at playing speed chess, where the entire game lasts only five minutes. The tactical accuracy of these programs seems to offset their lack of knowledge to the extent that even the strongest human players in the world have a difficult time winning. No human has ever beaten CRAY

BLITZ in over-the-board speed chess, including several chess Masters. Even David Levy, who established himself as the arch-nemesis of computer chess programs and programmers, fell to BLITZ in speed chess. Five years ago, this record would have been labeled science fiction; today it is a demonstrable fact.

While no one can predict when a computer will become world chess champion, very few people will deny that one day the computer will be unbeatable.

ACM has sponsored the computer chess tournament annually as a controlled experiment. Since the first tournament in 1970, the time allowed per move has remained the same. Thus, increases in playing strength can be directly attributed to improvements in hardware and software.

In 1970, the best program entered in the ACM tournament was barely a United States Chess Federation (USCF) class C player with a rating of approximately 1500. In 1981, the best programs are rapidly approaching the Master rating (USCF rating of 2200 or better). CRAY BLITZ is the first (and only) program to have achieved this status to date, with a rating of 2258. In speed class, the better programs are currently rated at over 2400, and steady improvements are being seen in longer timed events.

CRAY BLITZ's performance

CRAY BLITZ has been playing chess for almost two years. Before being implemented on the CRAY-1, BLITZ had been playing chess for about four years. Needless to say, the CRAY-1 greatly improved the strength of the program, due to the depth of search made possible by the tremendous speed of the machine.

At a rate of one move every three minutes, CRAY BLITZ generally performs an exhaustive search to a depth of seven plies in the middle game. In the end game, CRAY BLITZ has performed searches exceeding 35 plies. While a depth of seven half-moves might not sound very impressive at first, it is deep enough to find some extremely clever tactics. Research has shown that as depth increases, the accuracy of move selection in a human lessens. In a program using exhaustive searching, however, inaccuracy is not a problem because every move is considered.

Tournament action

To appreciate what goes on at a tournament, join me in playing the following game. This game was played by CRAY BLITZ in the 1981 Mississippi State Closed Chess Championship. CRAY BLITZ won with a perfect score of 5 wins, 0 losses. The program's performance earned it the title of "Mississippi State Chess Champion" for 1981, making CRAY BLITZ the first computer program ever to win a state chess championship tournament. The opponent is a USCF chess Master and state champion for the previous two years. CRAY BLITZ played black. I am including the number of nodes the program examined, the position evaluation (where +1.2 means the program is 1.2 pawns ahead, for example), and the program's analysis (the moves it anticipates being played). I am also including the time elapsed per move for each side so that it is possible to determine how much time each side has left at any point. The time rules for the tournament require 50 moves every two hours. Also included are my remarks and (in quotes) those that came directly from CRAY BLITZ.

We are sitting across the board from our human opponent. A terminal connected to the CRAY-1 is facing us so that the opponent cannot see. Whenever our opponent makes a move, we enter the move via the terminal and wait for CRAY BLITZ's response. While BLITZ performs the search, it periodically displays on the terminal the current evaluation and expected sequence of moves. These values are updated whenever BLITZ's evaluation changes. Because the program is a much stronger evaluator than any human present, we rely on its analysis to let us know how the game is going.

Because computers don't mind noise, the spectators can actively participate by booing, hissing, applauding, and suggesting moves.

The only problem is time. We must sit patiently, waiting for a clue from CRAY BLITZ to let us know how the game is going. If the opponent takes 15 minutes for a move, we sweat it out until the move is made and the program starts displaying its analysis. As the evaluation climbs, we smile; as it drops sharply, we worry. It is very much like watching one's children play in a competitive event.

Remember that while the tournament is in progress, we can't turn the page to check the evaluation 10 moves from now! We have to wait (and worry).

Round 4
White: human (USCF rating 2260)
Black: CRAY BLITZ
English opening

1. c4 (0:15) **Nf6 (0:00)**

2. Nc3 (0:21) **c6 (0:00)**

3. Nf3 (0:16) **d5 (2:17) 408,258 nodes −0.048**
d5 e3 e6 d4 Nbd7 Qa4 Bd6 Program is temporarily "out of book"

4. cxd5 (0:28) **cxd5 (2:17) 558,670 nodes +0.000**
cxd5 d4 Nc6 e3 e6 Bb5 Bb4

5. d4 (0:50) **Nc6 (0:00)**
"Back in book"

6. g3 (0:14) **Ne4 (2:19) 384,099 nodes +0.183**
Ne4 Bg2 Nxc3 bxc3 Qa5 Qd3 e6 "Out of book" again

7. Bg2 (1:14) **Nxc3 (3:23) 877,648 nodes +0.085**
Nxc3 bxc3 e6 0-0 Be7 e3 0-0

8. bxc3 (0:11) **e6 (3:06) 565,507 nodes +0.129**
e6 0-0 Bd6 Qd3 0-0 e4 f5 exd5 exd5

9. 0-0 (0:28) **Bd6 (2:36) 509,561 nodes +0.127**
Bd6 Rb1 0-0 Qa4 f5 Bg5 Qd7

10. Qc2 (2:15) **0-0 (2:55) 508,413 nodes +0.117**
0-0 Rb1 f5 Bd2 Re8 e3 e5

11. Ng5 (5:10) **f5 (2:43) 433,129 nodes +0.167**
f5 f4 Na5 Rb1 Nc4 e3...

12. f4 (2:58) **Na5 (0:00) 493,756 nodes +0.148**
Na5 e3 Nc4 Nf3 Qf6 Ne5 Bxe5 fxe5 Notice CRAY BLITZ used no time to select this move since it had correctly predicted the opponent's move (f4, see previous analysis for move 11).

13. Qd3 (3:55) **Qd7 (2:27) 381,838 nodes +0.138**
Qd7 Nf3 Nc4 Nd2 Nxd2 Bxd2

14. Bd2 (6:13) **Nc4 (2:18) 348,683 nodes +0.147**
Nc4 e3 Qc6 Rfb1 b5 Rb3

15. Bc1 (2:22) **Qa4 (2:18) 355,534 nodes +0.220**
Qa4 e3 Bd7 Rb1 b5...At this point I was happy! White's C pawn is backward, Black's knight is well placed, and the program thinks it is nearly ¼ pawn ahead. Little did we realize what was coming.

16. g4! (30:55) **h6 (2:18) 378,020 nodes +1.243**
h6 gxf5 hxg5 fxg5 Ba3 Bd2 Nxd2 Qxd2 CRAY BLITZ is a pawn up! Watch the evaluation slip for the next few moves, because the human opponent used 30 minutes to calculate deeper than the program.

17. gxf5 (1:08) **hxg5 (1:09) 326,700 nodes +1.193**
hxg5 fxg5 Qe8 f6 Qh5 Bh3

18. fxg5 (0:27) **Ba3 (1:52) 320,602 nodes +1.068**
Ba3 Bxa3 Qxa3 e4 exf5 exf5

19. g6! (1:50) **Bxc1 (2:21) 403,760 nodes +1.212**
Bxc1 Rfxc1 Rxf5 Qh3 Rg5 Qh7+ Kf8 Rf1+ Ke7 Qxg7+ Kd8 It's getting complicated! Note how far ahead the program is analyzing.

20. Raxc1 (0:26) **Nd6 (2:21) 362,642 nodes +0.891**
Nd6 Qh3 Rxf5 Qh7+ Kf8 Qh8+ Ke7 Qxg7+ Kd8 Rxf5 Nxf5 Note the evaluation. I now thought the program was lost. How can it stop the g pawn from queening? Watch...

21. Qh3 (0:36) **Rxf5 (2:21) 408,459 nodes +0.557**
Rxf5 Qh7+ Kf8 Bh3 Rxf1+ Rxf1+ Ke7 Qxg7+ Kd8 Rf8+ Ne8 Help! We're now only one-half pawn up!

22. Qh7+ (2:59) **Kf8 (0:00) 426,135 nodes +0.557**
Kf8 Bh3 Rxf1+ Rxf1+ Ke7 Qxg7+ Kd8 Rf8+ Ne8 At least the evaluation held steady for one move!

23. Qh8+ (1:52) **Ke7 (0:00) 349 nodes**
No analysis, because move is forced.

24. Qxg7+ **Kd8 (2:01) 358,566 nodes −0.431**
Kd8 Qh8+ Kc7 g7 Nf7 Rxf5 exf5 Bxd5 At this point, the program sees trouble ahead. However, the Master has used a lot of time and can't afford to carefully analyze each move now, and he soon begins to falter.

25. Rxf5 (6:33) **Nxf5 (2:29) 419,712 nodes +0.413**
Nxf5 Qf8+ Qe8 g7 Ne7 c4 Bd7 Qxe8+ Kxe8 cxd5 exd5 Now we are ahead again. Rxf5 was not best, as can be seen from the program's prior analysis. Qh8+ was better.

26. Qf6+ (0:32) **Ne7 (2:29) 417,621 nodes +0.455**
Ne7 g7 Qe8 c4 Kd7 cxd5 exd5 Now the pawn is finally stopped. CRAY BLITZ is threatening Ng8, blockading it further.

27. g7 (2:27) **Qe8 (0:15) 383,644 nodes +0.266**
Qe8 e4 Kd7 exd5 Nxd5 Qf8 Ne7 Qxe8+ Kxe8 The pawn looks dangerous, but we have defended well. For the time being, everything is held together.

28. Bf3 (3:01) **Kd7 (2:35) 385,273 nodes +0.451**
Kd7 e4 Rb8 Kh1 dxe4 Qe5 Nc6 Qxe4 So far, so good...

29. Rf1 **Ng8 (2:35) 382,522 nodes +0.306**
Ng8 Qg5 Qe7 Qxe7 Kxe7 e4 Nf6 exd5 exd5 Trading queens saves everything! However, the pawn is now threatening again via Rf8 Rxf8 gxf8=Q. Can we survive this last rush?

30. Qg5 (3:27) **Qe7 (0:00) 515,188 nodes +0.209**
Qe7 Qg6 Kd6 e4 dxe4 Bxe4 Kd7 Rf7 Now the opponent has only 34 minutes for the final 20 moves, while the program has over one hour left.

31. Qg6 (0:53) **Kd6 (1:49) 351,300 nodes +0.278**
Kd6 Qg3+ Kc6 c4 Qd8 Qg6 Kc7 cxd5 exd5

32. e4 (10:08) **dxe4 (2:45) 385,266 nodes −0.219**
dxe4 Qg3+ e5 Bxe4 Qe6 Bf5 Qd5 dxe5+ Kc7 Oops! There goes the evaluation again. However, material is even. Time is really serious for the Master now.

33. Bxe4 (1:18) **Qh4 (2:46) 391,722 nodes −0.713**
Qh4 Bg2 Bd7 Bxb7 Rb8 Qg2 Bb5 Now we are losing a pawn if the opponent plays correctly.

34. Qg3 (6:23) **Qxg3+ (2:46) 610,609 nodes −1.459**
Qxg3+ hxg3 Bd7 Rf8 Rc8 Rxc8 Bxc8 Bh7 Ne7 g8=Q Nxg8 Bxg8 Now we are over a pawn behind. BLITZ is analyzing deeper than the Master, however, and the Master doesn't find the best moves.

35. hxg3 (0:37) **Bd7 (2:08) 470,710 nodes −1.359**
Bd7 Rf8 Rc8 Rxc8 Bxc8 Bh7 Ne7 g8=Q Nxg8 Bxg8 The opponent has 15 minutes left. Note that the program's evaluation is climbing now, as it will for the remainder of the game.

36. Rf8 (7:31) **Rc8 (0:00) 1,395,040 nodes −1.311**
Rc8 Rxc8 Bxc8 Bh7 Ne7 g8=Q Nxg8 Rxc8 is the Master's only chance. However, he is almost out of time.

37. Bh7 (1:56) **Rxc3 (3:00) 604,912 nodes +0.000**
Rxc3 Kh2 Rc1 Rf2 Rc8 Rf8 Rc1 Bh7 looks good to drive the knight away, but it is too late. CRAY BLITZ thinks everything is exactly even.

38. Rxg8 (4:14) **Rxg3+! (3:00) 610,779 nodes −0.090**
Rxg3+ Kf2 Rg4 Be4 b5 Ra8 Rxg7 Rxa7 The move Rxg8 is too late!

39. Kf2 (0:07) **Rg5 (2:52) 615,741 nodes −0.010**
Rg5 Be4 e5 dxe5 Kxe5 Bxb7 Be6 Re8 Rxg7 Looking better every move. Just one more inexact move, and...

40. Be4 (0:46) **b6 (2:14) 568,593 nodes −0.009**
b6 Ke3 e5 a3 Be6 Rd8+ Ke7 Ra8 Now it is our turn!

41. Ke3 (0:35) **e5 (2:30) 616,227 nodes +0.004**
e5 Ra8 Rxg7 Rxa7 Rg3+ Kf2 Rc3 dxe5+ Kxe5 Rxd7 Kxe4 Evaluation has (finally) gone positive!

42. Ra8 (1:37) **Rg3+! (1:32) 702,663 nodes +0.636**
Rg3+ Bf3 exd4+ Kxd4 Be6 Bb7 Rg4+ Ke3 Bxa2 Rxa7 Rxg7 We're a pawn up!

43. Kf2 (0:08) **Rxg7 (3:22) 787,876 nodes +0.764**
Rxg7 Rxa7 exd4 Rb7 b5 Bd3 Rg5 a3 Rd5

44. dxe5 (0:07) **Kxe5 (3:22) 708,164 nodes +0.785**
Kxe5 Bf3 Be6 a3 Rc7 Re8 Rc2+ Kg3 Kd6 Getting better!

45. Bf3 (0:07) **Be6 (3:07) 675,932 nodes +0.761**
Be6 Re8 ...

46. a4 (0:07) **Rf7 (3:25) 732,838 nodes +1.665**
Rf7 Re8 Rf4 a5 bxa5 Ke3 Rf7 Be4 Two pawns ahead looks good, but watch this...

47. Ke3? (0:11) **Rxf3! (3:26) 760,544 nodes +4.093**
Rxf3 Kd2 Rf7 Ke3 Rh7 Kd2 Rh2+ Ke3 Rh3+ Kd2 If Kxf3, then Bd5+ wins the rook as in the game. "Be careful."

48. Kxf3 (0:06) **Bd5+ (2:00) 703,217 nodes +5.071**
Bd5+ Ke2 Bxa8 Kd3 Bc6 a5 bxa5 Kc4 a4 Kc3 Be4 I will drop the analysis as the game is basically over.

49. Kc3 (0:05) **Bxa8 (0:40) 266,098 nodes +5.079**
"That was easy."

50. a5 (0:06) **Be4! (1:53) 722,217 nodes +7.694**

51. Kd2 (1:04) **Kd4 (2:00) 774,460 nodes +10.866**
"Be careful."

52. Kc1 (0:25) **b5 (2:00) 752,079 nodes +11.151**

53. Kb2 (1:57) **Kc4 (0:00) 834,892 nodes +11.319**

54. a6 (0:16) **b4 (2:00) 912,576 nodes +20.412**
"Be careful."

55. Ka2 (1:28) **Kc3, and BLITZ announced mate in 6.**

That was a wild game that could have gone either way. I have some general comments on the game. First, the worst thing CRAY BLITZ saw was coming out a pawn down, but even being a pawn down was not critical because the opponent was so short on time. Second, the opponent was behind on time because the program came up with some surprising defensive moves and generally presented the opponent with a lot of tactical problems.

In winning the other four games in the tournament, the program never found itself with a negative evaluation; that is, it was ahead all the way. In winning the state championship title, the program achieved a rating of 2258, placing CRAY BLITZ in the *Guinness Book of World Records* as the first computer chess Master.

It should be noted that, to date, only three programs have beaten chess Masters in tournament play: BELLE of Bell Laboratories, Control Data Corporation's CHESS 4.9, and CRAY BLITZ. Three years ago, no one thought a program would ever beat a human. Now it is becoming commonplace. Watch out, Bobby!

The future for CRAY BLITZ

Performance against other programs is the next testing phase for CRAY BLITZ. The annual "computer only" tournament sponsored by ACM takes place in November in Los Angeles, California. CRAY BLITZ will be there to defend its "World Computer Speed Chess Champion" title and to try to wrest the regular world title from BELLE.

The current version of CRAY BLITZ has only played one other computer program, BELLE. In a four-game match played in August, BELLE and CRAY BLITZ split at two games each, which gives an indication of how close they really are. Remember that tactical errors don't really exist in games between top-class programs, so Lady Luck has a chance to enter into the fray, sometimes at the most embarassing times.

CRAY BLITZ is anxiously awaiting the successor to the CRAY-1 for additional hardware advantages, while human opponents have resigned themselves to the fact that computer chess programs can only improve.

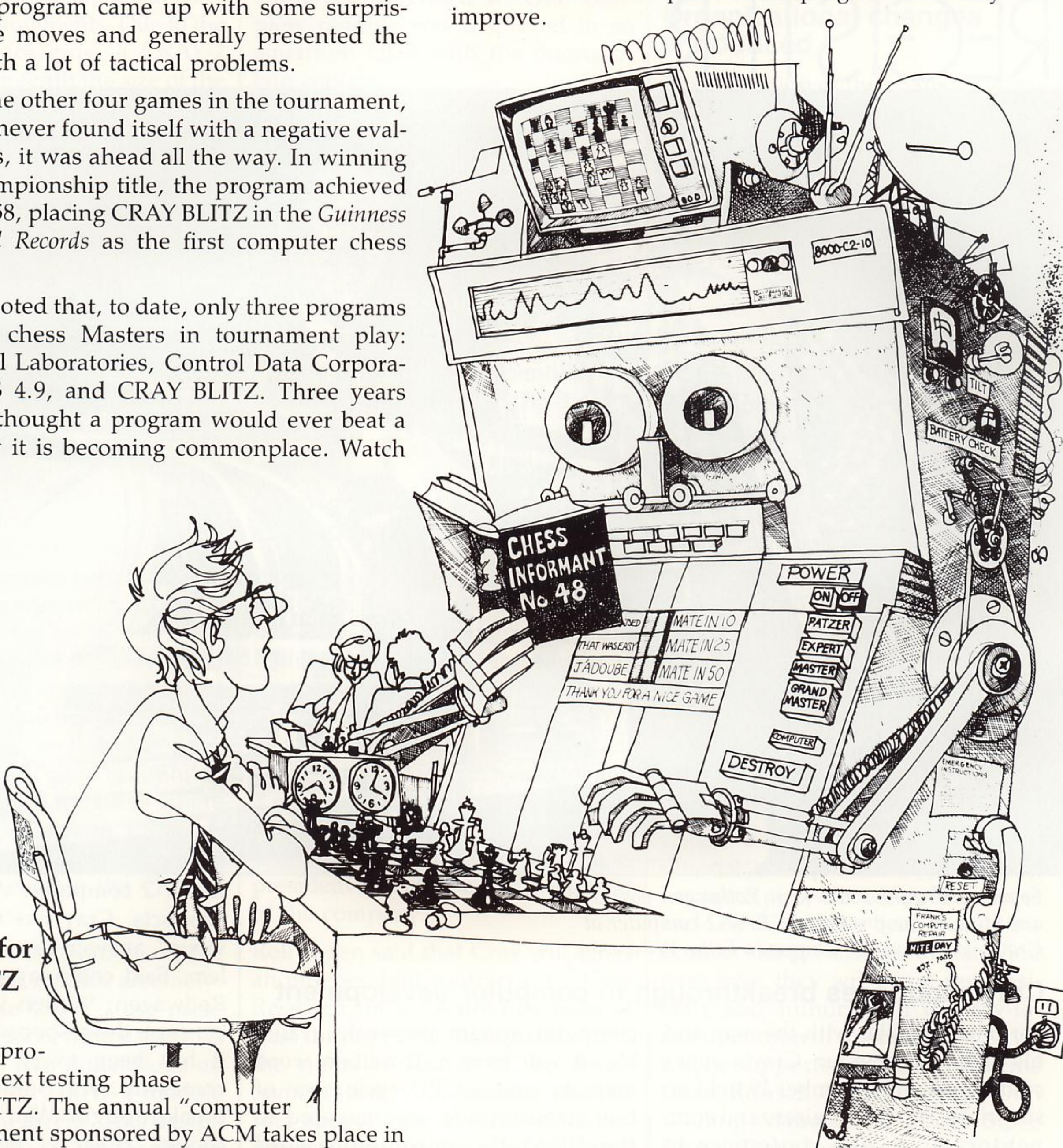
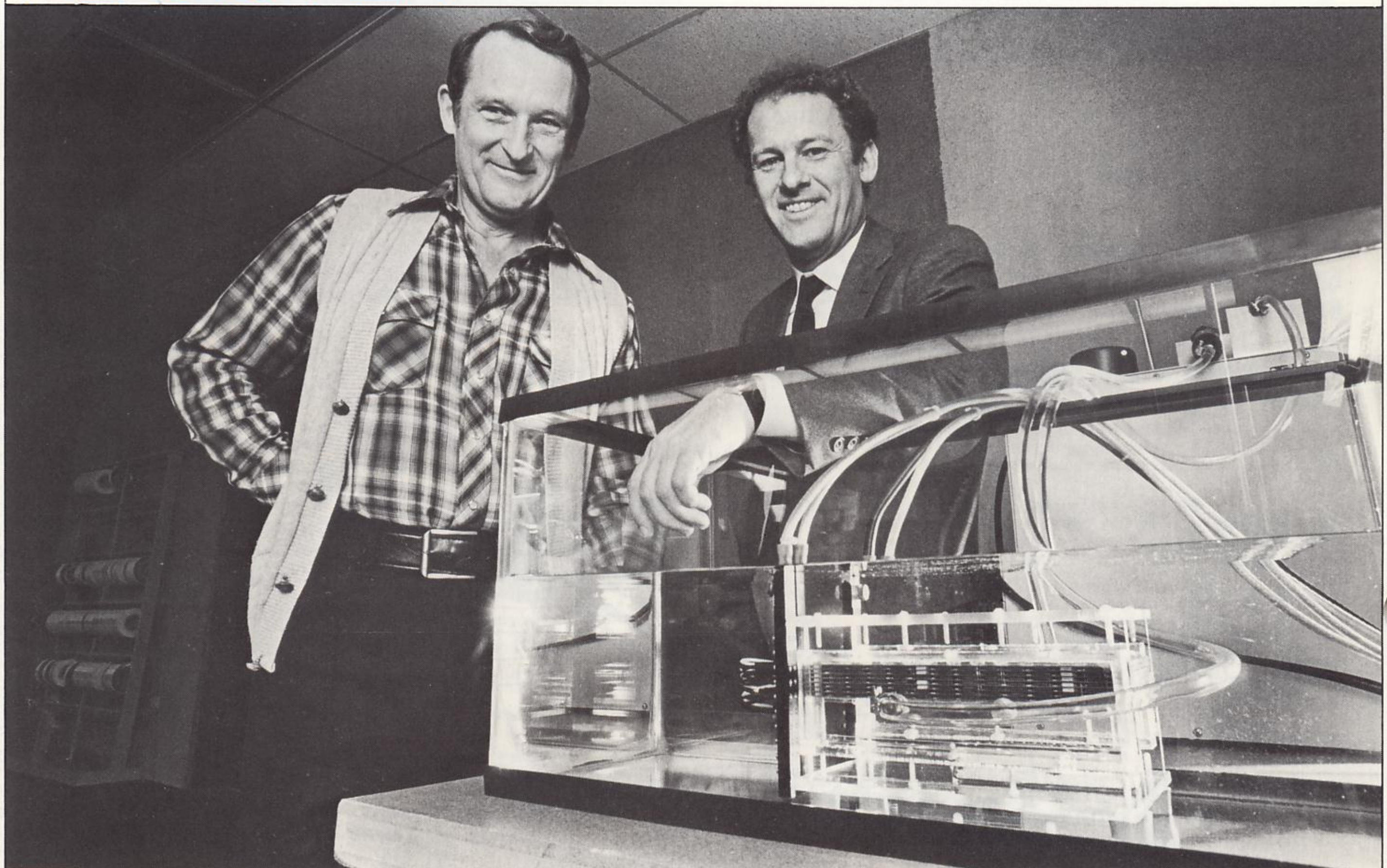


Illustration by Bob Walker, courtesy of the U.S. Chess Federation.

—ABOUT the AUTHOR—

Robert Hyatt *is an Instructor and Chief of Systems at the University of Southern Mississippi in Hattiesburg. He received his B.S. in Computer Science from USM in 1970 and has remained there to teach and do research. Bob has been competing in computer chess tournaments with BLITZ since 1976. He has had CRAY-1 support from Cray Research since April of 1980.*

CORPORATE REGISTER



Seymour Cray (l.) and John Rollwagen pose with a module of the prototype CRAY-2 computer at Cray's laboratory in Chippewa Falls, Wisconsin.

Cray announces breakthrough in computer development

For those familiar with the man and his habits, Seymour Cray's news conference on November 19 held no surprises. But for admirers and competitors alike, the conference in Minneapolis demonstrated once again Seymour Cray's ingenuity and dedication. The occasion was the announcement of the technology that will allow development of the CRAY-2, the company's successor to the CRAY-1 computer system.

Cray Research announced that upon completion, the CRAY-2 is projected to be 6 to 12 times faster than any computer system presently available. It will have a 32-million word memory and a CPU cycle time of four nanoseconds, as compared to the CRAY-1's four-million word memory and 12.5 nanosecond cycle time. Additionally, the CRAY-2 will achieve further gains in speed through multiprocessing, using a four-processor system, compared to one unit on the CRAY-1.

At the conference, Seymour Cray unveiled a technological development that will enable him to complete the development stage of the CRAY-2 computer. As in previous products, Cray has found an "obvious" answer to a complex problem. Said company president John Rollwagen, "When we explain the concept, the response is the same as it has been every time Seymour comes up with some fundamental breakthrough: Well, sure . . . of course." However, he noted that the adaptation of an obvious solution to mass production while preserving ease-of-maintenance is more complicated than it sounds.

Cray applied liquid immersion technology in the design of the CRAY-2 to solve a basic problem in computer design, that of cooling. By immersing the computer in a bath of clear inert liquid, the cooling problems inherent in large computer systems are substantially reduced. The resultant cooling system is extremely efficient and enables higher-density packaging of components. Due to the more dense packaging, a CRAY-2 CPU will be one-tenth the size of the CRAY-1, standing 26 inches high and 38 inches long.

The coolant to be used in the system is a pure fluorocarbon liquid. Interestingly enough, the coolant is not a recent technological breakthrough. It has been used for decades in atomic research and in a number of industrial processes. The liquid has also been used in medicine for blood transfusions and to keep arteries inflated during surgery.

An interesting sidelight to the liquid immersion technology is that it has an unusual functional value. The fluorocarbon liquid is normally quite clear and the consistency of salad oil. However, engineers have observed on the prototype module that when the circuits are on, the liquid becomes somewhat turbulent due to heat generation. The turbulence has been described as "quite beautiful to watch", and it also indicates where hot spots are located in the computer. For these two reasons, the company may enclose the CRAY-2 in a clear frame.

Another design innovation on the CRAY-2 concerns module assembly. Modules for the CRAY-2 are packaged closely in three dimensions, as compared with two dimensions on the CRAY-1. Each CRAY-2 module consists of eight layers. This design substantially reduces the lengths of connecting wires, thus taking advantage of the fact that shorter wires result in greater potential speed. The longest wire in the CRAY-2 will be 16 inches, compared to four feet in the CRAY-1.

At the news conference in November, Cray displayed a portion of the prototype CRAY-2 he has been working on in his Chippewa Falls laboratory. "He brought his fishbowl downtown for the world to see," was how one Cray Research employee described it. One complete module was displayed in an aquarium filled with the fluorocarbon coolant.

A new building is now under construction in Chippewa Falls, Wisconsin for CRAY-2 prototype development. Work will progress under Seymour Cray's direction. The CRAY-2 system is expected to be phased into production over the next three to four years. When it is available, the CRAY-2 will be marketed to the initial group of scientific customers served by the CRAY-1.

Seymour Cray to devote full time to new technology

After unveiling the technology that will be the basis of the CRAY-2 computer system, Seymour Cray announced that he will step down as chairman of Cray Research in order to devote full time to the CRAY-2 and other design and development work. Cray will remain a director and a member of the executive committee. John Rollwagen will assume the chairman's title while continuing as president and chief executive officer of the company.

Rollwagen said that Cray will act as an independent contractor for Cray Research on a royalty-free basis at least through 1985. Both parties have the rights to results of the development work. Cray Research also has first opportunity to fund additional projects and production of future advanced computer systems that Cray may decide to pursue.

Rollwagen reported that the program at Cray Laboratories in Boulder, Colorado, which has been pursuing CRAY-2 development from a separate technological base, is being redirected to other areas of company activity where its technology is applicable. Cray Laboratories will become the company's Boulder Division.

Organizational changes announced

In recognition of the changing management relationships at Cray Research, a number of modifications have been made to the company's organizational structure. As mentioned previously, Seymour Cray has stepped down as chairman, and the position will be assumed by President and Chief Executive Officer John A. Rollwagen.

In assuming the company chairmanship, Rollwagen will take on additional responsibilities and projects of long-range significance to Cray Research. One important function he will assume is ensuring that the relationship between Seymour Cray and Cray Research continues to be a strong and mutually beneficial one. Rollwagen will also monitor the direction of activities at the company's laboratory in Boulder, Colorado and will take a more active role in corporate policy making and planning.

To ensure continuing strong support of the company's current customers and existing products, additional management restructuring has taken place. Peter Appleton Jones and Les Davis have been named executive vice presidents, and in their new roles they will share responsibility and authority for the day-to-day operation of the business. Davis will be supported by vice presidents Dean Rousch (Engineering), Don Whiting (Manufacturing), and Steve Chen (Development). Appleton Jones will receive support from vice presidents Bruce Kasson (U.S. Sales), Mike Dickey (International Marketing), and Margaret Loftus (Software Development).

The executive committee of the company has been reconstituted and now consists of John Rollwagen, Seymour Cray, Peter Appleton Jones, Les Davis, and Andrew Scott. Scott is also joining the company as counsel, and as such will devote his full efforts to the corporation.

Two senior vice presidents have been named: John Carlson (Finance) and G. Stuart Patterson (Boulder Division). Other newly-named vice presidents are Peter Gregory (Corporate Planning) and Howard Sachs (Boulder Division).

CRAY-1 to be installed at NASA-Ames

A CRAY-1 S/1300 computer system will be installed at NASA-Ames Research Center, Mountain View, California in the fourth quarter of 1981 under contract with Technology Development of California (TDC).

The system is part of a major program to provide an advanced computational facility for NASA-Ames. Said Director C. A. Syvertson, "The selection of a CRAY-1/S by TDC represents an initial step in providing Ames researchers with a state-of-the-art computer system to enable them to remain in the forefront of computation in their research fields. The reputation of Cray Research is well established, and we anticipate that the use of their system will have a significant impact on our research efforts."

Boeing to expand its CRAY-1

Boeing Computer Services will expand its CRAY-1 from one million words of memory to two million words. The two million word CRAY-1/S system will be installed at Boeing's new computer center in Bellevue, Washington.

Lawrence Livermore Labs to add two more CRAY computers

The Lawrence Livermore National Laboratory Computing Center has ordered a new computer system to be installed in the first quarter of 1982 and an option for a system to be installed in the second quarter of 1982 at the Computing Center in Livermore, California. These two new systems will be the third and fourth CRAY-1 computers at the Center. Each will be installed with two million words of memory, with plans for the second system to be upgraded to four million words in the fall of 1982.

The Lawrence Livermore National Laboratory is operated for the United States Department of Energy by the University of California. Its CRAY-1 systems are used to solve mathematical equations used in nuclear weapons design and laser fusion reseach.

Sandia National Labs orders CRAY-1

Cray Research announced recently that it will lease a CRAY-1 S/1000 computer system to Sandia National Laboratories in Albuquerque, New Mexico. Sandia National Laboratories is a multiprogram research and development organization that operates under contract for the United States Department of Energy. The Lab's CRAY-1 will be installed in the first quarter of 1982 and will be used for research programs.

Four installations made

During the third quarter, a CRAY-1 S/1000 was installed to replace the CRAY-1A system leased by the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. The new installation, done under contract with Systems Development Corporation of Santa Monica, California, permits future expansion. The CRAY-1A has been reinstalled at another site for use under contract services by the U.S. Government.

A CRAY-1B system was installed at the University of Minnesota's Lauderdale Computer Center in September. The system, which has undergone acceptance testing, will be purchased by the University.

A two-million word CRAY-1/S was installed at the National Magnetic Fusion Energy Computer Center in Livermore, California. A one-million word CRAY-1 computer system was installed at the Westinghouse Electric Corporation in Pittsburgh, Pennsylvania.

LANL places order for two systems

The University of California, under its prime contract with the U.S. Department of Energy, placed an order for a new CRAY-1 system to be installed in the fourth quarter of 1981 and an option for a system to be installed in the fourth quarter of 1982 at the Los Alamos National Laboratory in Los Alamos, New Mexico. The first system will be installed as a two million word memory system, with an upgrade to four million words scheduled for the first quarter of 1982. The second system will be installed with a full four million words of memory. The two systems will be the third and fourth CRAY-1s installed at LANL.

Cray Research corporate offices to move

The senior executives and certain support staff of Cray Research will be moving from the Mendota Heights, Minnesota building to new offices in downtown Minneapolis, Minnesota early in 1982. Company President John A. Rollwagen noted that this move is in keeping with Cray's organizational philosophy of working in small, manageable groups: "For instance, our research work is carried out by three separate teams, two located in Chippewa Falls, Wisconsin, and one in Boulder, Colorado. Our manufacturing and engineering staffs in Chippewa Falls work in discrete groups. Our present building in Mendota Heights has developed into a highly productive technical center." The new location comprises approximately 30,000 square feet.

APPLICATIONS IN DEPTH

Cray Applications Software Library released

Cray Research, Inc. has released Version 1.0 of its Cray Applications Software Library. This Library brings together a wide variety of publicly available applications software implemented for the CRAY-1. Thus, CRAY-1 users have access to software developed by Cray Research, Inc. and by other CRAY-1 users.

The primary functions of the Library are:

- To acquire, verify, document, and distribute publicly available CRAY-1 software,
- To demonstrate and supervise in-house, vendor-supplied CRAY-1 software,
- To support new CRAY-1 software conversions by Cray Research, Inc., and
- To provide a general information service for Cray applications software.

The Cray Applications Software Library contains a growing collection of applications software, ranging from low-level mathematical and utility routines to major applications programs and packages. Much of the software included in this first release was provided by the Cray User Group software exchange. Software in the Library is divided into three sections: mathematical and statistical, utility, and special applications.

Detailed external documentation will be available for all distributed software. This documentation specifies the exact functions, characteristics, and usage of the software.

The *Cray Applications Software Library Catalog* is also available from the company. This catalog identifies all of the software currently included in the Library and provides a brief description of each routine, program, or package. Copies of this catalog may be obtained from your nearest Cray Research sales office.

All Library software follows a verification and validation procedure prior to inclusion in the Library. This procedure includes the running of test cases with standard data or drivers at regular intervals. Although Cray Research does not accept responsibility for the programs after distribution, every effort has been made to ensure accuracy, reliability and suitability prior to distribution.

Most software within the Library is available to all customers of Cray Research, Inc. In certain cases, however, distribution may be restricted according to the licensing regulations of the original code developer or distributor. Software is distributed on magnetic tape (800 bpi, unlabelled, blocked, ASCII, card image or binary).

The software listed below is in Version 1.0 of the Library.

- The majority of software previously available through the CRAY Users' Group, including the NCAR Software Support Library (including elliptic PDE solvers); matrix solution routines by T. Jordan (Los Alamos), A. Cline (U. of Texas), N. Werner (NCAR), and others; and various utilities, including sorting, indexing, text processing, and so on.
- AMOSLIB package for evaluating special functions (Bessel, Legendre, beta, gamma, error functions, etc.), by D.E. Amos and S.L. Daniel of Sandia Labs, Albuquerque.
- Statistical software including the LINWOOD program by F. Wood.
- Additional utilities written at Cray Research, including UPDATE preprocessors, random I/O (READMS/

WRITMS package), dataset cataloging, log file statistics, etc.

- Large special applications programs and packages, including SAP4 and HONDO2 (finite element analysis of structures); TRAC-P1A (reactor transient analysis); SPICE2 (circuit simulator); several FLO programs by A. Jameson (transonic fluid flow); GAUSSIAN76 (molecular structure simulation); NCAR Graphics Library; and the CRAY BLITZ chess program.

For more information on the Applications Software Library, contact your nearest Cray Research sales office or the Applications Department of the company.

MARC being converted to run on CRAY-1

MARC, a general-purpose finite element system that provides capabilities for solving a wide range of structural analysis problems, will soon be available for the CRAY-1. Conversion of MARC will take place late this year using the CRAY-1 at the Cray Research Mendota Heights, Minnesota facility. Upon completion, MARC will be a fully-supported product available from Marc Analysis Research Corporation.

The MARC system includes a library of elements and a selection of material behaviors, both linear and nonlinear. MARC can be used for linear elastic analysis of 2- and 3-D solids, shells and beams, and for applications in which nonlinear material and geometric effects dominate and must be included in conjunction with sophisticated geometric modeling.

Applications areas in which MARC is particularly useful are welding, low-cycle fatigue of piping systems and post-buckling behavior of steel liners in a containment vessel. MARC is designed for expert engineers and is especially well-suited to general fracture mechanics problems such as 3-D linear crack or nonlinear elastic-plastic 2- or 3-D problems.

MARC is a proprietary product of Marc Analysis Research Corporation. For more information, contact Marc Analysis at 260 Sheridan Avenue, Suite 200, Palo Alto, CA 94306; telephone (415) 326-7511.

TEGAS5 to be available on CRAY-1

Conversion of TEGAS5 to the CRAY-1 will commence at the Cray Research facility in Mendota Heights, Minnesota early in 1982. TEGAS5, *TE*st *G*eneration *A*nd *S*imulation, analyzes and verifies digital logic networks. It is a complete package allowing a choice of three options: design verification, test generation, and fault simulation. The same input language and network description is used for all three options.

Applications include verification of digital logic designs (including race, hazard and spike analysis), assessment of diagnostic tests, investigation of the fault-tolerance, generation of production and diagnostic tests, and interactive design analysis.

TEGAS5 on the CRAY-1 will be a fully-supported product of Comsat General Integrated Systems, Inc. For more information, contact CGIS at 7801 N. Lamar Boulevard, Austin, TX 78752; telephone (512) 451-7938.

CRAY-1 version of the IMSL package now available

International Mathematical and Statistical Libraries, Inc. now fully supports a CRAY-1 version of the IMSL Library. The IMSL Library is a package of almost 500 FORTRAN subroutines including many of the most commonly used building blocks for the development of scientific application programs.

The IMSL Library consists of 17 chapters and includes routines for categorizing data analysis, eigensystem analysis, forecasting, econometrics, analysis of experimental data, basic statistics, time series, generation and testing of random numbers, interpolation, approximation, smoothing, linear algebraic equations, sampling, utility functions, vector and matrix arithmetic, zero and extrema, and linear programming.

For more information about the IMSL Library, contact International Mathematical and Statistical Libraries, Inc., 7500 Bellaire Blvd., 6th Floor, Houston, TX 77036; telephone (713) 772-1927.

Vector and parallel processor conference held in U.K.

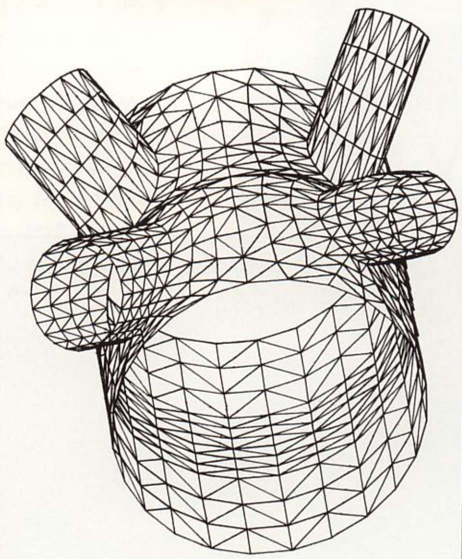
A conference entitled "Vector and Parallel Processors in Computational Science" was held from August 26-28, 1981 on the Chester College campus in Chester, U.K. Presentations were made in three areas: hardware and languages, numerical methods, and applications. The conference was jointly sponsored by the European Physical Society, the Institute of Physics, the Institute of Mathematics and Its Applications, and SRC Daresbury Laboratory.

G. Stuart Patterson of the Boulder Division, represented Cray Research as one of the speakers in the hardware and language section. His presentation was entitled "Scientific computers—future directions." Several other presentations were made by CRAY-1 users from various locations in the U.K. and the United States.

A special tour of SRC Daresbury Laboratory was offered to those attending the conference. A CRAY-1 is at the center of the Laboratory's network of terminals extending to universities and other institutions throughout the U.K. The Daresbury CRAY-1 thus gives support to a wide range of university scientists conducting research work in such diverse areas as protein crystallography, astrophysics and engineering.

SCIENTIFIC APPLICATIONS PACKAGE HIGHLIGHT

ANSYS



A golfer steps up to the tee, tugs on her visor, adjusts her grip on the club, modifies her stance, takes her backswing and . . . WHAP!

A farmer climbs down from his tractor after a long day, thankful for the smooth ride.

A child screams, half in enjoyment and half in agony, as the roller coaster climbs steeply and flies around the tight turn.

The teenager turns up the sound as a favorite song is played on the stereo.

What do the golfer, the farmer, the child at the amusement park, and the teenager have in common? The ANSYS 3-D finite element analysis program has entered all of their lives, although it's unlikely that any of them know it.

ANSYS is a large-scale general purpose computer program employing finite element technology for the solution of several classes of engineering analysis problems. It has both linear and nonlinear capabilities in the structural and heat transfer areas. Marketed by Swanson Analysis Systems, Inc., ANSYS offers the engineer many analytic tools to solve a broad range of problems.

On the CRAY-1, ANSYS enables solution of a variety of complex problems. It may be applied to a large number of structures, including two- and three-dimensional frame structures, piping systems, two-dimensional plane and axisymmetric solids, and three-dimensional shells and solids. The nonlinear options in ANSYS include geometric nonlinearity, nonlinear material behavior, and special nonlinear elements such as gaps and interfaces. Many industries have found the broad general capabilities of ANSYS to be useful in solving structural, heat transfer, and fluid flow analysis problems.

The availability of ANSYS on the CRAY-1 makes possible efficient solution of the production analysis problems facing the oil, aerospace, automotive, nuclear, steel, chemical, civil construction, glass, plastic, power, medical, and electronic industries.

The ANSYS program offers many options to help the engineer in the petrochemical industry. Applications of ANSYS in this area include analysis of stacks, offshore platforms, mooring cables, and offshore pipe laying, to name a few.

The medical industry is another area in which ANSYS promises to provide scientists with answers. For example, ANSYS has been used in the analysis of artificial joints, with the hope of finding materials that are stronger and lighter than those that are used currently.

The transportation industry has found many features of ANSYS quite useful in evaluating designs of such vehicles as railroad cars, automobiles, airplanes, and trucks. Vehicle crash studies have been conducted using the program's capabilities to determine deflected shapes and energy absorption characteristics of components. As another example, ANSYS has been used to test out locomotive wheel designs for maximum strength, stability, and durability.

Even the computer industry found applications for the capabilities of ANSYS. The program was used to analyze shock and vibration in computer equipment and to study disk drive dynamics and vibrations.

How did ANSYS enter the lives of the golfer, the farmer, the child, and the teenager?

The larger deflection and large rotation analysis capabilities of ANSYS were used by a firm in the sports industry to test the dynamic response and feel of a new material for a golf club. By analyzing new materials, the company was able to avoid costly construction errors.

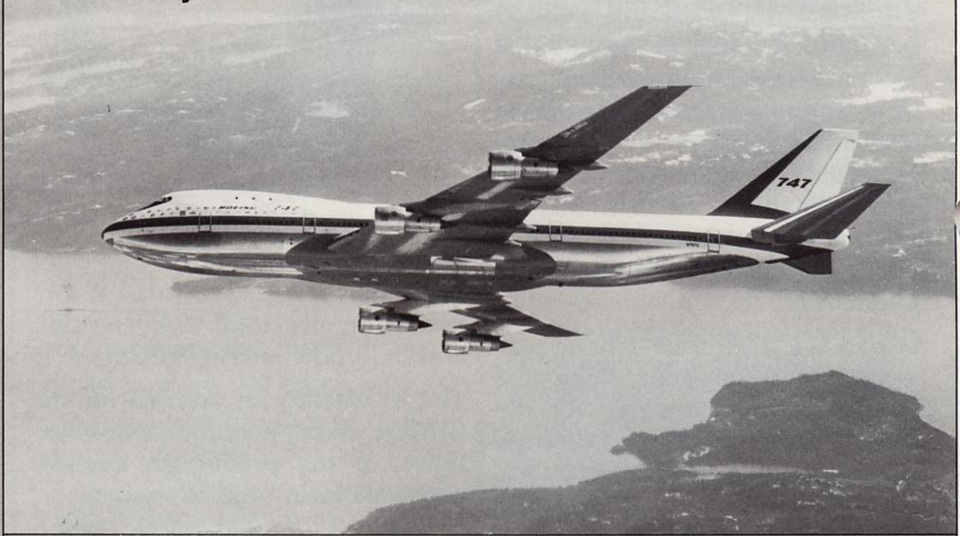
The transportation industry used ANSYS to minimize the vibrations a rider experiences in a tractor ride over rough terrain. ANSYS was also used for structural and safety testing of amusement park rides.

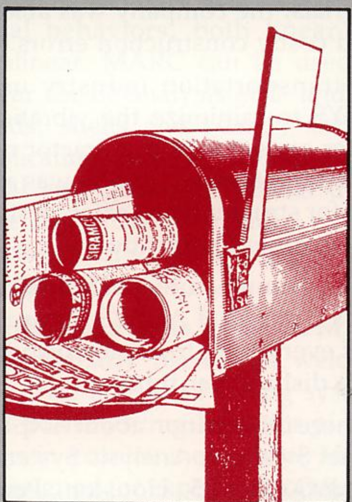
Finally, manufacturers of household goods have used ANSYS for analysis of everything from stereo speakers to dishwasher tubs.

For more information about ANSYS, contact Swanson Analysis Systems, Inc., P.O. Box 65, Houston, Pennsylvania, 15342; telephone (412) 746-3304, TWX 510-690-8655.

USER NEWS

CRAY-1 analysis tests a fuel-thrifty 747





In the 1950's, when Boeing built the 707, an aeronautical engineer's tools were slide rules, wind tunnels, and flight tests. But in the 60's and 70's, as computers grew more sophisticated and the problems of jet-age flight more complex, slide rules moved from belt scabbards to the back of desk drawers and stacks of printouts began growing in the engineering areas. In the 80's, the time and expense of wind tunnel and flight testing is promoting analysis-based design. Computers and advanced algorithms may soon replace some of the familiar wind tunnel models and flight test procedures in use today.

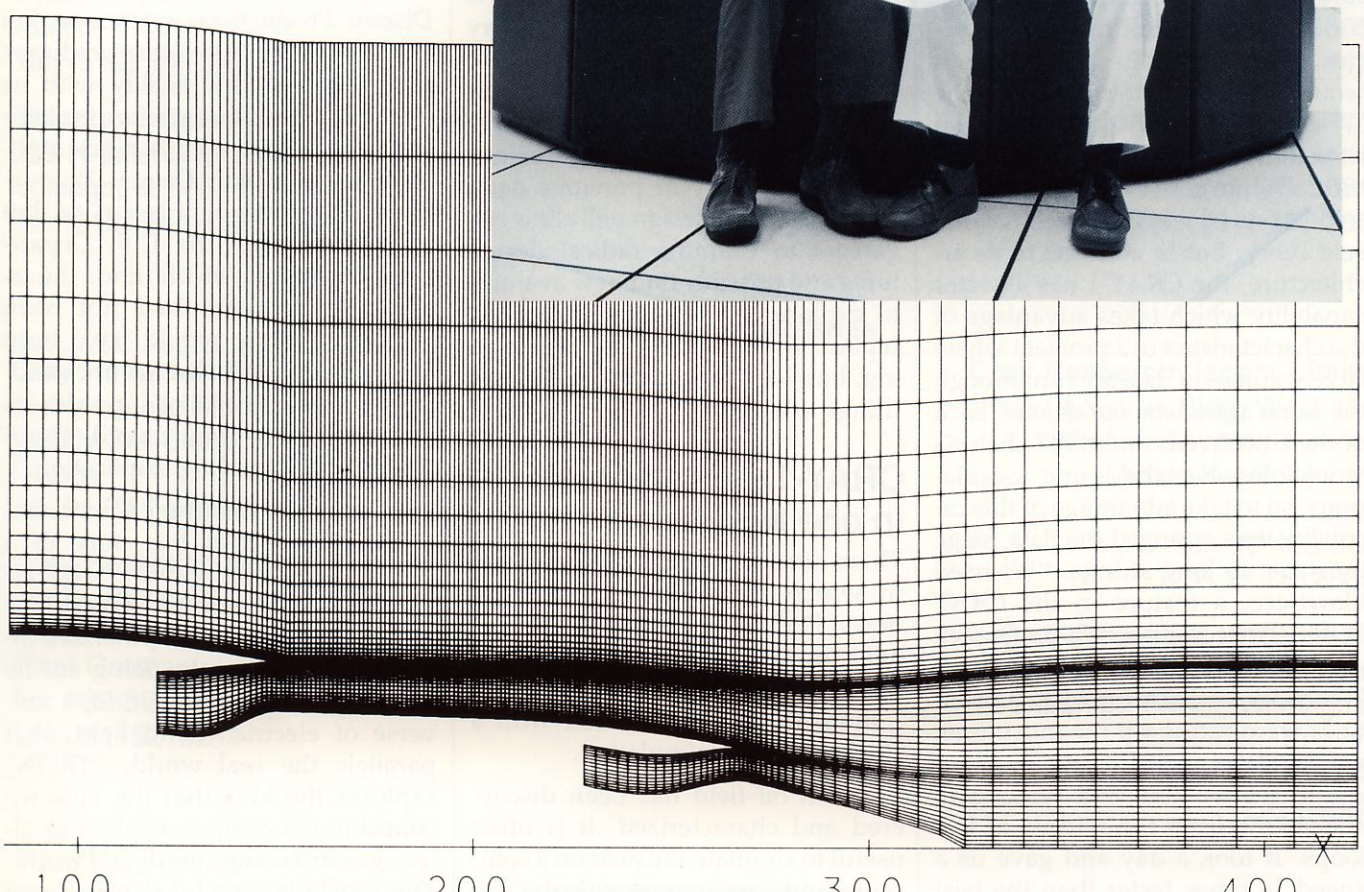
Boeing's Propulsion Systems Fluid Mechanics group has been pioneering the development of numerical techniques for analysis-based design. When 747 engineers engaged in a flight test project to improve engine efficiency decided that they needed more data, they called on this small team of specialists to help.

"We're primarily researchers and computer code developers," said Mike Peery, who worked with Cliff Forester on the 747 analysis project. "Much of our time is spent developing algorithms that will be used by designers several years from now. But practical projects like this give us a chance to prove our work."

Peery and Forester had already written and tested algorithms which solved the complex fluid problems that the 747 engine project was studying. They had published articles and given papers at conferences about their findings done with simplified models in modest scale. By contrast, the full-scale 747 problem was immense. The current technique for analyzing something like an airflow is to break its large continuous process into a series of small discrete processes patchworked onto a grid called the computational mesh. This moves the problem from the realm of differential calculus, beyond the scope of today's hardware, to the world of algebra. Individual solutions for each cell of the mesh are combined to form a model of the whole flow. The models that Peery and Forester had used in their development work had a mesh of 2,500

Below Forester, Peery and the CRAY-1 are some of the 10,000 cells in the geometric mesh used for their engine outlet analysis. The engine structure itself is the blank white space with the inlet end to the left. The two grid intrusions are the outlets, the leftmost being the bypass air, the next the engine exhaust. Only the top half of the engine was modeled.

(Thanks to Chas Dowd, Boeing Computer Services Company)



cells and had strained the resources of a CYBER 175. The 747 analysis would require 10,000 cells.

"The differences of shape that we were modeling were very subtle," Forester explained, "but transonic flows—flows just at or approaching the speed of sound—are very tricky and small variations have significant results. Remember too, that we were not doing the initial analysis, we were optimizing an already successful and proven design. A few tenths of a percent of improvement were all we could expect." Time was pressing, too. They would have only a few weeks. So Forester and Peery became the first users of the new Boeing Computer Services Company (BCS) CRAY-1 supercomputer.

With a memory capacity of 500,000 64-bit words, the new CRAY-1 was large enough. (The current production CRAY is even larger—a full one million words.) Its unique architecture gave it the speed that would let the two researchers run several series of computations in the time it would have taken to run one on the 175s. "First we moved our program from the 175s to the CRAY-1 and with virtually no conversion effort, the solution speed was five times as fast," said Peery. But in addition to its architecture, the CRAY-1 has a vector capability which takes advantage of the characteristics of a problem where large volumes of data are run through the same arithmetic operations. Each of the 10,000 cells in the 747 analysis would involve the same calculations, so to take advantage of this capability they arranged the data, stage by stage, in long strings. "We used Flowtrace, a feature in the CRAY FORTRAN compiler that times each step of a problem," Peery continued. "Once we could see which subroutines were eating up the most time, we could go in and vectorize them. About all we did was remove IF statements from the middle of DO loops. It took a day and gave us a speed 16 times faster than the best we had done on a 175." With this speed, Peery and Forester were able to run complete analyses of two engine nozzle configurations in only three weeks. Their findings help confirm the selection of a design that may cut fuel use by 0.6%, a 75,500 gallon yearly reduction for every 747 in service. With jet fuel at $1.10 a gallon and climbing, that's a substantial saving for customer airlines.

"Of course, a computer is just a tool," Forester commented. "We're constrained by the algorithms. We'll do more, and do it several orders of magnitude better as we build more comprehensive numerical techniques. This was an axisymmetric analysis where we worked on a two-dimensional slice of the length of the engine and its plume. With the CRAY-1's capacity, we could do a full 3-D analysis in case someone wants to try an asymmetric engine nozzle. Supercomputers and superalgorithms go together," he grinned.

"Cliff's point about the asymmetric nozzle is a good one," adds Dr. Gerry Paynter, head of the seven-person Fluid Mechanics group. "The cost and time needed for wind tunnel tests favors evolutionary design, based on a body of previous data. Analysis-based design will allow engineers to examine radical departures and possibly find new avenues to explore. We'll never completely replace wind tunnels or flight testing, but we will sure give them new things to test."

CRAY-1 pays for itself in one simulation

There are several applications areas in which the CRAY-1 is making news. Perhaps one of the most dramatic instances can be found in the petroleum industry, where a CRAY-1 more than paid for itself with a single reservoir simulation.

After an oil field has been discovered and characterized, it is often useful to simulate the field on a computer and experiment with the different possibilities for developing the field. Using such simulation in decision making can result in a significant difference in the total amount of oil extracted from the field.

ARCO Oil and Gas Company was faced with a decision about the method of development to use for a Prudhoe Bay field on the north slope of Alaska. Analysis of the field on the CRAY-1 resulted in a decision that is expected to produce about seven percent more oil. On a field estimated at over twenty billion barrels, seven percent is extremely significant, both in terms of product and additional profit—enough to pay for the CRAY-1 a number of times over.

New Disney motion picture filmed in part at MFECC

The Magnetic Fusion Energy Computer Center in Livermore, California was featured recently in a Disney Productions science fiction movie, "TRON." The film's producers chose the MFECC facility with its CRAY-1 computer system because the location offered a "unique high-technology look." Disney Productions requested permission to film at MFECC from the U.S. Department of Energy, which funds the facility. If approval had not been granted, Disney would have been forced to duplicate the set at considerable cost. The film's producers estimate that they saved about $250,000 by avoiding duplication.

"TRON" is an electronic science-fiction fantasy. It is the story of a young computer genius who attempts to short-circuit a runaway program in a vast, computerized information system. In doing so, he is drawn into another world, a universe of electricity and light, that parallels the real world. "TRON" explores the idea that the data we contribute to computers gives us alter-egos in a computer-digital world. The movie is scheduled for release in the summer of 1982.

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