

# Programming the Game of Go

---

Jonathan K Millen  
661 Main St  
Concord MA 01742

---

Go is a board game. Like chess, it is a game of pure skill; moreover, a considerable body of literature has been devoted to it. Go was invented in China around 2000 BC. Since its introduction into Japan around 700 AD, it has flourished there to the extent that the most accomplished masters of the game are now Japanese. However, the game has spread world-wide. In the United States, one can find Go clubs in the vicinity of large cities and universities, and most large bookstores have at least one substantial book on the game.

Go is played on a 19 by 19 square grid having black spots on nine intersections, as illustrated in figure 1. The traditional board, called a *Go Ban*, is a wooden block about 17 inches square and several inches thick, with four short feet. It stands alone as a table at just the correct height for players sitting on floor cushions.

One player has a supply of black stones; the other, white stones. The stones are disks about the same size as the grid spacing; they are approximately three-eighths of an inch thick in the middle and almost sharp around the edge. The black stones traditionally are made of slate, and the white stones of clam shell.

Players move alternately, each

placing a stone on the point of intersection of a pair of grid lines. The object of the game is to enclose the most area, measured by the number of unoccupied points enclosed by stones of a given color. A point is enclosed by, say, black, if no path along the grid from the point runs into a white stone. Figure 2 shows some enclosed areas. Note that the edge of the board can form one boundary of an area.

A player can increase his area by capturing the opponent's stones. Stones are captured a connected group at a time. A set of stones forms a connected group if there are paths along the grid from any stone to any other stone in the set, such that all points on the path are occupied by stones in the set. This criterion is easy to visualize because the stones, being as large as the grid spacing, actually touch along paths of connection. The phrase "connected group" also implies that the stones in the group are all of the same color, and that the group is not merely a part of some larger connected group.

A group of stones is captured when it has no *liberties*. A liberty of a connected group is an unoccupied point adjacent (vertically or horizontally) to a stone in the group. If a group has just one liberty, the opponent may capture it by placing one of his stones

on the liberty. The opponent then picks up the captured stones and keeps them as prisoners. At the end of the game, a player's point count of area is augmented by the number of prisoners he has captured. Figure 3 shows a group having one liberty.

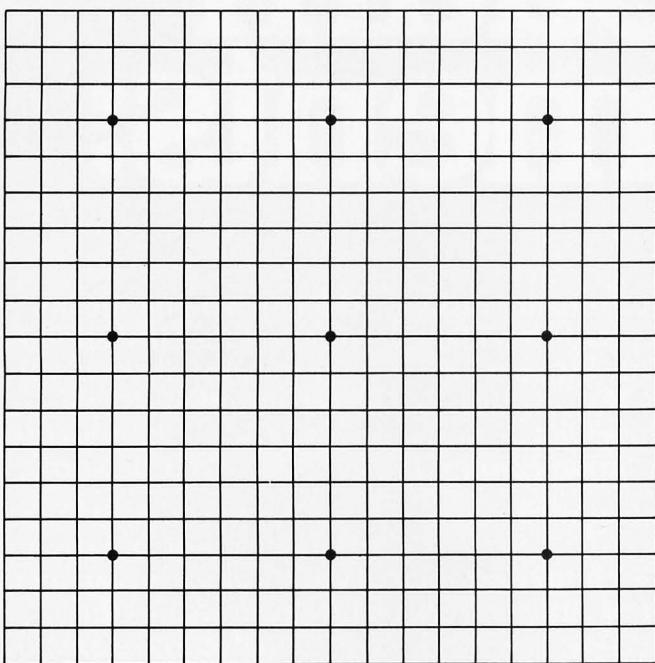
The game ends when both players pass consecutively, because they both see no further advantage in playing more stones. Usually, when this happens, there are white stones within areas enclosed by black, and vice versa. These stones have been given up because the owner can predict that they will be captured. They are removed as prisoners at the end of the game before counting the score.

The remaining rules are technicalities. Two that have a significant effect on the game, concerning "ko" and "suicide," will be mentioned later on. The rest involve details of ending the game and scoring, and are rarely invoked.

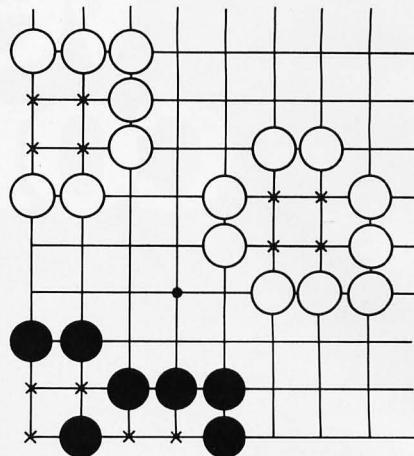
## A Go-Playing Program

A Go opponent, called Wally, was programmed on a KIM-1 within its approximately 1 K bytes of memory. Wally's algorithm is based on essentially two capabilities: finding the liberties of a connected group, and matching a few common patterns. Moves take less than a second.

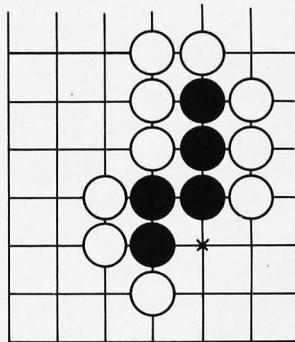
A 15 by 15 board was used because



**Figure 1:** The Go board. Players move alternately, placing stones on the points of intersection of the lines, rather than in the spaces. The nine dots are handicap-stone locations. The line spacing is about 2.2 cm (seven-eighths of an inch).



**Figure 2:** Enclosed areas. Points marked *x* are in areas enclosed by one player or the other. The figure shows five black points and eight white points.



**Figure 3:** A black group with exactly one liberty, marked *x*. If it is white's turn, he can capture the black group by placing a stone at *x* and removing the black group as his prisoners.

# MARK GORDON COMPUTERS

DIVISION OF MARK GORDON ASSOCIATES, INC.  
P.O. Box 77, Charlestown, MA 02129 (617) 491-7505

## COMPUTERS

|                     |         |
|---------------------|---------|
| Atari 800 W 16K     | 799.00  |
| 4K Model III        | 599.00  |
| Model-II 64K System | 3499.00 |
| 16K Model III       | 879.00  |

## DISK DRIVES

|                           |        |
|---------------------------|--------|
| 40 Track 5 1/4 inch drive | 314.00 |
| 80 Track 5 1/4 .....      | 544.00 |
| 4 Disk Drive Cable        | 39.00  |

## PRINTERS

|                      |                |
|----------------------|----------------|
| Centronics 730       | 599.00         |
| Epson MX80B          | Call for price |
| Epson MX70           | Call for price |
| Centronics 737       | 849.00         |
| Okidata Microline 83 | 999.00         |
| Okidata Microline 82 | 729.00         |
| Integral Data 440G   | 999.00         |
| NEC 5510 w-tractor   | 2679.00        |
| Okidata Microline 80 | 499.00         |
| Diablo 630           | 2495.00        |

## MISC HARDWARE

|                          |        |
|--------------------------|--------|
| Expansion int TRS-80(OK) | 269.00 |
| Novation D-Cat Modem     | 166.00 |
| 16K Memory Kit           | 41.99  |
| Leedex Monitor           | 119.00 |
| Leedex 100G              | 139.00 |
| Printer Cable for above  | 49.00  |
| ISO-2 Isolator           | 54.00  |
| AC LINE FILTER           | 24.00  |

## STORAGE MEDIA

|                            |       |
|----------------------------|-------|
| Scotch-box 10-5 1/4 .....  | 27.00 |
| Memorex-box 10-5 1/4 ..... | 22.00 |
| Plastic Storage Box        | 5.00  |

## OPERATING SYSTEMS

|                                 |        |
|---------------------------------|--------|
| NEWDOS by APPARAT INC .....     | 49.00  |
| NEWDOS+ by APPARAT INC .....    | 99.00  |
| MMS FORTH DISKETTE-PRIMER ..... | 79.95  |
| NEWDOS 80 .....                 | 149.00 |

## DISKETTE TRS-80\*

### BUSINESS SOFTWARE FOR TRS-80 BY SBSG

Free enhancements and upgrades to registered owners for the cost of media and mailing. 30 day free telephone support. User reference on request.

Fully Interactive Accounting Package, General Ledger, Accounts Payable, Accounts Receivable and Payroll Report Generating Complete Package (requires 3 or 4 drives) .. \$475.00 Individual Modules (requires 2 or 3 drives) .. \$125.00 Inventory II (requires 2 or 3 drives) .. \$99.00 Mailing List Name & Address II (requires 2 drives) .. \$129.00 Intelligent Terminal System ST-80 III .. \$150.00 The Electric Pencil from Michael Shrayer .. \$150.00 File Management System .. \$ 49.00

## FINE PRINT

TRS-80 is a Tandy Corporation trademark. Use of above operating systems may require the use of Radio Shack TRS-DOS. Radio Shack equipment subject to the will and whim of Radio Shack.

## ORDERING INFORMATION

We accept Visa and Mastercharge. We will ship C.O.D., certified check, or money order only. There will be a 40 percent deposit on orders over \$300.00. Massachusetts residents add 5 percent sales tax.

To order call toll-free 1-800-343-5206

For information call 617-491-7505

The Company cannot be liable for pictorial or typographical inaccuracies.

The above prices do not include shipping.

it was convenient for addressing reasons to represent it internally within a single 256-byte page, using one byte per point. Although there would be room for a 16 by 16 board, a Go board ought to have a center point. Rows and columns were numbered from 1 to F (in hexadecimal) so that the coordinates of a move could be entered on the KIM keyboard.

When a move is entered, Wally responds with the coordinates of his move on the KIM display, and the complete board is also output on a video terminal. The display of a game in progress is shown in photo 1.

Once the board representation and the input and output routines were set up, the first major component of the

program to be written was the routine that walks through a connected group of stones, marking the members of the group, and both marking and counting its liberties. Called COUNT, this routine is a variety of the maze-search algorithm. It was programmed recursively in machine language.

What COUNT does for each board location it looks at is based on the "invariant assertion" that any point it looks at is one of the following:

- a stone in the connected group
- a liberty of the connected group
- a stone of the other color adjacent to the connected group

If it is looking at a stone in the group, it checks to see whether that stone has previously been marked. If not, it marks the stone and calls itself to repeat the same process, starting with each of the four locations north, east, south, and west of the present stone.

Marking a stone or point, of course, means to set a particular bit in the byte corresponding to that point in the board representation. Other bits encode whether the point is



**Photo 1:** A game in progress. Wally (the computer) is playing black, represented by the solid-looking crosshatches (#). The author is playing white, represented by 0s. The computer uses a 15 by 15 board; the points of play are indicated by periods. In this game, black was given a nine-stone handicap.

occupied and, if so, by what color stone.

If COUNT is looking at an unoccupied point, it marks the point as a liberty and increments the count of liberties, unless the point has already been marked and counted.

If COUNT is looking at a stone of the other color, it does nothing, and

just returns.

If a stone is on the edge, or first line, of the board, then one (or, in a corner, two) of its neighbors will be off the board. If COUNT is called for an off-board location, it returns immediately.

Note that, if COUNT starts on a stone and operates as described above, the recursive calls to COUNT will carry the center of attention all over the group and onto all neighboring points. The invariant assertion is satisfied because COUNT progresses one step each time only from stones in the group, as sketched in figure 4.

The algorithm for COUNT is specified concisely in listing 1 using a kind of "structured English." The rest of the Go-playing program will be specified similarly, as a collection of modules like COUNT.

Recursion is not difficult to implement; COUNT just calls itself with the usual jump-to-subroutine instruction for each of the neighboring points. The current board location is in a register; it is saved on the KIM stack before it is replaced by the location of each neighboring point, and then restored upon return from each call. The size of the connected group

## THUNDERCLOCK PLUS™

### PUT TIME AND REMOTE CONTROL IN YOUR APPLE II

The THUNDERCLOCK PLUS is two peripheral systems on one card for your APPLE II OR II PLUS. An accurate, reliable, real-time clock/calendar and an interface for the popular BSR X-10 Home Control System.

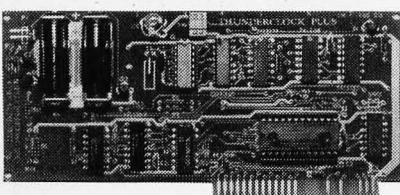
The THUNDERCLOCK clock/calendar makes accurate time and date available to your programs: month, date, day-of-week, hour, minute, and second, in any of four software selectable formats. On-board batteries keep your THUNDERCLOCK running when your APPLE II is turned off - for up to four years before battery replacement. On-card 1K firmware makes reading or setting the time easy from APPLESOFT or INTEGER BASIC, PASCAL, or assembly language programs. And it provides software selectable interrupts at any of three rates: 64, 256, or 2048 interrupts/second.

#### THE PLUS

Add THUNDERWARE'S X-10 ULTRASONIC INTERFACE OPTION to your THUNDERCLOCK and your programs can send all 22 BSR X-10 commands so you can remotely control lights and appliances. A full 128 dim/bright levels. And a powerful disk software package! The THUNDERWARE SCHEDULER software lets you create schedules to control lights, appliances, security systems, or almost any other electrical device. The software includes: SCUTIL- the SCHEDULER utility that lets you make or change a schedule, and SCHED- executes your schedules in real-time using the THUNDERCLOCK. SCHED runs in the 'background' so you can run other programs in the 'foreground'.

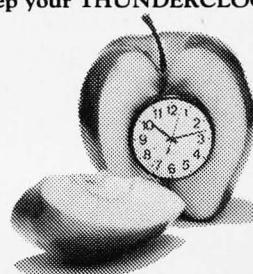
The THUNDERCLOCK PLUS is a SYSTEM for your APPLE II. Supported by intelligent, easy to use firmware, a powerful software package, and good documentation!

Available through your dealer.



BSR X-10 is a trademark of BSR (USA) LTD.  
APPLE II is a trademark of APPLE COMPUTER, INC.

|  |       |
|--|-------|
| THUNDERCLOCK PLUS.....   | \$139 |
| Clock/calendar card with batteries and user's manual                                   |       |
| X-10 INTERFACE OPTION .....  | \$49  |
| BSR X-10 Ultrasonic interface, disk with SCHEDULER SOFTWARE & demos, and user's manual |       |
| PASCAL SOFTWARE.....   | \$29  |
| Disk with PASCAL interface for clock and X-10 interface, and user's guide              |       |
| MANUALS ONLY, each .....   | \$5   |
| California residents add 6% sales tax  |       |



If your dealer doesn't carry the THUNDERCLOCK PLUS:

ORDER TOLL FREE (VISA/MC) CALL:  
800-227-6204 EXT 307 (Outside California)  
800-632-2131 EXT 307 (California Only)

OR WRITE TO:

THUNDERWARE INCORPORATED  
P.O. Box 13322, Oakland, CA 94661

is limited by the size of the stack; one byte of board location plus two bytes of return address are pushed for each call, and the calls are nested as the algorithm "walks" around the group. A 100-byte stack can handle a 33-stone group. A group of that size would occur, if at all, only near the end of the game, when Wally's play deteriorates for other reasons anyway.

### Main Loop

After COUNT was coded, a reasonable overall structure for a program to use it followed quickly. The main loop is specified in listing 2. The "consequences" of counting a group of stones include removing it from the board (zero out the board locations) if it has no liberties; other consequences have to do with suggesting tentative moves for Wally. Wally always plays black, in accordance with the Go tradition of giving the black stones to the weaker player.

The pattern-matching facility was not implemented immediately. In fact, the first version of the program chose black moves randomly, trying again if it hit upon an occupied point.

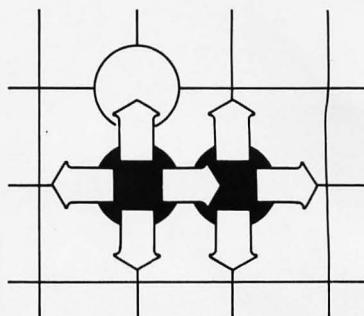
At least the capturing of black groups could be tested, and, for the most part, it was playing legal Go.

### Tactics and Priorities

The next step in the design of the program was the decision that Wally would make contact moves, adjacent to white stones. In this way, the program would appear to be attempting to capture white groups, and would eventually fill up the liberties of each white group and capture it, if no defensive action were taken.

At the same time, it was clear that Wally also should take some defensive moves to avoid capture. This brought up the question of priorities: when is a black group threatened enough so that Wally should stop attacking white and make a defensive move instead? The answer had to be based on the number of liberties remaining in the black and white groups. It was decided that threats would be ignored until a black group had been reduced down to one or two liberties. Otherwise, Wally attacks whichever white group has the least number of liberties, because that group promises the best chance of being captured.

This strategy was implemented by associating a number of liberties with each suggested black move—namely, the number of liberties remaining for the group contacted by the stone. When a move is suggested, such as some liberty of a white group being



**Figure 4:** How the procedure COUNT works. When tracing a black group, COUNT begins on a stone in the group and calls itself recursively to look at the four neighboring locations. If a neighbor is a black stone, the process is repeated until all stones in the connected group have been found. All unoccupied points adjacent to stones in the groups (ie: liberties) are also found and counted.



## ROOTS IRISH FAMILY HERITAGE



Search for your Irish Family Roots through a unique Micro-Program from Ireland.

Eiron Computers are proud to offer you an original computerized Irish Family Heritage Program, containing a summary of every Irish Family and areas from which they originated.

Also a background summary and emigration dates.

Included are Map with Crest names and Family locations

Price: \$100.

#### Send To:

**Eiron Computers Ltd.,  
Eiron House, Park Road,  
Dun Laoghaire,  
Co. Dublin.  
IRELAND  
Tel: 808575/805045  
Cables: Eiron, Dublin. Telex: 31502**

Allow 28 days for delivery  
Mastercharge, American Express  
Diners Club, Visa,  
or Personal Cheque accepted.

Add \$5 for Post & Packaging.

\*\*When ordering state your Name, Address and Disk Type and Format  
e.g. North Star Horizon 5 1/4" Single Density, and whether you  
are using North Star, TRS-80, Apple or PET, etc.

*EIRON COMPUTERS are distributors of North Star, NEC and Epson Products.*

**Listing 1:** Structured English specification of COUNT module to find and count the liberties of a connected group containing a stone at point "x" of color "color." COUNT calls itself recursively, saving x on the push-down stack during each call.

```
COUNT(x, color):
  IF x is not off the edge
  THEN
    IF there is a stone at x AND
      it is the given color AND
      it is not marked
    THEN
      mark it
      CALL COUNT(NORTH(x), color)
      CALL COUNT(EAST(x), color)
      CALL COUNT(SOUTH(x), color)
      CALL COUNT(WEST(x), color)
    ELSE IF there is no stone at x
    THEN
      mark the point as a liberty
      increment the liberty count
    END
  END
```

counted, a best (move, liberties) pair is updated if the new move is adjacent to a group of a smaller or equal number of liberties. Since black groups are counted after the phase in which white groups are counted, a move by black in contact with a black group with one or two liberties is automatically preferred to a move adjacent to a white group with the same number of liberties. An exception was put in later: when Wally finds a chance to capture a white group on the next move, he always takes it, even if some black group also has only one liberty. There is some doubt whether this exception was wise, however.

### Ko and Illegal Moves

There are two situations in which a

move on an unoccupied point is illegal. A move that leaves one's own group with no liberties is illegal. Figure 5a shows a move by black that would be illegal because the resulting black group would have no liberties. A move resulting in the capture of an opponent's group, as in figure 5b, is permissible because removing the captured group creates at least one liberty.

The second type of illegal move arises from a *ko*, illustrated in figure 6a. If white captures the central black stone on his next move, the position will look as in figure 6b. Now black can capture the white stone and reproduce the original position in figure 6a. This could go on forever. To prevent such infinite repetition, the *Rule of Ko* was introduced: no

**Listing 2:** Module specification for the main loop of the Go-playing program and two of its called modules.

```
MAIN:
  place black handicap stones
  LOOP
    display the board
    get white's move from keyboard
    CALL WEFFECT for the effect of white's move
    CALL BEFFECT to obtain a tentative black move
    CALL PATS to check for a pattern match
    place black stone
  END

WEFFECT:
  FOR each point x with a black stone DO
    CALL COUNT(x,black)
    IF the group has no liberties
    THEN remove its stones
    ELSE IF the group has at least one liberty
```

```
  THEN
    choose a liberty not on edge line
    IF the group has 1 or 2 liberties
    THEN CALL EVAL for the chosen liberty
  END
END
```

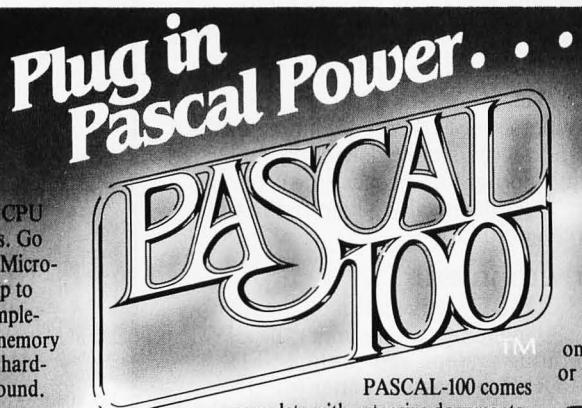
```
BEFFECT:
  FOR each point x with a white stone DO
    CALL COUNT(x,white)
    IF the group has exactly 1 liberty
    THEN
      designate it as the black move
      remove the white stones
      EXIT
    ELSE IF the group has 2 or more liberties
    THEN
      choose a liberty
      CALL EVAL for the chosen liberty
    END
  END
```

## Microengine Power

Plug in PASCAL-100™ new CPU Boardset for S-100 computers. Go with the power of the Pascal Micro-engine! Run UCSD Pascal<sup>2</sup> up to 10 times faster than typical implementations—with twice the memory capacity. You've got the best hardware for the best software around.

## On-board Z80

PASCAL-100 includes a Z80<sup>3</sup> processor, so you can run your current software—including CP/M<sup>4</sup>—without modification. Ready to convert an application to Pascal? Do it anytime, with no disruptive hardware changes.



PASCAL-100 comes complete with extensive documentation—our users say it's the best around!

## New Generation S-100

PASCAL-100 is designed for the versatile, flexible S-100 bus. Fully compatible with the new IEEE-696 standard, yet works with

most pre-standard boards.

- 16 bit operation
- 128K byte memory capacity; 1 Mega-byte with Extended Memory Map
- Works with 8 or 16 bit memory

Want to know more? Just circle our number on the reader service card. For fast action, call or write us directly.

### OEM'S/DEALERS

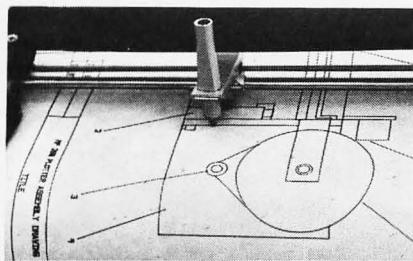
Be sure to specify our PASCAL-100 OEM/Dealer Information Package

**Digicomp Research**

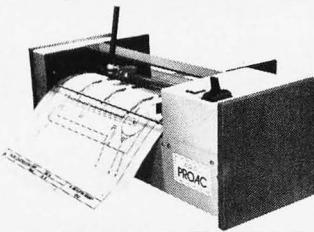
Terrace Hill Ithaca, NY 14850  
(607) 273-5900



<sup>1</sup>Trademark of Western Digital <sup>2</sup>Trademark of University of California  
<sup>3</sup>Registered Trademark of Zilog, Inc. <sup>4</sup>Registered Trademark of Digital Research



**Price/Performance Breakthrough!**



## Mauro MP-250B Proac

The \$695 pen plotter that gives professional accuracy with superb line quality!

Mauro's design innovations make it possible to produce a high quality, low cost plotter that out-performs every other plotter of comparable price on the market today. In fact, its line quality matches that of plotters costing \$2,000 or more.

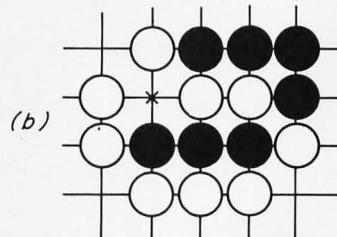
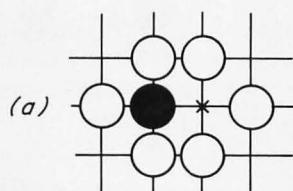
Proac draws with .005"/step resolution and  $\pm 0.5\%$  @ 17" degree of accuracy at speeds of 2.5" per second or higher. A unique multi-point paper drive helps achieve this level of accuracy, making Proac suitable for a wide variety of applications for which Mauro is developing supportive software. Programs currently available include: [1] Complete 2D and perspective plotting, including ASCII and curve generation which are available as relative linking libraries (L80) for Microsoft compatible software products, Fortran-80, Cobol-80, Compiler Basic, and Macro-80 in CP/M compatible files on 8" IBM-3740 or 5 1/4" Northstar formatted disks. [2] Apple II UCSD Pascal implementation of Turtle Graphics including full 128 ASCII character set; Pascal subroutines are Fortran compatible. [3] Complete scientific and business data graphing package for Apple II. Includes data editor, Hi Res screen preview, Axis tic marks, labeling and scaling, data overlays, names and comments, point, line, bar, and pie graphs, 128 ASCII character set, data file handling. [4] Schematic drawing system for TRS-80. Has two font system: .15" grid for B size, and .1" for A size drawings. Comes complete with predefined symbols for standard logic, linear devices, passive and active components, connectors, and 128 ASCII character set. System is menu driven with placement of symbols and interconnectors done under cursor control on the screen before plotting. Other software is in development and will be available upon completion.

Proac comes with full vector driving software for 8080, 6502, and 6800 based computers. Interfaces are available for Apple, TRS-80 and PET. With the addition of the SIA 250 intelligent interface, Proac becomes compatible with any computer.

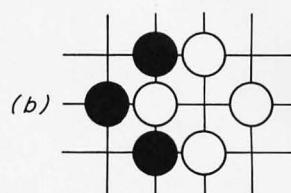
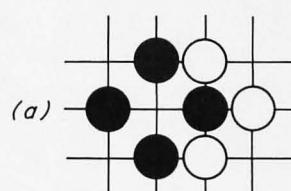
Contact Mauro Engineering about complete information and specifications for MP-250B Proac and available software.

## MAURO ENGINEERING

2220 Pack Trail, Mount Shasta, CA 96067  
Telephone 916 926-4406



**Figure 5:** Illegal moves. The point marked *x* in 5a is illegal for black because it would result in a black group with no liberties. The point marked *x* in 5b is permissible, however, because it captures the two white stones, leaving the inner black group with two liberties.



**Figure 6:** Ko. In 6a, white can capture the black stone, resulting in 6b. It is illegal for black to restore 6a immediately by recapturing the white stone; he must wait a turn.

player may move so as to reproduce the board position existing just prior to his opponent's last move. A move must be made elsewhere to change the board position before the ko capture is allowed.

### Lookahead

Kos are common and often critical in master games, but at Wally's level it was simpler to leave out the Rule of Ko. However, it is essential to avoid suicidal or totally wasted moves which fill in the last liberty of a group, or leave it only one liberty, so that the group will be captured anyway. Hence a limited lookahead capability was adopted. The last step in evaluating a suggested black move is to put the stone down tentatively and count the liberties of the resulting black group. This is done by calling COUNT. The move is rejected if the resulting group does not have at least two liberties.

The complete move evaluation module, EVAL, is shown in listing 3. The module LOOKAHEAD saves the current (move, liberties) pair before COUNT is called with the tentative black stone in place.

### Pattern Matching

Wally's most intelligent-looking moves are pattern matches. There are common configurations of stones which suggest an obvious next move to a good player. Wally has a table of

patterns of this sort; these patterns are illustrated in figure 7. Each pattern includes one white stone and two black stones, with a third black move indicated. Patterns 7a thru 7e represent responses to threatened connections. Patterns 7f and 7g create good "shape."

In Go, as in other spheres, there is truth to the motto, "In unity there is strength." The first step in capturing a group of stones is to cut it off from any other large groups nearby. Two weak groups, when connected into a single large group, often have a much better chance of survival. That is why defensive moves like figures 7a thru 7e are important.

Good shape in Go is a local positional strength. It is characterized by diamond-shaped configurations, or box-like shapes with at least two solid walls. These patterns enclose an area in an easily defended way, and serve as a basis for expansion. Moves like those in figures 7f and 7g are aggressive moves that take area while expanding against the opponent's outposts.

The program looks at each white stone, trying to find two black stones near it in the same relative positions as in one of the patterns. The table entry for a pattern contains the vertical and horizontal displacements of the two black stones relative to the white stone, and that of the suggested black move. If the two black stones

are found and the point for the black move is unoccupied, the black move is returned for evaluation.

Each pattern must be considered in all possible orientations around the

**Listing 3:** Module specifications for move evaluation, lookahead, and pattern matching.

```
EVAL(move,liberties):
  GLOBAL (best-move, best-liberties)
  IF liberties ≤ best-liberties AND
    LOOKAHEAD(move) ≥ 2
  THEN
    best-move = move
    best-liberties = liberties
  END
```

```
LOOKAHEAD(move):
  place black stone at move
  CALL COUNT(move,black)
  remove black stone
  RETURN count of liberties
```

```
PATS:
  FOR each white stone DO
    IF there is a pattern in the table
      centered on that white stone
    THEN
      get suggested black move y
      CALL EVAL(y,2)
    EXIT
  END
END
```

white stone. Three-stone patterns have either four or eight orientations, depending on their lateral symmetry. The program trades table space against program space by performing 180° rotations automatically. Thus, two or four table entries representing different orientations of each pattern are needed to account for all possibilities.

Pattern matches are checked last, because they almost always take priority over moves arising from the earlier phase of counting the liberties of groups. Pattern-match moves are associated with an artificial figure of two liberties to set their priority. Thus, if Wally can capture a white group, or avoid the capture of a black group having one liberty, he will do so despite any pattern matches. The priorities of the patterns are determined by the order in which they are checked, since the first match found is returned.

### Ghost Stones

The edge of the Go board is strategically important because it helps to wall off areas. An attempt by white, for example, to invade be-

tween a black stone and the edge of the board should be defended against. The first five patterns in figure 7 already defend against threatened connections; why not use them to protect the connection between a stone and the edge of the board? Imagine that there is an additional row of black "ghost" stones all around the board. As figure 8 shows, a white move near the edge can then invoke a pattern. This idea was implemented in the pattern match by allowing off-board positions to count as black stones tested for in each pattern.

### Edge Moves

One of the most startling improvements in Wally's performance resulted from a simple observation in the first few games. Groups on the edge of the board, when attacked, often extended fruitlessly along the edge, as in figure 9. A prohibition against edge moves, except to capture or on a pattern match, was added. Wally's play began at that moment to take on the character of an opponent to be reckoned with.

### Handicaps

Go has a handicap system that allows an expert to play an even and interesting game with a novice. Black is given a head start of two to nine stones on designated points—the ones marked with black spots on the board (see figure 1). The handicap stones are placed symmetrically like die spots, except that a handicap of three stones is placed on three corners. Additional handicap points, for a total of up to seventeen stones, were added for Wally's benefit, since it was not expected that he would be a strong player. Each additional handicap stone accounts for roughly 10 points difference in score.

The handicap stones help to make up for Wally's lack of overall strategy. The handicap points are good points to occupy early in the game, so a large handicap solves much of the strategy problem.

### Eyes and Life

Wally has a blind spot that costs him dearly against experienced players: he does not understand that any group, no matter how large, will be captured unless it has two "eyes," or sufficient space to make them. An eye is an unoccupied point or connected group of points. A group enclosing two eyes is immune from

## MAIL ORDER ONLY

Micro Computer

Your One Stop For... Quality and Huge Savings

## DISCOUNT Company

QUALITY • DELIVERY • SERVICE

60 E. 42nd St. Suite 411 New York, NY 10017

(212) 986-7690

**SALE!**

EPSON MX-80  
EPSON MX-70

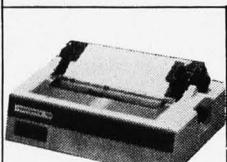
PAPER TIGER  
445 & 460

CALL FOR PRICE

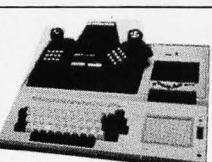


SUPERBRAIN\*

32K - \$2445  
64K - \$2749  
64KQD - \$3395



CENTRONICS  
CALL FOR PRICES



APF  
IM1 - \$495  
IM2 - \$988

COMMODORE

16K - \$888  
32K - \$1088  
2022 - \$695  
2040 - \$1088  
8050 - \$1535  
8032 - \$1495



SUPERBRAIN\*

32K - \$2445  
64K - \$2749  
64KQD - \$3395



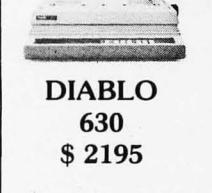
ATARI  
800 - \$795



XYMEC  
HQ 1000 - \$2395

NEC  
SPINWRITER

5510 - \$2795  
5520 - \$2990



DIABLO  
630  
\$ 2195

1730 - \$2195

## MAIL ORDER ONLY

Send Certified Check (Personal or Company Checks require 2 weeks to clear.)  
We pay all shipping and insurance charges except items marked with asterisk.  
VISA, MasterCharge add 5%. N.Y.S. Residents add appropriate sales tax.

\* (DENOTES ITEMS  
SHIPPED F.O.B. NYC)

PHONE (212) 986-7690



## MORE FOR YOUR RADIO SHACK TRS-80 MODEL I !

### THE DATAHANDLER

#### DATABASE MANAGEMENT SYSTEM IN MMSFORTH

Now the power, speed and compactness of MMSFORTH drive a major applications program for many of YOUR home, school and business tasks! Imagine a sophisticated database management system with flexibility to create, maintain and print mailing lists with multiple address lines, Canadian or the new 9-digit U.S. ZIP codes, and multiple phone numbers, plus the speed to load hundreds of records or sort them on several fields in 5 seconds! Manage inventories with selection by any character or combination. Balance checkbook records and do CONDITIONAL reporting of expenses or other calculations. File any records and recall selected ones with optional upper/lower case match, in standard or custom formats. Personnel, membership lists, bibliographies, catalogs of record, stamp and coin collections—you name it! ALL INSTANTLY, without wasted bytes, and with cueing from screen so good that non-programmers quickly master its use! With manual, sample data files and custom words for mail list and checkbook use.

**Technical:** Handles data as compressed indexed sequential subfiles of up to 25K characters (9K in 32K RAM). Access 1.4 data diskettes. Modified Quicksort. Optionally precompiles for 5-second program load. Self-adjusts for many routine mods. Structured and modular MMSFORTH source code ideal for custom modifications.

THE DATAHANDLER V1.1, a very sophisticated database management system operable by non-programmers (requires Disk MMSFORTH, 1 drive & 32K RAM); with manuals, \$59.95\*

# mmsFORTH

#### THE PROFESSIONAL FORTH FOR TRS-80 MODEL I

(Over 1,000 systems in use)

MMSFORTH Disk System V1.9 (requires 1 disk drive & 16K RAM) ..... just \$79.95\*  
MMSFORTH Cassette System V1.8 (requires Level II BASIC & 16K RAM) ..... \$59.95\*

#### AND MMS GIVES IT PROFESSIONAL SUPPORT

Source code provided  
MMSFORTH Newsletter  
Many demo programs aboard  
MMSFORTH User Groups  
Programming staff can adapt  
THE DATAHANDLER to YOUR needs.

MMSFORTH UTILITIES DISKETTE: includes FLOATING POINT MATH (L2 BASIC ROM routines plus Complex numbers, Rectangular-Polar coordinate conversions, Degrees mode, more), plus a full Forth-style Z80 ASSEMBLER; plus a powerful CROSS-REFERENCER to list Forth words by block and line. All on one diskette. (requires MMSFORTH, 1 drive & 16K RAM), .. \$39.95\*

#### FORTH BOOKS AVAILABLE

MICROFORTH PRIMER (comes with MMSFORTH) separately ..... \$15.00\*  
USING FORTH — more detailed and advanced than above ..... \$25.00\*

THREADED INTERPRETIVE LANGUAGES—advanced, excellent analysis of MMSFORTH-like language ..... \$18.95\*  
CALTECH FORTH MANUAL — good on Forth internal structure, etc ..... \$10.00\*

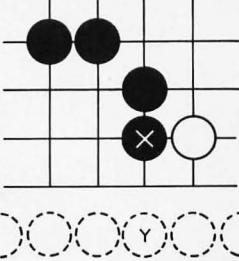
\* Software prices include manuals and require signing of a single-system user license. Add \$2.00 S/H plus \$1.00 per additional book; Mass. orders add 5% tax. Foreign orders add 20%. UPS COD, VISA & M/C accepted; no unpaid purchase orders, please.

Send SASE for free MMSFORTH information.  
Good dealers sought.

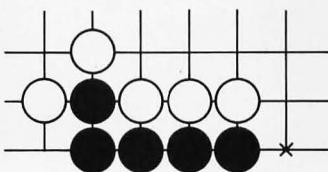
Get MMSFORTH products from your computer dealer or

#### MILLER MICROCOMPUTER SERVICES (B4)

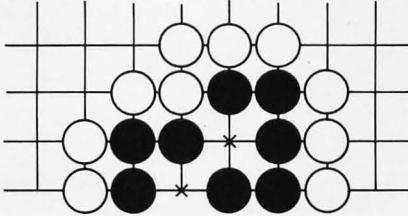
61 Lake Shore Road, Natick, MA 01760  
(617) 653-6136



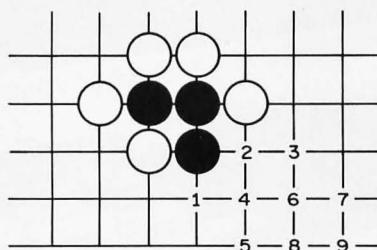
**Figure 8: Ghost stones.** The black move at *x* is suggested by the pattern in figure 7d because there is an imaginary black stone at point *Y*, off the edge of the board, for purposes of pattern matching.



**Figure 9: Running along the edge.** Before the program was modified, black would move at *x*, white could respond just above *x*, and the process would be repeated until the black "worm" reached the edge of the board and was captured. Edge moves are now prohibited except for captures and pattern matches.



**Figure 10: A safe group with two eyes.** White cannot capture black because both eyes, marked *x*, would have to be filled. But white can make only one move at a time, and a move in either point is illegal.



**Figure 11: A ladder.** White threatens to capture black by moving at 1. When black attempts to escape at 2, white moves at 3, and so on. The black stones form a staircase that eventually reaches the edge of the board and is captured by white 9. If there were a black stone at 6, however, black would escape, and white would be left in a vulnerable position.

an estimate of the area controlled by each player. When an area is only loosely surrounded, however, or an invasion is in progress, it is very difficult to determine the ownership of many points. A possible approach is the perceptual-grouping heuristic method developed by Zobrist (reference 3). Move tree searching is probably the only way to find the best move in confined tactical situations, like those that appear in Go problem books.

Another improvement suggested by chess programs is to include some of the countless known corner openings, or "joseki." Joseki are useful anywhere in the board, and should be implemented as an extension of the pattern matching.

After a move that leaves an opponent's group with only one liberty, one is supposed to say "atari" to warn him that his group is about to be captured. Wally says nothing, and I have lost large groups by failing to notice an impending capture. "Atari" goes in next. ■

#### References

1. Ryder, J. "Heuristic Analysis of Large Trees as Generated in the Game of Go." Stanford University: Ph D Thesis, 1971.
2. Wilcox, B. "Computer Go." American Go Journal, 1979.
3. Zobrist, A. "A Model of Visual Organization for the Game of Go." AFIPS Spring Joint Computer Conference, 1969, pages 103 thru 112.

# Make America smarter.

# Give to the college of your choice.