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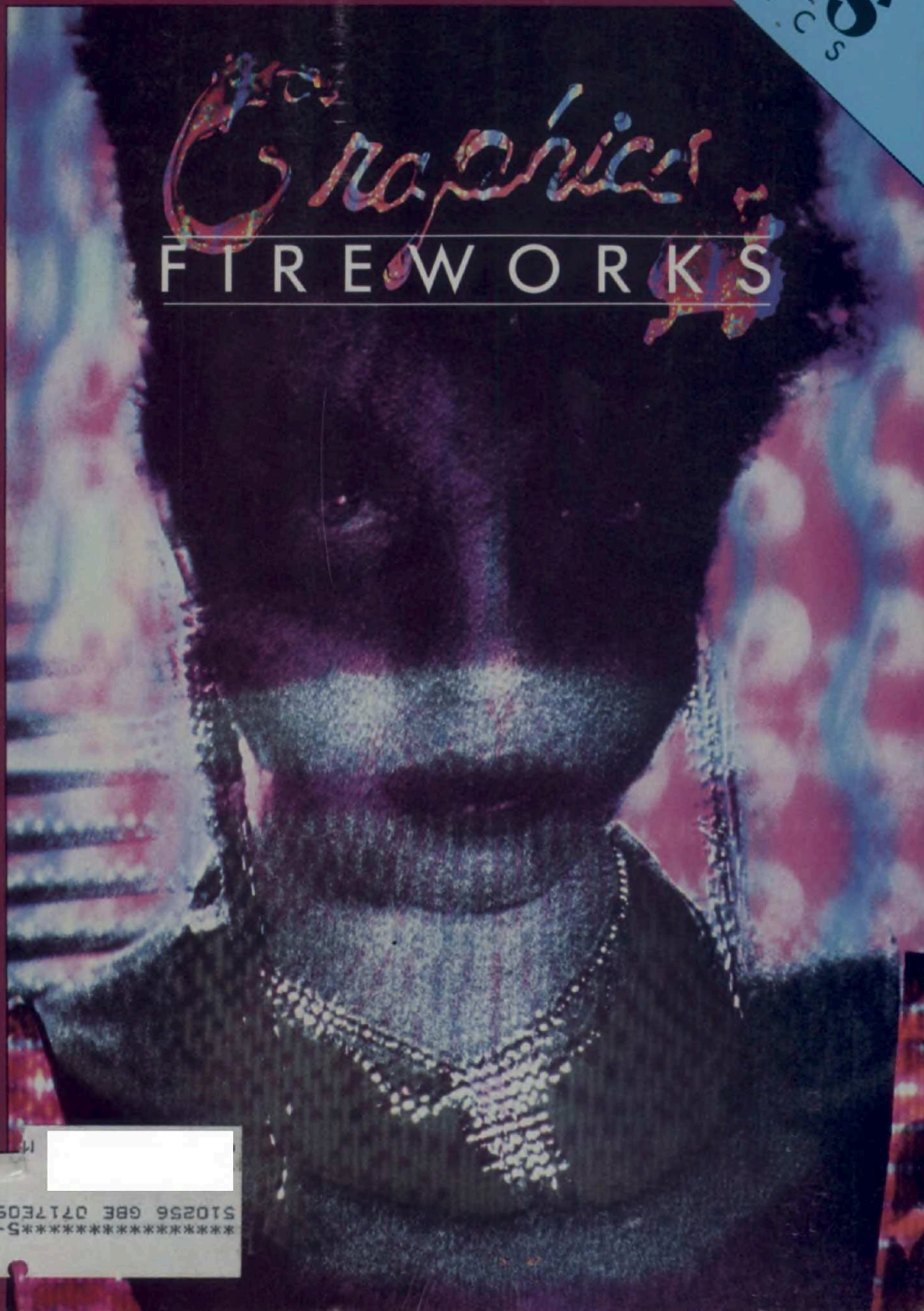
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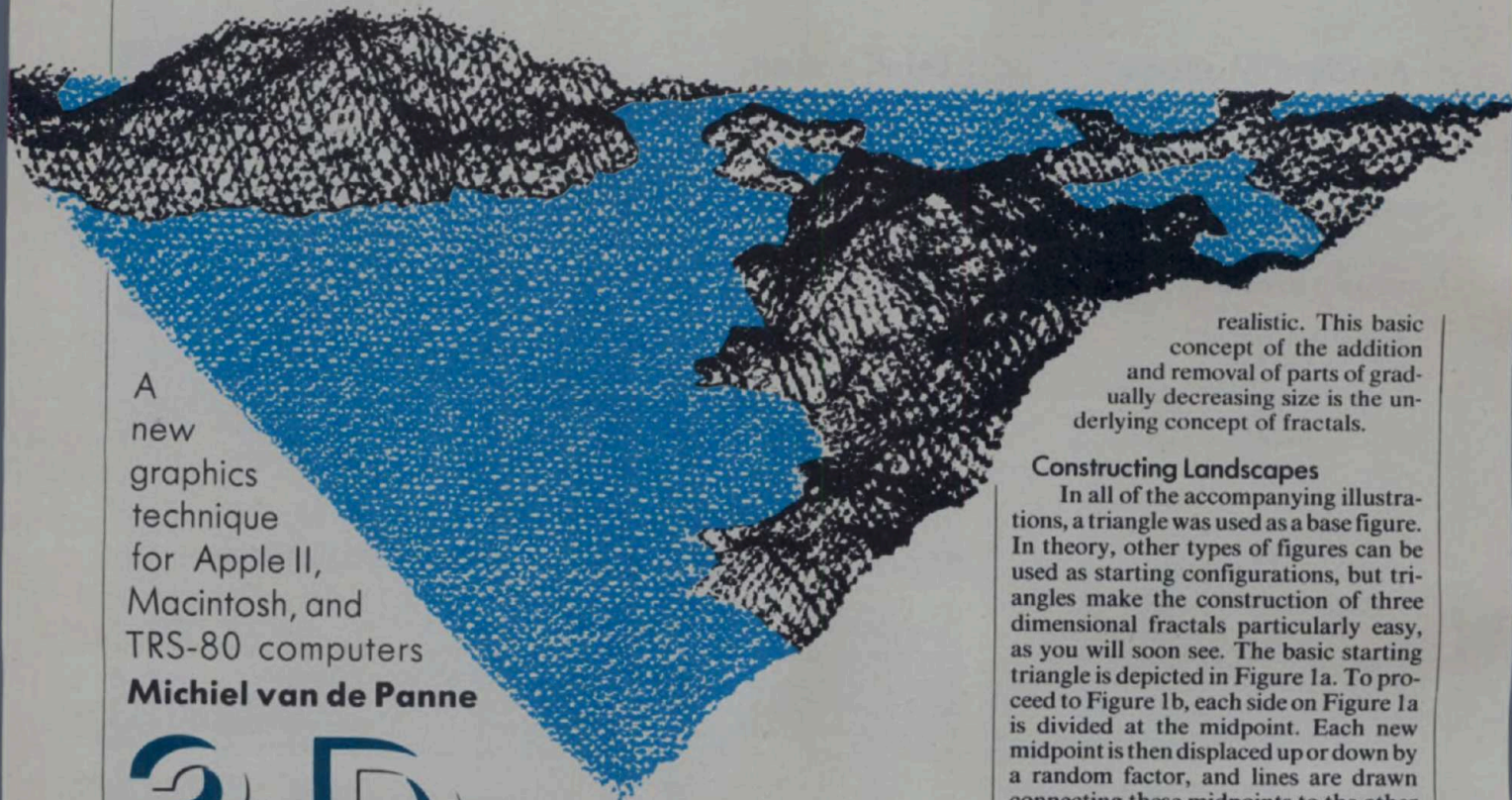
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A new graphics technique for Apple II, Macintosh, and TRS-80 computers

Michiel van de Panne

3-D

Fractals

If you have no idea of what a fractal is, you are not alone. Fractals are, however, being used increasingly in a variety of modelling applications where it is desirable to obtain realistic simulations of such natural phenomena such as crystal growth, coastlines, and clouds. In this article, I will focus primarily on how to build realistic three-dimensional landscapes that are constructed with the aid of many random numbers.

Fractals: An Explanation

A fractal is an object that is put together by beginning with some basic shape such as a sphere and then adding or removing fractions of it. First, large fractions, or chunks, are removed or

added in a random fashion. Then, in the next step of the procedure, smaller sized fractions are similarly removed or added. This process is repeated until the desired effect has been achieved.

It can easily be seen how this process can be used to construct landscapes when examining the structure of a mountain or other such natural phenomena in detail. A mountain can be thought of as a very large chunk of rock in the shape of a pyramid with parts taken out in some spots and added on in others. These parts serve to create the ridges, crests, bowls, etc. seen on real mountains. When smaller parts are added and removed from our model of a mountain, the resulting object becomes even more

realistic. This basic concept of the addition and removal of parts of gradually decreasing size is the underlying concept of fractals.

Constructing Landscapes

In all of the accompanying illustrations, a triangle was used as a base figure. In theory, other types of figures can be used as starting configurations, but triangles make the construction of three dimensional fractals particularly easy, as you will soon see. The basic starting triangle is depicted in Figure 1a. To proceed to Figure 1b, each side on Figure 1a is divided at the midpoint. Each new midpoint is then displaced up or down by a random factor, and lines are drawn connecting these midpoints to the other midpoints created.

To create Figure 1c from Figure 1b, the same procedure is followed. The midpoint of each side is moved up or down by random amount and is then connected with straight lines to the surrounding points. Each time this procedure is repeated the number of triangles quadruples. We began in Figure 1a with one triangle, produced Figure 1b with four triangles and Figure 1c with 16 triangles, and end up in Figure 1g with a total of 4096 individual triangles.

When running the program, you have the option of choosing the number of times you wish to repeat the quadrupling process for the triangles. This is done by replying appropriately to the question Number of Levels?. Replying with 1 to indicate one level will result in a figure with four triangles. In other words, the dividing process will have been repeated once. Replying 2 will result in 16 triangles as a result of the dividing process having been repeated twice. Level 3 results in 64 triangles; Level 4, in 256 triangles, etc.

The Sea Level

You will have noticed at this point that all the illustrations in the article except for those in Figure 1 have a sea or

Figure 1a.
Level 6.

Figure 1b.

Figure 1c.

Figure 1d.

Figure 1e.

Figure 1f.

Figure 1g.

Listing 1. TRS-80 Model I/III/4 version with CGP-115 plotter.

```

10 DEFINT A-N
20 DIM D(64,32)
30 INPUT "NUMBER OF LEVELS";LE
40 DS=2:FOR N=1 TO LE:DS=DS*2:(N-1):NEXT N
50 MX=DS-1:MY=MX/2:PI=3.1416:RH=PI*30/180:VT=RH*1.2
60 FOR N=1 TO LE:L=10000/1.8*EN
70 PRINT "WORKING ON LEVEL";N
80 IB=MX/2:IN:SK=IB*2
90 GOSUB 150 :REM *** ASSIGN HEIGHTS ALONG X IN ARRAY ***
100 GOSUB 220 :REM *** ASSIGN HEIGHTS ALONG Y IN ARRAY ***
110 GOSUB 290 :REM *** ASSIGN HEIGHTS ALONG DIAG. IN ARRAY ***
120 NEXT N
130 GOTO 640 :REM *** DRAW ***
140 REM * HEIGHTS ALONG X *
150 FOR YE=0 TO MX-1 STEP SK
160 FOR XE=IB+YE TO MX STEP SK
170 AX=XE-IB:AY=YE:GOSUB 370 :D1=D:AX=XE+IB:GOSUB 370 :D2=D
180 D=(D1+D2)/2+RND(L/2)-L/4:AX=XE:AY=YE:GOSUB 420
190 NEXT XE
200 NEXT YE:RETURN
210 REM * HEIGHTS ALONG Y *
220 FOR XE=MX TO 1 STEP -SK
230 FOR YE=IB TO XE STEP SK
240 AX=XE:AY=YE+IB:GOSUB 370 :D1=D:AY=YE-IB:GOSUB 370 :D2=D
250 D=(D1+D2)/2+RND(L/2)-L/4:AX=XE:AY=YE:GOSUB 420
260 NEXT YE
270 NEXT XE:RETURN
280 REM * HEIGHTS ALONG DIAG. *
290 FOR XE=0 TO MX-1 STEP SK
300 FOR YE=IB TO MX-XE STEP SK
310 AX=XE+YE-IB:AY=YE-IB:GOSUB 370 :D1=D
320 AX=XE+YE+IB:AY=YE+IB:GOSUB 370 :D2=D
330 AX=XE+YE:AY=YE:D=(D1+D2)/2+RND(L/2)-L/4:GOSUB 420
340 NEXT YE
350 NEXT XE:RETURN
360 REM *** RETURN DATA FROM ARRAY ***
370 IF AY>MY THEN 390
380 BY=AY:BX=AX:GOTO 400
390 BY=MX+1-AY:BX=MX-AX
400 D=D(BX,BY):RETURN
410 REM *** PUT DATA IN ARRAY ***
420 IF AY>MY THEN 440
430 BY=AY:BX=AX:GOTO 450
440 BY=MX+1-AY:BX=MX-AX
450 D(BX,BY)=D:RETURN
460 REM *** PUT IN SEA LEVEL HERE ***
470 IF X0<>-999 THEN 500
480 IF ZZ<0 THEN GOSUB 1070 :ZZ=ZZ:ZZ=0:GOTO 620
490 GOSUB 1090 :GOTO 610
500 IF ZZ>0 AND ZZ>0 THEN 610
510 IF ZZ<0 AND ZZ<0 THEN ZZ=ZZ:ZZ=0:GOTO 620
520 W3=ZZ/(ZZ-Z2):X3=(X2-XX)*W3+XX:Y3=(Y2-YY)*W3+YY:Z3=0
530 ZT=ZZ:YT=YY:XT=XX
540 IF ZZ>0 THEN 590
550 REM *** GOING INTO WATER ***
560 ZZ=Z3:YY=Y3:XX=X3:GOSUB 950
570 GOSUB 1070 :ZZ=0:YY=YT:XX=XT:ZZ=ZT:GOTO 620
580 REM *** COMING UP OUT OF WATER ***
590 ZZ=Z3:YY=Y3:XX=X3:GOSUB 950
600 GOSUB 1090 :ZZ=ZT:YY=YT:XX=XT
610 ZZ=ZZ
620 X2=XX:Y2=YY:RETURN
630 REM ***** DISPLAY HERE *****
640 GOSUB 1110 :REM *** SET UP PLOTTING DEVICE OR SCREEN ***
650 XS=.04:YS=.04:ZS=.04:REM ***** SCALING FACTORS *
660 FOR AX=0 TO MX:X0=-999:FOR AY=0 TO MY
670 GOSUB 370 :ZZ=D:YY=AY/MX*10000:XX=AX/MX*10000-YY/2
680 GOSUB 940 :NEXT AY:NEXT AX
690 FOR AY=0 TO MX:X0=-999:FOR AX=AY TO MX
700 GOSUB 370 :ZZ=D:YY=AY/MX*10000:XX=AX/MX*10000-YY/2
710 GOSUB 940 :NEXT AX:NEXT AY
720 FOR EX=0 TO MX:X0=-999:FOR EY=0 TO MX-EX

```

(continued on next page)

water level, making the landscapes look like land with lakes, or islands, depending on how much of the land is above the water level. All these figures are constructed with the same process used to obtain Figure 1g, only they have a sea or water level inserted.

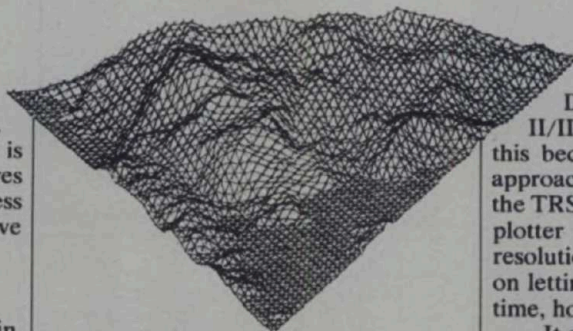
Running the Program

The programs as they are shown in the listings will produce only landscapes with sea levels. In the version for the Radio Shack Model I/III/4 with CGP-115 plotter and the Apple II version, the sea is colored blue while the land is colored black and white. Because the Apple Macintosh lacks color, the sea or water is indicated by dots. If you desire to produce a plot without a sea level inserted, simply change line 470 to read:

470 RETURN

This applies to the versions for all three computers.

The only input the program requires is the number of levels you wish. This changes the number of triangles of which the resulting figure is made and hence, how realistic the resulting image



is. A level 3 figure takes only about five minutes to plot, but does not produce a very realistic looking landscape. On the other hand, a level 6 figure might take an hour, but will produce a landscape that is very realistic. Generally, a good compromise is level 5. As listed, the programs create levels from 1 to 6.

Possible Modifications

If you have enough memory in your computer, you may wish to modify the program so that you can do up to seven levels. The enlarged illustration on page 82 is a figure with seven levels (16384 triangles). The only change required to do this is to change the dimension statement in line 20 from DIM D(64,32) to

DIM D(128,64). On the Apple II/Ile there is not much point in doing this because the triangles are already approaching the pixel size in level 6. On the TRS-80 Model I/III/4 with CGP-115 plotter and the Apple Macintosh, the resolution is sufficient. You should plan on letting the computer plot for a long time, however.

It should not be difficult to modify the program to run on a different type of computer, providing it supports a sufficiently complex version of Basic and has a graphics resolution of at least 150 x 200 or so. All the program lines that are computer dependent are located at the end of the program from line 1030 on.

Acknowledgements

The technique used in the program for generating the landscapes is not my own. It is based on a technique described in the September 1984 issue of *Scientific American*. They in turn credit the original idea of fractal geometry to Benoit Mandelbrot, "the father of fractals", and the further development of the idea to Lucasfilm Ltd.



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Listing 1. (continued)

```

730 AX=EX+EY:AY=EY:GOSUB 370 :ZZ=D:YY=AY/MX*10000
740 XX=AX/MX*10000-YY/2:GOSUB 940 :NEXT EY:NEXT EX
750 GOTO 1130 :REM *** DONE PLOTTING, GOTO END
    LOOP ***
760 REM *** ROTATE ***
770 IF XX<>0 THEN 800
780 IF YY<=0 THEN RA=-PI/2:GOTO820
790 RA=PI/2:GOTO820
800 RA=ATN(YY/XX)
810 IF XX<0 THEN RA=RA+PI
820 R1=RA+RH:RD=SQR(XX*XX+YY*YY)
830 XX=RD*COS(R1):YY=RD*SIN(R1)
840 RETURN
850 REM *** TILT DOWN ***
860 RD=SQR(ZZ*ZZ+XX*XX)
870 IF XX=0 THEN RA=PI/2:GOTO900
880 RA=ATN(ZZ/XX)
890 IF XX<0 THEN RA=RA+PI
900 R1=RA-UT
910 XX=RD*COS(R1)+XX:ZZ=RD*SIN(R1)
920 RETURN
930 REM *** MOVE OR PLOT TO (XP,YP) ***
940 GOSUB 470
950 XX=XX*XS:YY=YY*YS:ZZ=ZZ*ZS
960 GOSUB 770 : REM *** ROTATE ***
970 GOSUB 860 : REM *** TILT UP ***
980 IF XD=-999 THEN PR$="M" ELSE PR$="D"
990 XP=INT(YY)+CX:YP=INT(ZZ)
1000 GOSUB 1030
1010 RETURN
1020 REM *** PLOT LINE HERE ***
1030 LPRINTPR$:XP;"":YP:XO=XP
1040 REM
1050 RETURN
1060 REM *** SWITCH TO SEA COLOR ***
1070 LPRINT"C1":RETURN
1080 REM *** SWITCH TO LAND COLOR ***
1090 LPRINT"C0":RETURN
1100 REM *** SET UP PLOTTING DEVICE OR SCREEN ***
1110 LPRINT CHR$(18):LPRINT"I":RETURN
1120 REM *** END LOOP ***
1130 LPRINT"A"
1140 END

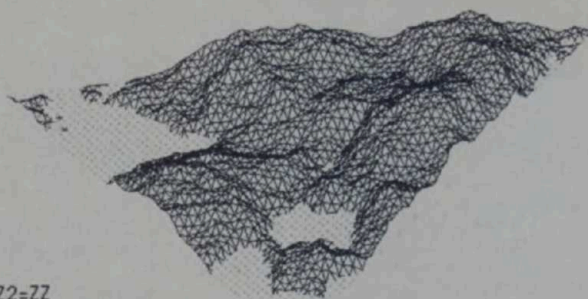
```


Listing 2. Apple Macintosh version.

```

10 DEFINT A-N
20 DIM D(64,32):RANDOMIZE
30 INPUT "Number of levels",LE
40 DS=2:FOR N=1 TO LE:DS=DS*2^(N-1):NEXT N
50 MX=DS-1:MY=MX/2:PI=3.1416:RH=PI*30/180:VT=RH*1.2
60 FOR N=1 TO LE:L=10000/1.8*N
70 PRINT "Working on level",N
80 IB=MX/2*N:SK=IB*2
90 GOSUB 150:REM *** Assign heights along x in array ***
100 GOSUB 220:REM *** Assign heights along y in array ***
110 GOSUB 290:REM *** Assign heights along diag. in array ***
120 NEXT N
130 GOTO 640:REM *** draw ***
140 REM *** heights along x ***
150 FOR YE=0 TO MX-1 STEP SK
160 FOR XE=IB+YE TO MX STEP SK
170 AX=XE-IB:AY=YE:GOSUB 370:D1=D:AX=XE+IB:GOSUB 370:D2=D
180 D=(D1+D2)/2+RND(1)*L/2-L/4:AX=XE:AY=YE:GOSUB 420
190 NEXT XE
200 NEXT YE:RETURN
210 REM *** heights along y ***
220 FOR XE=MX TO 1 STEP -SK
230 FOR YE=IB TO XE STEP SK
240 AX=XE:AY=YE+IB:GOSUB 370:D1=D:AY=YE-IB:GOSUB 370:D2=D
250 D=(D1+D2)/2+RND(1)*L/2-L/4:AX=XE:AY=YE:GOSUB 420
260 NEXT YE
270 NEXT XE:RETURN
280 REM *** heights along diag. ***
290 FOR XE=0 TO MX-1 STEP SK
300 FOR YE=IB TO MX-XE STEP SK
310 AX=XE+YE-IB:AY=YE-IB:GOSUB 370:D1=D
320 AX=XE+YE+IB:AY=YE+IB:GOSUB 370:D2=D
330 AX=XE+YE:AY=YE:D=(D1+D2)/2+RND(1)*L/2-L/4:GOSUB 420
340 NEXT YE
350 NEXT XE:RETURN
360 REM *** return data from array ***
370 IF AY>MY THEN 390
380 BY=AY:BX=AX:GOTO 400
390 BY=MX+1-AY:BX=MX-AX
400 D=D(BX,BY):RETURN
410 REM *** put data in array ***
420 IF AY>MY THEN 440
430 BY=AY:BX=AX:GOTO 450
440 BY=MX+1-AY:BX=MX-AX
450 D(BX,BY)=D:RETURN
460 REM *** put in sea level here ***
470 IF X0<-999 THEN 500
480 IF Z2<0 THEN GOSUB 1070:Z2=Z2:Z2=0:GOTO 620
490 GOSUB 1090:GOTO 610
500 IF Z2>0 AND Z2>0 THEN 610
510 IF Z2<0 AND Z2<0 THEN Z2=Z2:Z2=0:GOTO 620
520 W3=Z2/(Z2-Z2):X3=(X2-XX)*W3+XX:Y3=(Y2-YY)*W3+YY:Z3=0
530 ZT=Z2:YT=YY:XT=XX
540 IF Z2>0 THEN 590
550 REM *** going into water ***
560 Z2=Z3:YY=Y3:XX=X3:GOSUB 950
570 GOSUB 1070:Z2=0:YY=YT:XX=XT:Z2=ZT:GOTO 620
580 REM *** coming up out of water ***
590 Z2=Z3:YY=Y3:XX=X3:GOSUB 950
600 GOSUB 1090:Z2=ZT:YY=YT:XX=XT

```



```

610 Z2=Z2
620 X2=XX:Y2=YY:RETURN
630 REM *** display here ***
640 GOSUB 1110:REM *** set up plotting device or screen ***
650 X5=.04:Y5=.04:Z5=.04:REM *** scaling factors ***
660 FOR AX=0 TO MX:X0=-999:FOR AY=0 TO AX
670 GOSUB 370:Z2=D:YY=AY/MX*10000:XX=AX/MX*10000-YY/2
680 GOSUB 940:NEXT AY:NEXT AX
690 FOR AY=0 TO MX:X0=-999:FOR AX=AY TO MX
700 GOSUB 370:Z2=D:YY=AY/MX*10000:XX=AX/MX*10000-YY/2
710 GOSUB 940:NEXT AX:NEXT AY
720 FOR EX=0 TO MX:X0=-999:FOR EY=0 TO MX-EX
730 AX=EX+EY:AY=EY:GOSUB 370:Z2=D:YY=AY/MX*10000
740 XX=AX/MX*10000-YY/2:GOSUB 940:NEXT EY:NEXT EX
750 GOTO 1130:REM *** done plotting, goto end loop ***
760 REM *** rotate ***
770 IF XX<0 THEN 800
780 IF YY<0 THEN RA=-PI/2:GOTO 820
790 RA=PI/2:GOTO 820
800 RA=ATN(YY/XX)
810 IF XX<0 THEN RA=RA+PI
820 R1=RA+RH:RD=SQR(XX*XX+YY*YY)
830 XX=RD*COS(R1):YY=RD*SIN(R1)
840 RETURN
850 REM *** tilt down ***
860 RD=SQR(Z2*Z2+XX*XX)
870 IF XX=0 THEN RA=PI/2:GOTO 900
880 RA=ATN(Z2/XX)
890 IF XX<0 THEN RA=RA+PI
900 R1=RA-VT
910 XX=RD*COS(R1)+XX:Z2=RD*SIN(R1)
920 RETURN
930 REM *** move or plot to (xp,yp) ***
940 GOSUB 470
950 XX=XX*X5:YY=YY*Y5:Z2=Z2*Z5
960 GOSUB 770:REM *** rotate ***
970 GOSUB 860:REM *** tilt up ***
980 IF X0=-999 THEN PR$="M" ELSE PR$="D"
990 XP=INT(YY)+CX:YP=INT(Z2)
1000 GOSUB 1030
1010 RETURN
1020 REM *** plot line here ***
1030 XP=XP*1.1:YP=80-YP:IF PR$="M" OR F1=1 THEN X8=XP:Y8=YP
1040 LINE (X8,Y8)-(XP,YP):X8=XP:Y8=YP:X0=XP
1050 RETURN
1060 REM *** switch color to sea color ***
1070 F1=1:RETURN
1080 REM *** switch to land color ***
1090 F1=0:RETURN
1100 REM *** set up plotting device or screen ***
1110 CLS:RETURN
1120 REM *** end loop ***
1130 A$=INKEY$:IF A$="" THEN 1130
1140 END

```


Listing 3. Apple II version.

```

20 DIM D(64,32)
30 INPUT "NUMBER OF LEVELS";LE
40 DS = 2: FOR N = 1 TO LE:DS = D
  S + 2 ^ (N - 1): NEXT N
50 MX = DS - 1:MY = MX / 2:PI = 3
  .1416:RH = PI * 30 / 180:VT =
  RH * 1.2
60 FOR N = 1 TO LE:L = 10000 / 1
  .8 ^ N
70 PRINT "WORKING ON LEVEL";N
80 IB = MX / 2 ^ N:SK = IB * 2
90 GOSUB 150: REM *** ASSIGN HE
  IGHTS ALONG X IN ARRAY ***
100 GOSUB 220: REM *** ASSIGN H
  EIGHTS ALONG Y IN ARRAY ***
110 GOSUB 290: REM *** ASSIGN H
  EIGHTS ALONG DIAG. IN ARRAY
  ***
120 NEXT N
130 GOTO 640: REM *** DRAW ***
140 REM * HEIGHTS ALONG X *
150 FOR YE = 0 TO MX - 1 STEP SK
160 FOR XE = IB + YE TO MX STEP
  SK
340 NEXT YE
350 NEXT XE: RETURN
360 REM *** RETURN DATA FROM AR
  RAY ***
370 IF AY > MY THEN 390
380 BY = AY:BX = AX: GOTO 400
390 BY = MX + 1 - AY:BX = MX - AX
400 D = D(BX,BY): RETURN
410 REM *** PUT DATA INTO ARRAY
  ***
420 IF AY > MY THEN 440
430 BY = AY:BX = AX: GOTO 450
440 BY = MX + 1 - AY:BX = MX - AX
450 D(BX,BY) = D: RETURN
460 REM *** PUT IN SEA LEVEL HE
  RE ***
470 IF XO < > - 999 THEN 500
480 IF ZZ < 0 THEN GOSUB 1070:Z
  2 = ZZ:ZZ = 0: GOTO 620
490 GOSUB 1090: GOTO 610
500 IF ZZ > 0 AND ZZ > 0
  THEN 610
680 GOSUB 940: NEXT AY: NEXT AX
690 FOR AY = 0 TO MX:XO = - 999
  : FOR AX = AY TO MX
700 GOSUB 370:ZZ = D:YY = AY / M
  X * 10000:XX = AX / MX * 100
  00 - YY / 2
710 GOSUB 940: NEXT AX: NEXT AY
720 FOR EX = 0 TO MX:XO = - 999
  : FOR EY = 0 TO MX - EX
730 AX = EX + EY:AY = EY: GOSUB 3
  70:ZZ = D:YY = AY / MX * 100
  00
740 XX = AX / MX * 10000 - YY / 2
  : GOSUB 940: NEXT EY: NEXT
  EX
750 GOTO 1130: REM *** DONE PLO
  TTING, GOTO END LOOP ***
760 REM *** ROTATE ***
770 IF XX < > 0 THEN 800
780 IF YY < > 0 THEN RA = - PI
  / 2: GOTO 820
790 RA = PI / 2: GOTO 820
800 RA = ATN (YY / XX)
810 IF XX < 0 THEN RA = RA + PI
820 R1 = RA + RH:RD = SQR (XX *
  XX + YY * YY)
830 XX = RD * COS (R1):YY = RD *
  SIN (R1)
840 RETURN
850 REM *** TILT DOWN ***
860 RD = SQR (ZZ * ZZ + XX * XX)
870 IF XX = 0 THEN RA = PI /
  2: GOTO 900
880 RA = ATN (ZZ / XX)
890 IF XX < 0 THEN RA = RA + PI
900 R1 = RA - VT
910 XX = RD * COS (R1) + XX:ZZ =
  RD * SIN (R1)
920 RETURN
930 REM *** MOVE OR PLOT TO (XP
  ,YP) ***
940 GOSUB 470
950 XX = XX + XS:YY = YY + YS:ZZ =
  ZZ + ZS
960 GOSUB 770: REM *** ROTATE *
  **
970 GOSUB 860: REM *** TILT UP
  ***
980 IF XO = - 999 THEN PR$ = "M
  "
985 IF XO < > - 999 THEN PR$ =
  "D"
990 XP = INT (YY) + CX:YP = INT
  (ZZ)
1000 GOSUB 1030
1010 RETURN
1020 REM *** PLOT LINE HERE ***
1030 XP = XP * 0.625:YP = 33.14 -
  0.663 * YP
1040 IF PR$ = "M" THEN X8 = XP:Y
  8 = YP:X0 = X
1045 IF Y8 > 179 OR Y8 < 0 OR YP
  > 179 OR YP < 0 THEN RETURN
1050 H$PLOT X8,Y8 TO XP,YP:X8 = X
  P:Y8 = YP: RETURN
1060 REM *** SWITCH TO SEA COLD
  R ***
1070 H$COLOR = 6: RETURN
1080 REM *** SWITCH TO LAND COL
  OR ***
1090 H$COLOR = 7: RETURN
1100 * * * SETUP PLOT TINGDEVI
  CE OR SCREEN * * *
1110 HGR2: RETURN
1120 REM *** END LOOP ***
1130 INPUT A$
1140 TEXT: END
170 AX = XE - IB:AY = YE: GOSUB 3
  70:D1 = D:AX = XE + IB: GOSUB
  370:D2 = D
180 D = (D1 + D2) / 2 + RND (1) *
  L / 2 - L / 4:AX = XE:AY = Y
  E: GOSUB 420
190 NEXT XE
200 NEXT YE: RETURN
210 REM * HEIGHTS ALONG Y *
220 FOR XE = MX TO 1 STEP - SK
230 FOR YE = IB TO XE STEP SK
240 AX = XE:AY = YE + IB: GOSUB 3
  70:D1 = D:AY = YE - IB: GOSUB
  370:D2 = D
250 D = (D1 + D2) / 2 + RND (1) *
  L / 2 - L / 4:AX = XE:AY = Y
  E: GOSUB 420
260 NEXT YE
270 NEXT XE: RETURN
280 REM * HEIGHTS ALONG DIAG. *
290 FOR XE = 0 TO MX - 1 STEP SK
300 FOR YE = IB TO MX - XE STEP
  SK
310 AX = XE + YE - IB:AY = YE - I
  B: GOSUB 370:D1 = D
320 AX = XE + YE + IB:AY = YE + I
  B: GOSUB 370:D2 = D
330 AX = XE + YE:AY = YE:D = (D1 +
  D2) / 2 + RND (1) * L / 2 -
  L / 4: GOSUB 420
510 IF ZZ < 0 AND ZZ < 0 THEN ZZ
  = ZZ:ZZ = 0: GOTO 620
520 W3 = ZZ / (ZZ - ZZ):X3 = (X2 -
  XX) * W3 + XX:Y3 = (Y2 - YY)
  * W3 + YY:Z3 = 0
530 ZT = ZZ:YT = YY:XT = XX
540 IF ZZ > 0 THEN 590
550 REM *** GOING INTO WATER **
  *
560 ZZ = Z3:YY = Y3:XX = X3: GOSUB
  950
570 GOSUB 1070:ZZ = 0:YY = YT:XX
  = XT:ZZ = ZT: GOTO 620
580 REM *** COMING UP OUT OF WA
  TER ***
590 ZZ = Z3:YY = Y3:XX = X3: GOSUB
  950
600 GOSUB 1090:ZZ = ZT:YY = YT:X
  X = XT
610 ZZ = ZZ
620 X2 = XX:Y2 = YY: RETURN
630 REM ***** DISPLAY HERE *****
640 GOSUB 1110: REM *** SET UP
  PLOTTING DEVICE OR SCREEN **
  *
650 XS = .04:YS = .04:ZS = .04: REM
  ***** SCALING FACTORS *****
660 FOR AX = 0 TO MX:XO = - 999
  : FOR AY = 0 TO AX
670 GOSUB 370:ZZ = D:YY = AY / M
  X * 10000:XX = AX / MX * 100
  00 - YY / 2

```

