

## Calhoun: The NPS Institutional Archive DSpace Repository

---

Theses and Dissertations

1. Thesis and Dissertation Collection, all items

---

1986-12

A general purpose graphics support library for  
the Ada programming language hosted on the  
Zenith H/Z-100 computer

Brown, Thomas R., Jr.

Monterey, California: U.S. Naval Postgraduate School

---

<http://hdl.handle.net/10945/21879>

---

*Downloaded from NPS Archive: Calhoun*



<http://www.nps.edu/library>

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community.

Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School  
411 Dyer Road / 1 University Circle  
Monterey, California USA 93943



DUDLEY WOOD LIBRARY  
NAVAL AIRCRAFT ENGINE SCHOOL  
MONTEREY, CALIFORNIA 93943-5002





# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

A GENERAL PURPOSE GRAPHICS SUPPORT  
LIBRARY FOR THE ADA PROGRAMMING LANGUAGE  
HOSTED ON THE ZENITH H/Z-100 COMPUTER

by

Thomas R. Brown, Jr.

December 1986

Thesis Advisor

U. R. Kodres

Approved for public release; distribution is unlimited

T230149



unclassified

## SECURITY CLASSIFICATION OF THIS PAGE

## REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION unclassified		1b RESTRICTIVE MARKINGS	
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b DECLASSIFICATION/DOWNGRADING SCHEDULE			
4 PERFORMING ORGANIZATION REPORT NUMBER(S)		5 MONITORING ORGANIZATION REPORT NUMBER(S)	
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b OFFICE SYMBOL (If applicable) 52	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School	
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000		7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	
8a NAME OF FUNDING/SPONSORING ORGANIZATION	8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c ADDRESS (City, State, and ZIP Code)		10 SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO	PROJECT NO
		TASK NO	WORK UNIT ACCESSION NO
11 TITLE (Include Security Classification) A GENERAL PURPOSE GRAPHICS SUPPORT LIBRARY FOR THE ADA PROGRAMMING LANGUAGE HOSTED ON THE ZENITH H/Z-100 COMPUTER			
12 PERSONAL AUTHOR(S) Brown, Thomas R. Jr.			
13a TYPE OF REPORT Master's Thesis	13b TIME COVERED FROM _____ TO _____	14 DATE OF REPORT (Year, Month, Day) 1986 December	15 PAGE COUNT 67
16 SUPPLEMENTARY NOTATION			
17 COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Ada programming language; Zenith H/Z-100; Graphics library	
19 ABSTRACT (Continue on reverse if necessary and identify by block number)  This thesis explores the requirements necessary to develop a graphics support library for the Ada programming language hosted on the Zenith H/Z-100 microcomputer. A prototype graphics library is implemented in 8086 assembly language embedded in an Ada package. The library operates with JANUS/Ada under the CP/M-86 operating system. Listings of library routines developed are provided as well as a user's guide and demonstration programs. Potential areas for further investigation and development are suggested. It is concluded that an Ada graphics library for microcomputers is feasible and practical.			
20 DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		21 ABSTRACT SECURITY CLASSIFICATION unclassified	
22a NAME OF RESPONSIBLE INDIVIDUAL Prof. Uno R. Kodres		22b TELEPHONE (Include Area Code) (408) 646-2197	22c OFFICE SYMBOL Code 52Kr

Approved for public release; distribution is unlimited.

A General Purpose Graphics Support  
Library for the Ada Programming Language  
Hosted on the Zenith H Z-100 Computer

by

Thomas R. Brown, Jr.  
B.S., Eastern New Mexico University, 1981

Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL  
December 1986

---

## ABSTRACT

This thesis explores the requirements necessary to develop a graphics support library for the Ada programming language hosted on the Zenith HZ-100 microcomputer. A prototype graphics library is implemented in 8086 assembly language embedded in an Ada package. The library operates with JANUS Ada under the CP/M-86 operating system.

Listings of library routines developed are provided as well as a user's guide and demonstration programs. Potential areas for further investigation and development are suggested.

It is concluded that an Ada graphics library for microcomputers is feasible and practical.

## THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

Some terms used in this thesis are registered trademarks of commercial products. Rather than attempt to cite each occurrence of a trademark, all trademarks appearing in this thesis will be listed below, following the organization holding the trademark:

1. United States Government (Ada Joint Program Office)  
Ada
2. Intel Corporation  
Intel
3. Digital Research Corporation  
CP/M  
CP/M-86
4. Microsoft Corporation  
MS-DOS
5. Zenith Data Systems Corporation  
Zenith  
H/Z-100

## TABLE OF CONTENTS

I.	INTRODUCTION .....	9
	A. BACKGROUND .....	9
	B. PURPOSE .....	10
	C. THESIS ORGANIZATION .....	11
II.	ALGORITHMS .....	12
	A. H Z-100 ARCHITECTURE .....	12
	B. JANUS ADA .....	15
	C. GRAPHICS ALGORITHMS .....	17
	1. Clear Screen (CLS) .....	17
	2. Color Selection .....	18
	3. Video Ram Addressing .....	18
	4. Pixel Display .....	19
	5. Line Drawing .....	19
	6. Circle Drawing .....	23
	7. Color Testing .....	23
	8. Area/Polygon Filling .....	25
	9. Cursor Control .....	26
III.	PERFORMANCE AND EVALUATION .....	28
	A. DEMONSTRATION PROGRAMS .....	28
	1. Program AGTEST1 .....	28
	2. Program AGTEST2 .....	28
	3. Program AGTEST3 .....	28
	4. Program AGTEST4 .....	28
	B. ADA GRAPHICS LIBRARY LIMITATIONS .....	28
	C. H Z-100 HARDWARE LIMITATIONS .....	29
	D. TIMING MEASUREMENTS .....	29

IV.	RECOMMENDATIONS FOR FUTURE DEVELOPMENT .....	31
V.	CONCLUSION .....	32
APPENDIX A:	USER'S GUIDE .....	33
1.	INTRODUCTION .....	33
2.	CLEARING THE SCREEN .....	33
3.	COLOR SELECTION .....	34
4.	COLOR TESTING .....	34
5.	PIXEL SETTING/RESETTING .....	35
6.	LINE DRAWING .....	35
7.	CIRCLE DRAWING .....	35
8.	AREA POLYGON FILLING .....	36
APPENDIX B:	GRAPHICS TEST 1 .....	38
APPENDIX C:	GRAPHICS TEST 2 .....	39
APPENDIX D:	GRAPHICS TEST 3 .....	40
APPENDIX E:	GRAPHICS TEST 4 .....	41
APPENDIX F:	SPECIFICATION PACKAGE .....	42
APPENDIX G:	ASSEMBLY CODE LISTING .....	43
LIST OF REFERENCES .....	64	
BIBLIOGRAPHY .....	65	
INITIAL DISTRIBUTION LIST .....	66	

## LIST OF TABLES

1. COLOR PLANE ADDRESSES .....	15
2. COLOR TABLE .....	16
3. COLOR CONTROL .....	18
4. PERFORMANCE RESULTS .....	30
5. COLOR CODES .....	34

## LIST OF FIGURES

2.1	H/Z-100 Block Diagram .....	13
2.2	Display Matrix .....	14
2.3	Parameter Passing .....	17
2.4	Bresenham's Circle Algorithm .....	24
2.5	Pascal Boundary-Fill Procedure .....	25

## I. INTRODUCTION

### A. BACKGROUND

The Naval Postgraduate School (NPS) utilizes approximately fifty Zenith H/Z-100 microcomputers in the microcomputer laboratories of the Computer Science Department. There were many reasons for choosing this particular computer, foremost of which is the hardware architecture [Ref. 1] and the availability of support software. The H/Z-100's central processing unit (CPU) includes an INTEL 8085 8-bit processor and an INTEL 8088 16-bit processor. The simple architecture and instruction set of the 8085 processor supports the popular CP/M operating system and is compatible with 8080 code. The more complex architecture of the 8088 processor is compatible with 8086 code and includes more internal registers (some usable as either 8 or 16-bit), extended addressing modes, and a more complex memory management scheme using segment registers. The 8088 processor supports the more advanced CP/M-86 and MS-DOS operating systems.

An important feature of the H/Z-100 is its display versatility. The basic H/Z-100 includes an internal monochrome display and allows the addition of an additional external color monitor. The color monitor is of medium resolution with 640 horizontal and 225 vertical pixels (640 X 512 in the interlace mode). Three 64k pages of video RAM memory provide eight colors (or eight intensity levels with a monochrome monitor).

A primary function of the microcomputer laboratory is to support computer science courses providing special emphasis on tactical computer applications. According to Department of Defense policy [Ref. 2], "The Ada programming language shall become the single, common computer programming language for defense mission-critical applications. Effective 1 January 1984 for programs entering full-scale engineering development, Ada shall be the programming language." To assist in meeting this requirement, NPS provides courses which include the use of Ada in the development of tactical program applications programs. Most of these programs are run on the H/Z-100 computers using the JANUS Ada compiler. To date, several validated Ada compilers have been approved for specific computer systems, with many more expected to be approved in the near future. However, as Patrice Wagner points

out [Ref. 3] there has been little measurable response within the computer graphics industry. An improvement in this area can be expected with the acceptance of the Ada Binding to the Graphical Kernel System (GKS) [Ref. 4] by the American National Standards Institute (ANSI) X3H3 committee on graphics standards. However, we cannot sit back and wait for industry to provide all the tools necessary to conduct Ada graphics education and research. Widespread use of Ada can be expected in the near future and with that use there will be increasing requirements for individuals with Ada graphics knowledge. The NPS has an obligation to assist the Navy in meeting those educational requirements.

## B. PURPOSE

It is the intent of this thesis to develop an Ada language graphics programming capability by developing a low level design and partial implementation of an Ada graphics library which can be expanded to include a subset of the Ada language binding to the GKS. Functions to be included will be those primitives necessary for:

- clearing the screen
- setting a pixel
- drawing a line
- selecting a color
- filling polygons
- cursor control

These basic primitives will be implemented using 8086 assembly language embedded in an Ada package. The CP/M-86 operating system and the JANUS Ada compiler will be used for this implementation.

It is expected that the primary use for this software will be in courses which emphasize tactical applications of computers. It is becoming more and more common to find graphical displays in tactical systems. The ability of computers to provide graphical displays which aid in tactical decision making is widely recognized and the list of tactical applications utilizing graphical displays can be expected to grow as faster and better graphics displays are developed.

It is anticipated that this software will assist in gaining an insight into the feasibility of developing a GKS implementation for Ada on a microcomputer. As an immediate benefit, it will aid in the development of Ada graphics programs on the HZ-100 computer.

## C. THESIS ORGANIZATION

Chapter II begins with a brief overview of the architecture of the H/Z-100 computer. The overview is presented to assist the reader in understanding the selection and implementation of the graphics algorithms. Next there is a brief discussion explaining the use of the JANUS Ada compiler and CP/M-86 operating system. Included in this discussion is a description of parameter passing procedures in JANUS Ada. The remainder of Chapter II is devoted to providing a detailed description of the implemented graphics routines.

Chapter III provides a description of the test/demonstration programs listed in Appendices B-E. Also included in this chapter is an evaluation of the H/Z-100 color graphics capability. Shortcomings and system hardware performance are discussed.

Chapter IV includes recommendations for further research and program development using the H/Z-100 computer.

Chapter V is the final chapter and includes the conclusion and general comments pertaining to the use of microcomputers and Ada in graphics programming.

Appendix A is a user's guide which describes the procedures available in the Ada graphics library. Also included are some programming tips on usage of the library procedures and sample procedure calls are provided as examples.

Appendices B-E are program listings of demonstration programs written in Ada. They are provided to demonstrate the use of the Ada graphics library as well as serving as a supplement to the user's guide.

Appendix F is a listing of the specification package for the Ada graphics library. The specification package defines the formats of all externally callable library procedures.

Appendix G is the assembly code listing of all procedures contained in the Ada graphics library.

## II. ALGORITHMS

### A. H/Z-100 ARCHITECTURE

The following overview of the H/Z-100 architecture is presented in order to clarify the method of implementation of specific algorithms. Figure 2.1 is a block diagram of the basic architecture of the H Z-100 computer.

NPS's H/Z-100 computers are in the process of being upgraded to include the Model ZVM-1330 color monitor, 192k of on-board cpu memory and three 64k pages of video RAM.

The display screen is formed by a matrix of 640 horizontal and 225 vertical pixels. Each pixel is mapped to a bit in each of the three color planes (red, green, and blue) in video RAM. Display management is provided by the video processor's CRT controller (CRT-C).

The CRT-C has two modes of operation: the character based mode and the pixel based mode. In the character based mode, the CRT-C is programmed for nine scan lines per character, 80 characters per line and 25 lines per screen. In the pixel based mode, the CRT-C is normally programmed to control a matrix of 640 X 225 pixels.

Mapping of video RAM to the screen is performed by the CRT-C to allow scrolling of the screen and management of displayable nondisplayable data. Mapping of the display to physical addresses in video RAM is organized such that 128 (numbered 0-127) consecutive bytes are allowed for each scan line. However, only 80 of the 128 bytes are used to control display of the 640 pixels per scan line. Bytes 80-127 of each line must not be used or erroneous data may be displayed. Additionally, the 225 displayable scan lines may be considered to be in sets of 16 lines of which only the first nine lines of each set are displayable.

When operating in the character based mode, the CRT-C is programmed to map around the non-displayable video RAM. However, in the pixel based mode, it is necessary to incorporate a mapping algorithm into graphics routines. This means that of the 400 scan lines, only 225 are displayable. In addition, the CRT-C is normally programmed so that the bottom character row (9 scan lines) is zeroed during vertical retrace time. This is done to keep uninitialized data from being displayed during scrolling. This means that only 24 of the 25 character rows or 216 of the 225

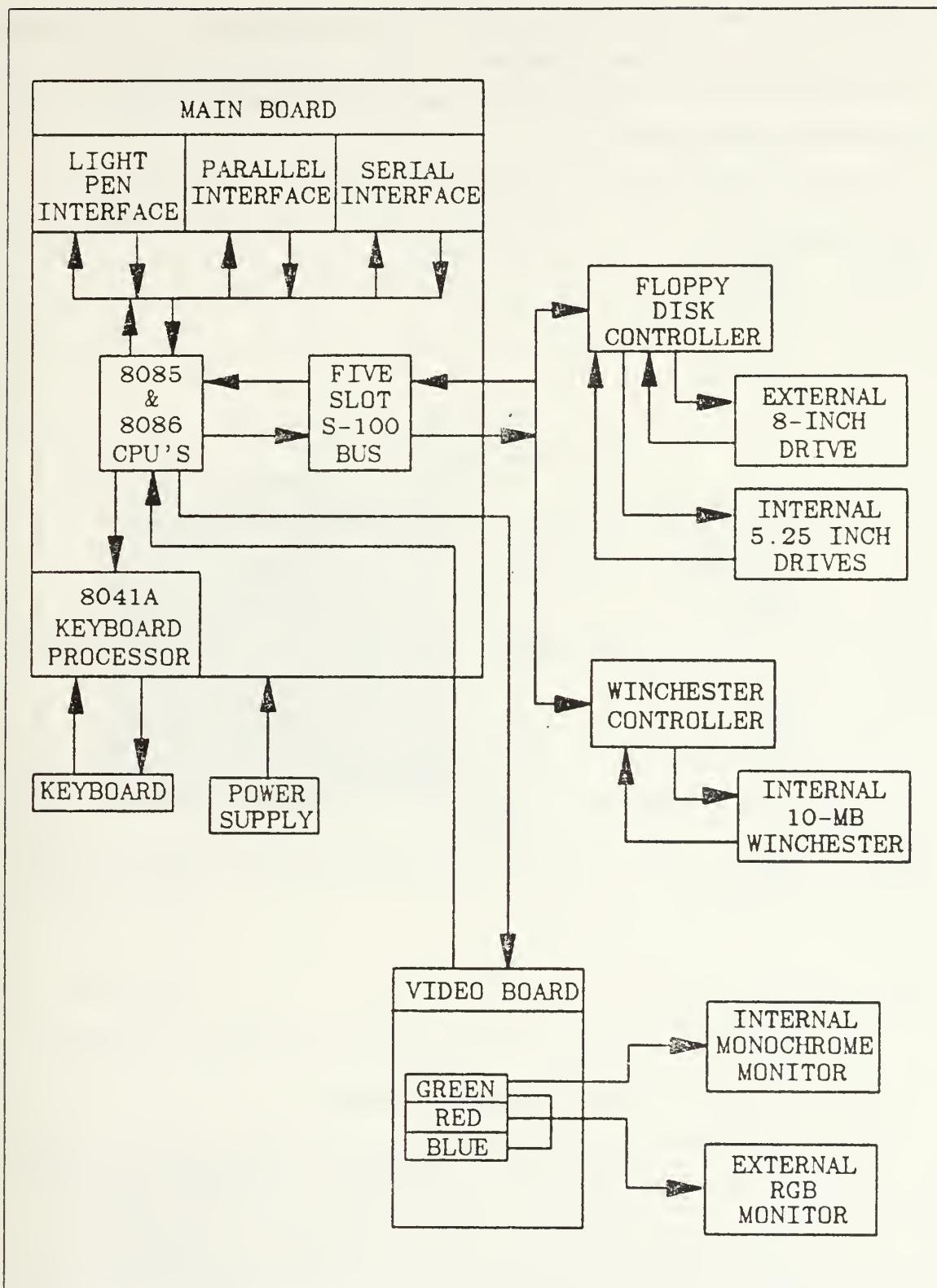


Figure 2.1 H/Z-100 Block Diagram.

displayable scan lines actually display data. The Ada graphics library has been designed to work within these restrictions in order to maintain compatibility with existing H.Z-100 software. Figure 2.2 illustrates the display matrix including the scan line and pixel numbering system.

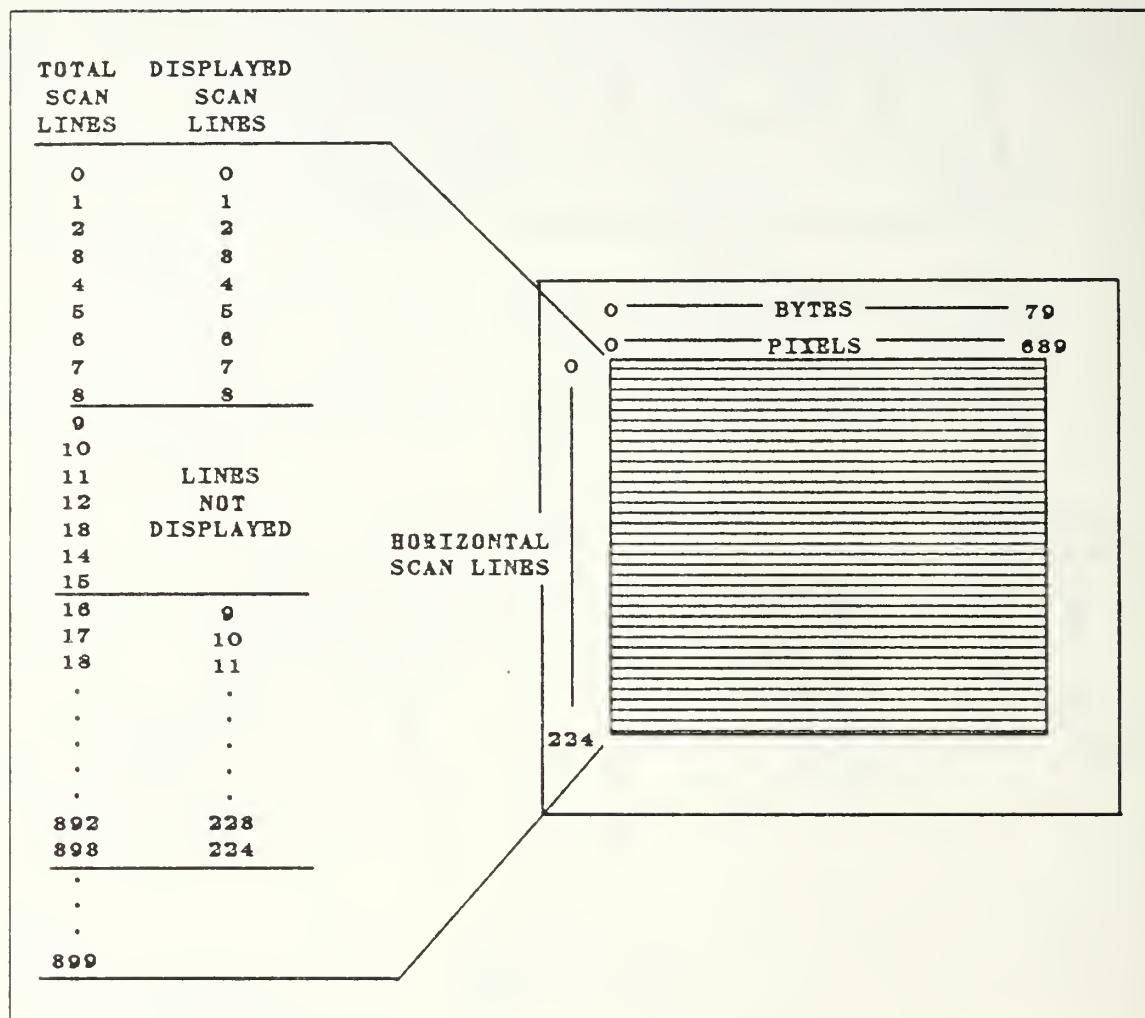


Figure 2.2 Display Matrix.

There are two ways in which to control writing into the individual color planes. The first method is by programming the video control register of the video logic board. With this method, when a write enabled color plane is accessed, all write enabled color planes are simultaneously written to. For example, if all three color planes are write enabled and the green color plane is written to, then the corresponding addresses in the

blue and red color planes will also be written to. However, this feature was found to be unsatisfactory when constructing a graphics picture consisting of multiple colors and adjacent or overlapping objects. Under these conditions, it was discovered that the only color plane which could be guaranteed to contain correct data was the one which was directly written to. Therefore, the algorithms implemented in the Ada graphics library utilize the second method which involves direct control over each of the three color planes. This means that the implemented algorithms must access all three color planes for each pixel that is set. [Ref. 1: pp. 4.30-4.38]

TABLE 1  
COLOR PLANE ADDRESSES

<u>COLOR PLANE</u>	<u>RAM ADDRESSES</u>
blue	OC0000 - OCFFFF
red	OD0000 - ODFFFF
green	OE0000 - OEFFFF

To produce color, the video RAM is divided into three main colors: red, green, and blue. Video RAM memory mapping of the three color planes is provided in Table 1 with all addresses in hexadecimal. The pixel seen on the color monitor is actually composed of three superimposed pixels, one in each color plane. By selecting combinations of the three basic colors, eight different colors may be displayed as indicated by Table 2.

## B. JANUS/ADA

An overview of the JANUS/Ada compiler [Ref. 5] and the CP/M-86 operating system [Ref. 6] relating to the implementation of the Ada graphics library is presented to assist the reader in understanding the methods used to implement the graphics algorithms. The graphics routines are available to an Ada language program by linking to library routine ADAGRAPH.LIB (Appendix F).

ADAGRAPH.LIB is implemented as an Ada specification package. That package contains the specifications of the callable library procedures plus a list of the variables used by the Ada graphics library assembly code. The assembly code is

included in Ada assembly package ADAGRAPH.ASM (Appendix G). The following steps are used to compile, assemble, and link the Ada graphics library.

- (1) JANUS ADAGRAPH.LIB
- (2) JASM86 ADAGRAPH
- (3) JLINK ADAGRAPH

TABLE 2  
COLOR TABLE

<u>GREEN</u>	<u>RED</u>	<u>BLUE</u>	<u>DISPLAY COLOR</u>
0	0	0	black
0	0	1	blue
0	1	0	red
0	1	1	magenta
1	0	0	green
1	0	1	cyan
1	1	0	yellow
1	1	1	white

Parameters are passed in Ada by pushing them onto the system stack. Discrete and access data type parameters of mode IN are passed by value. All other data type parameters and modes are passed by reference. Upon entry to a procedure, the top of the stack contains the return address. Parameters or parameter addresses appear on the stack with the last parameter nearest the top of the stack. Figure 2.3 is an example illustrating the format of a procedure specification and the corresponding location of parameters on the system stack when the procedure is executed.

If the parameters passed are only of mode IN, then the assembly procedure must remove those parameters from the stack and leave only the return address on top of the stack before executing a RET instruction to return from the procedure to the calling program. If the parameter list includes any mode OUT or IN OUT parameters, then the stack must be in the same configuration upon exit from the procedure as it was upon entry.

When it is desired to access parameters on the stack without altering the stack contents, then the BP register should be used. The following steps illustrate how this can be performed.

- (1) MOV BP, SP ;Copy SP register to BP register

```
procedure INQUIRE_COLOR( x_pos, y_pos: in INTEGER;
                           color: out INTEGER);
```

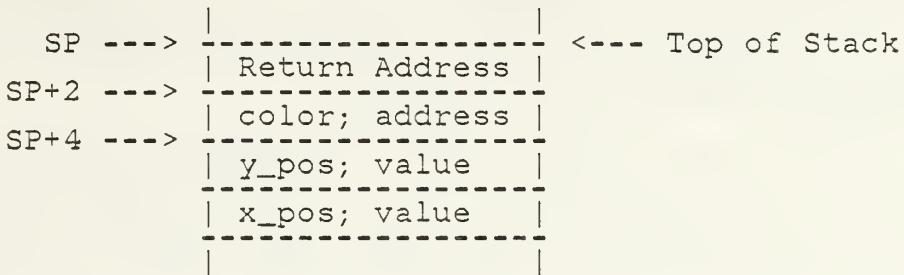


Figure 2.3 Parameter Passing.

- (2) `MOV AX, [BP+2]` ;Move last variable to AX register
- (3) `MOV BX, [BP+1]` ;Move next to last variable to BX

## C. GRAPHICS ALGORITHMS

The following paragraphs provide a detailed explanation of each graphics routine in the Ada graphics library and the algorithms used to implement those routines. Several of the low level subroutines used to implement the library are not available to the user and are therefore not listed in the User's Guide (Appendix A). Only those graphics routines that have an apparent use in an Ada language program were made externally callable.

### 1. Clear Screen (CLS)

The `CLS` routine will clear the screen in one frame time (approximately 16.7 ms for 60 Hz operation). The `CLS` algorithm [Ref. 1: p. 4-46] is described in the following steps:

- (1) Input and save the video status from I/O port D8(hex).
- (2) Blank the screen by outputting 0F(hex) via I/O port D8(hex).
- (3) Output a "0" in bit 3 of the B control port DB(hex). This signals the video controller that the bit planes will be set to zero. This step is performed by executing an input, modify, and output sequence.
- (4) Output a "0" to bit 3 of the A control port D9(hex). This enables the video processor's CLRSCRN signal.
- (5) Wait for one frame period to allow time to reset all of video RAM.
- (6) Output a "1" to bit 3 of port D9(hex). This disables the CLRSCRN signal.

- (7) Restore video status that was saved in step 1 by outputting the saved status via port D8(hex).

## 2. Color Selection

When the color routine is called, it is passed an integer identifying the selected color. In normal operation, once a color has been selected, it remains the system color until changed by another call to the color procedure.

The color procedure uses the color code parameter to perform two basic functions. First, it sets each of the three color plane variables to base addresses which will be used by other procedures to initialize the E segment register for addressing the required color planes. Second, a control word (78 hex) is output to the video control register via I O port D8(hex). The control word disables the simultaneous write capability of the video controller. Table 3 lists the data used to control color selection.

TABLE 3  
COLOR CONTROL

<u>Color Code</u>	<u>Color</u>	<u>Var. 1</u>	<u>Var. 2</u>	<u>Var. 3</u>
0	white	C000	D000	E000
1	cyan	C000	E000	E000
2	magenta	C000	D000	D000
3	blue	C000	C000	C000
4	yellow	D000	E000	E000
5	green	E000	E000	E000
6	red	D000	D000	D000
7	black	-----	-----	-----

In nornial operation, control word bits 0, 1, 2, 7 are set to "0" bit 3 is set to "1" and bits 4-6 are used to control the simultaneous write capability of video RAM. The color routine does not affect the contents of the E segment register, but simply initializes variables which will be used to modify the E segment register as required. This is done to maintain compatibility with other H Z-100 software which uses the E segment register, e.g., the standard I.O library.

## 3. Video Ram Addressing

Mapping of the video to the screen is accomplished in two steps. The first is performed by the ADJ\_SL procedure which accepts a Y position in the range 0-215

and maps that position to a displayable scan line. This mapping is described by the equation Scan\_Line\_Number = Y+(Y Mod 16)\*7. This function is implemented by a simple counter which adds seven to the scan line count for each block of 16 lines. Step two is performed by the REL\_VID\_ADDR procedure. This procedure uses the X position and scan line number to calculate the corresponding relative byte address in video RAM. This is a relative address since it is independent of the color plane. Relative byte addresses are calculated using the formula:

$$\text{Relative_Address} = Y * 128 + X \bmod 8.$$

Prior to address calculation, error checking is performed to insure that:

$$0 \leq X \leq 639 \text{ and } 0 \leq \text{Scan_Line_Number} \leq 376.$$

#### 4. Pixel Display

Displaying of individual pixels is performed by procedure SET\_PIXEL. Procedure SET\_PIXEL accepts an (X,Y) coordinate and performs the following steps:

- (1) Calls procedure ADJ\_SL to map the y coordinate to a displayable scan line.
- (2) Calls procedure REL\_VID\_ADDR to get the relative byte address.
- (3) Calculates the relative bit position within a byte based on the x coordinate.
- (4) Initializes segment E to provide the base address for the desired color plane.
- (5) Sets the selected pixel by writing to the relative address.
- (6) Repeats steps 4 and 5 for each of the three color plane variables.

#### 5. Line Drawing

Line drawing may be performed by either procedure DRAW\_LINE or procedure DRAW\_MLINE. The two procedures use the same algorithm for line drawing with the difference being in the way that intersecting lines are displayed. Procedure DRAW\_LINE always displays the most recently drawn line on top while procedure DRAW\_MLINE mixes the colors of crossing lines at the point of intersection. The line drawing algorithm is an adaptation of a general integer digital differential analyzer (integer DDA) algorithm described by Marc Berger [Ref. 7: pp. 41-45]. The general integer DDA has been expanded from four to six cases and a smoothing function has been included. The two additional cases were added to handle the special cases where a line is either vertical or horizontal. The smoothing function was added to improve symmetry in the staircase effect which is inherent with raster scan displays.

The integer DDA algorithm is an iterative process which operates by taking unit steps along the X and/or Y axis beginning at line start and continuing to line end.

The direction of each step is determined by an error variable which identifies whether the present position is above or below the ideal line. After each step, the error variable is updated based on the direction of movement. The initial value of the error variable is determined by the smoothing function which biases the error variable so that the first pixel step in one axis is delayed based on the slope of the line. Without this bias the DDA algorithm frequently makes an erroneous first move. An example of an extreme case illustrates this point. For example, if a near horizontal line with a single pixel change in Y is drawn by the unbiased algorithm the pixel step will occur at line start. However, in the biased algorithm the pixel step will occur at the approximate midpoint of the line. This provides an obvious enhancement in symmetry to a staircase line.

Implementation of the six cases in the line drawing algorithm assumes that the input coordinates are ordered so that  $Y\_START \leq Y\_END$ . This ordering is enforced by the line drawing procedure prior to plotting a line.

In the description of the six cases which follows, initial values of X and Y are respectively  $X\_START$  and  $Y\_START$  and the following definitions apply.

- X                X coordinate
- Y                Y coordinate
- $X\_START$     X coordinate of line start
- $Y\_START$     Y coordinate of line start
- $X\_END$         X coordinate of line end
- $Y\_END$         Y coordinate of line end
- DX               $X\_END - X\_START$
- DY               $Y\_END - Y\_START$
- E                error

(1)  $DY = 0$ .

This is a horizontal line.

```
initialize
  X:=X_START
  Y:=Y_START
end initialize
repeat until (X=X-END)
  X:=X+1
  plot(X,Y)
```

```
    end repeat
```

(2)  $DY \leq DX$ ,  $DX > 0$ , and  $DY > 0$ .

This is a line with positive slope between 0 and 1.

```
initialize
```

```
    X:=X_START
```

```
    Y:=Y_START
```

```
    E:=DX/(DY+1)
```

```
end initialize
```

```
repeat until (X=X_END & Y=Y_END)
```

```
    if (E<0) then
```

```
        X:=X+1
```

```
        E:=E+DY
```

```
    otherwise
```

```
        X:=X+1
```

```
        Y:=Y+1
```

```
        E:=E-DX+DY
```

```
    end if
```

```
end repeat
```

(3)  $DX < DY$ ,  $DX > 0$ , and  $DY > 0$ .

This is a line with positive slope greater than 1.

```
initialize
```

```
    X:=X_START
```

```
    Y:=Y_START
```

```
    E:=DY/(DX+1)
```

```
end initialize
```

```
repeat until (X=X_END & Y=Y_END)
```

```
    if (E<0) then
```

```
        X:=X+1
```

```
        Y:=Y+1
```

```
        E:=E-DX+DY
```

```
    otherwise
```

```
        Y:=Y+1
```

```
        E:=E-DX
```

```
    end if
```

```
end repeat
```

(4)  $DX = 0$ .

This is a vertical line.

```
initialize
    X:=X_START
    Y:=Y_START
end initialize
repeat until (Y=Y_END)
    Y:=Y+1
end repeat
```

(5)  $DY \geq ABS(DX)$ ,  $DX < 0$ , and  $DY < 0$ .

This is a line with negative slope between -1 and 0.

```
initialize
    X:=X_START
    Y:=Y_START
    E:=DX/(DY+1)
end initialize
repeat until (X=X_END & Y=Y_END)
    if (E<0) then
        X:=X-1
        E:=E+DY
    otherwise
        X:=X-1
        Y:=Y+1
        E:=E+DX+DY
    end if
end repeat
```

(6)  $ABS(DX) < DY$ ,  $DX < 0$ , and  $DY < 0$ .

This is a line with negative slope less than -1.

```
initialize
    X:=X_START
    Y:=Y_START
    E:=DY/(DX+1)
end initialize
repeat until (X=X_END & Y=Y_END)
    if (E<0) then
```

```

X: =X-1
Y: =Y+1
E: =E+DX+DY
otherwise
    y: =Y+1
    E: =E+DX
end if
end repeat

```

## 6. Circle Drawing

Circle drawing is performed by passing the (X,Y) coordinate of the circle center and a radius to procedure CIRCLE. The algorithm executed by the circle drawing routine is an implementation of Bresenham's circle algorithm described by Hearn and Baker [Ref. 8: pp. 67-69]. In this implementation, the algorithm has been modified to include a correction factor to compensate for the X:Y pixel ratio of the raster display.

Bresenham's algorithm takes advantage of the symmetry of a circle in providing an efficient incremental method for plotting a circle. In this algorithm, eight points are plotted for each parameter calculation. Although multiplications are required in parameter calculations, the multiplier is a power of 2, so all multiplications can be reduced to a less costly shift operation. Figure 2.4 is a flow chart representation of the implemented version of Bresenham's algorithm.

## 7. Color Testing

The color of an individual pixel may be determined by passing an (X,Y) coordinate to procedure INQUIRE\_COLOR. This procedure will determine the pixel color and return an integer value defining the color code. Color codes are listed in Table 2 .

The color testing algorithm uses the (X,Y) coordinate to calculate a relative byte address. It then uses the X coordinate to generate a bit mask to identify the specific bit location within a byte. The relative byte address and bit mask are then used to test the corresponding address in each of the three color planes. This test identifies the color components contained in that pixel and a color code is returned to the calling program.

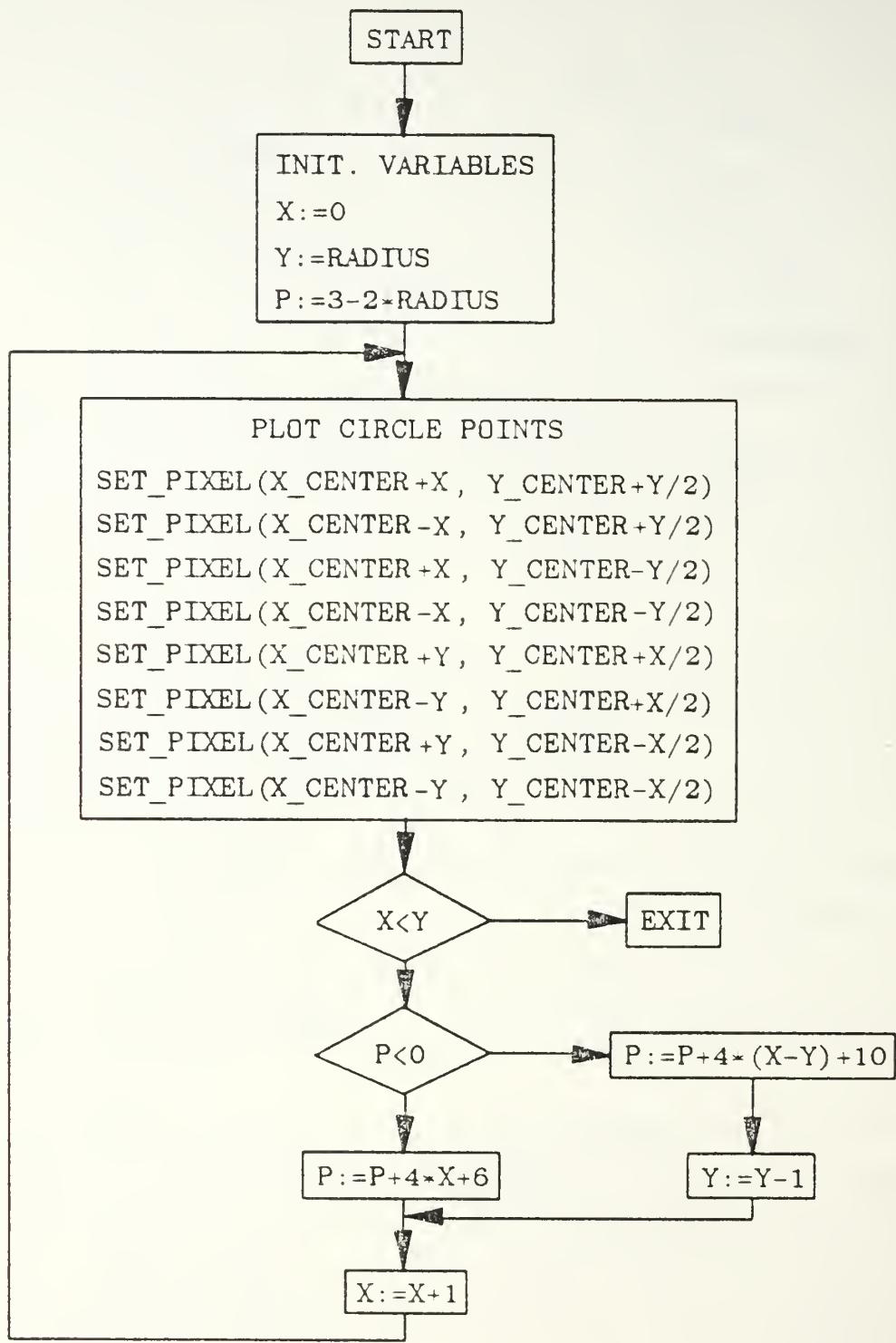


Figure 2.4 Bresenham's Circle Algorithm.

## 8. Area/Polygon Filling

Filling may be accomplished by calling either the procedure BOUNDARY\_FILL or procedure AREA\_FILL. Both of these procedures use algorithms based on a 4-connected boundary-fill algorithm described by Hearn and Baker [Ref. 8: pp. 92-93]. The 4-connected boundary-fill algorithm accepts as inputs the (X,Y) coordinate of an interior point of an area bounded by the specified boundary color and a fill color. Starting at the initial (X,Y) coordinate, each of the four neighboring points [(X+1,Y), (X-1,Y), (X,Y+1), (X,Y-1)] are tested. If the point is of a different color than the boundary, then it is set to the fill color and neighbors of the new point are tested. This procedure continues until all points within the bounded area have been tested. Figure 2.5 is a recursive Pascal 4-connected boundary-fill procedure from Hearn and Baker [Ref. 8: p. 93], which forms the basis for the following procedures.

```
procedure boundary_fill(x, y, fill_color,
                        boundary_color: integer);
var present_color: integer;
begin
  present_color := inquire_color(x, y);
  if (present_color <> boundary_color) and
    (present_color <> fill_color) then
    begin
      set_pixel(x, y, fill_color);
      boundary_fill(x+1, y, fill_color, boundary_color);
      boundary_fill(x-1, y, fill_color, boundary_color);
      boundary_fill(x, y+1, fill_color, boundary_color);
      boundary_fill(x, y-1, fill_color, boundary_color);
    end;
end;
```

Figure 2.5 Pascal Boundary-Fill Procedure.

Procedure BOUNDARY\_FILL is a recursive routine whose input parameters include a beginning (X,Y) coordinate, a fill color, and a boundary color. This routine uses the 4-connected fill algorithm to fill an area bounded by the specified boundary color.

Procedure AREA\_FILL is a recursive routine whose input parameters include only a beginning (X,Y) coordinate and a fill color. This routine uses the 4-connected fill algorithm to fill a contiguous area of the same color as that at the beginning (X,Y) coordinate.

The actual implementation of each of the two fill procedures is subdivided into two procedures. The first procedure initializes constant variables and then calls the second procedure. The second procedure is used for successive recursive calls. This technique minimizes the number of parameters which must be passed on each successive recursive call.

An individual call to either of the fill procedures can fill an area of at most a few square inches. Attempting to fill a larger area may result in a stack overflow error. This is an implementation limitation which can be circumvented by subdividing a large area into smaller areas, each of which may be filled separately. An exact upper limit on the size of an area which may be filled by a single call to a fill procedure is difficult to predict since it depends on the starting point within a specified area. Additionally, area filling is an inherently slow process due to the large number of calculations involved.

## 9. Cursor Control

The "+" symbol is used to represent a graphics cursor. Cursor positioning is controlled by procedures SET\_CURS and RESET\_CURS. Procedure SET\_CURS accepts an (X,Y) coordinate and displays a cursor centered at that coordinate. Procedure RESET\_CURS accepts an (X,Y) coordinate as input and erases a block of addresses surrounding that coordinate. Both procedures affect only the color planes that are enabled by the current system color.

Management of the cursor display and positioning is a responsibility of the user program. A cursor is not automatically displayed nor is there a limit on the number of cursor symbols which may be displayed concurrently.

The cursor symbol is composed of nine pixels with the center of the cursor being the reference point for positioning. In order to be able to position the cursor at any (X,Y) screen coordinate, it is necessary to consider individual components of the cursor. The vertical dimension (5 pixels) of the cursor spans five different relative byte addresses in video RAM. Additionally, the horizontal dimension (5 pixels) of the cursor may require an additional byte of memory. Whether an additional byte is required depends on the relative position within a byte of the cursor center. If the cursor center is near either end of a byte, then either the next lower or next higher byte from cursor center will also be required to display the cursor.

The set cursor algorithm uses the (X,Y) coordinate to calculate five relative byte addresses. These addresses represent a block on the screen which will contain the

cursor. The algorithm then uses the X coordinate to determine which of the eight bit positions within a byte represents cursor center. Then one of eight possible bit patterns is generated to represent the cursor. Resetting a cursor requires less program steps since a block of seven relative byte addresses are erased without regards to the exact position of the cursor within the block.

### III. PERFORMANCE AND EVALUATION

#### A. DEMONSTRATION PROGRAMS

Four demonstration programs are provided in Appendices B-E. Those programs along with the user's guide in Appendix A, will aid the user in writing graphics programs using the Ada language.

##### 1. Program AGTEST1

Program AGTEST1 draws a test pattern demonstrating the use of color selection, line drawing, circle drawing, and filling. This test uses ADAGRAPH procedures COLOR, SET\_CURS, CIRCLE, DRAW\_LINE, BOUNDARY\_FILL, and AREA\_FILL.

##### 2. Program AGTEST2

Program AGTEST2 draws a pattern consisting of two sets of curves and a color wheel illustrating the eight available colors. AGTEST2 uses ADAGRAPH procedures COLOR, DRAW\_LINE, DRAW\_MLINE, CIRCLE, and AREA\_FILL.

##### 3. Program AGTEST3

Program AGTEST3 demonstrates interactive control of the graphics cursor. The user is asked repetitively to enter an (X,Y) coordinate. The program then displays a cursor centered at that coordinate and erases the previous cursor.

##### 4. Program AGTEST4

Program AGTEST4 begins by drawing a circle of the approximate maximum area (approximately seven square inches) that can be filled by a single call to one of the fill procedures. It then fills the circle and goes on to demonstrate how polygons may be drawn by setting/resetting individual pixels. It also demonstrates filling an area containing an object. AGTEST4 uses ADAGRAPH procedures COLOR, SET\_PIXEL, RESET\_PIXEL, CIRCLE, BOUNDARY\_FILL, and AREA\_FILL.

#### B. ADA GRAPHICS LIBRARY LIMITATIONS

The Ada graphics library presented in this thesis was developed as a prototype. Limitations of the library procedures should not cause significant problems to the user as long as the guidelines presented in the user's guide (Appendix A) are followed. The only known procedures which can cause a catastrophic failure if limits are exceeded are the fill procedures. The fill procedures can fill at most a contiguous area of

approximately seven square inches. Even filling a seven square inch area may cause an error if the starting point is not near the center of the area. However, if the user will limit the size of contiguous areas to be filled to approximately 3-4 square inches, then the probability of failures is very low. The reason for this limitation is that the fill routines are implemented as recursive procedures. As a recursive procedure, each level of recursion requires that three more parameters be pushed onto the system stack. Attempting to fill too large an area simply results in a stack overflow.

Another area of inconvenience for the user may occur in attempting to use the graphics library along with other libraries, e.g., the standard I/O library. The standard I/O library procedure **GET** automatically causes scrolling of the display screen by one character row each time it is executed. This is an obvious problem when used in concurrence with a fixed position graphics display.

### C. H/Z-100 HARDWARE LIMITATIONS

A potential problem area for the user is due to the limited number of colors (8) available for display. This may be particularly inconvenient when writing interactive programs using the graphics cursor or any other symbols which are to be moved within the display. Management of movable objects can become very costly in terms of both processing time and amount of program code. The H/Z-100, while comparable to many other microcomputers, is still quite slow in displaying a complex graphics picture. One method of optimizing the management of moving objects in the display is to restrict those objects to a dedicated color plane. If this is done, then updating the position of a moved object can be done without disturbing the graphics objects defined in the other color planes. A disadvantage of this approach is that there are only three color planes available to begin with and by dedicating one color plane to something like a cursor reduces the colors available for other objects from eight to four.

### D. TIMING MEASUREMENTS

Table 4 provides a summary of timing measurements performed to determine average graphics processing times for the most critical operations. Times represented in the table are average times that one would expect to encounter in a call to Ada graphics library procedures when drawing a graphics picture.

The fill procedures are quite slow due to the large number of steps involved in testing and setting each pixel and the additional overhead related to a recursive procedure. The timing differences between drawing horizontal vertical lines and

TABLE 4  
PERFORMANCE RESULTS

<u>Operation</u>	<u>Time per Pixel (ms)</u>
Fill	3
Draw Line	
Horiz./Vert.	.54
Diagonal	.64
Set/Reset Pixel	.58

diagonal lines is due to the two additional cases which were implemented in the line drawing algorithm. Those cases were added to handle the special cases where a line is either vertical or horizontal. In those cases, since the slope of the line is not used in plotting the line, less calculations are required than when plotting a diagonal line.

Setting resetting of individual pixels by all of the graphics procedures is slowed by the overhead in address calculation of the bit mapped display. This is primarily a weakness in the design of the video processor of the H/Z-100. However, it would be interesting to see if a significant speedup could be realized if a lookup table was used to aid in pixel addressing instead of a pure mathematical addressing algorithm.

#### IV. RECOMMENDATIONS FOR FUTURE DEVELOPMENT

Any future additions modifications to the Ada graphics library should consider the following:

- (1) The feasibility of implementing a nonrecursive fill routine.
- (2) Development and implementation of different I O procedures that are more compatible with a graphics display to replace those in the standard I O library. In particular, these procedures should allow placement of alphanumeric symbols at any screen coordinate, not just the predefined character positions. Any scrolling of the screen should also be strictly under the control of the user program.
- (3) The possibility of optimizing some of the existing procedures. For example, perhaps the mapping from a Y coordinate to a displayable scan line could be performed more efficiently by a lookup table. But, would the time savings justify the additional memory required?
- (4) The feasibility of developing and implementing a subset of the GKS standard as a level of abstraction above the primitives provided in the Ada graphics library.
- (5) The feasibility of networking two or more H Z-100 computers to provide interactive operator communication on one system while providing a graphics display on another.
- (6) The feasibility of modifying the structure of the Ada graphics library so that it is compatible with the MS-DOS operating system hosted on the H/Z-100.

## V. CONCLUSION

The implementation of the Ada graphics library on the H/Z-100 computer has proven the feasibility of developing Ada graphics programs on a microcomputer. The H/Z-100 is certainly suitable for educational purposes but its ability to meet real time tactical requirements is limited. This limitation is not unique to the H/Z-100, but is a general limitation of most microcomputers available today. We can expect this limitation to ease significantly over the next several years as low cost multiprocessor systems are developed.

The Ada graphics library was implemented as low level primitives necessary to interface with and control the H/Z-100 hardware. The library functions were not designed in accordance with any recognized standards. However, the functions were designed with graphics standards in mind. The implementation of a higher level GKS standard graphics library would be able to use most of the present Ada graphics library primitives to interface with the H/Z-100 hardware. The implementation of a GKS standard as a level above the machine dependent Ada graphics library would assist in making any developed Ada language graphics programs transportable to other computers. The benefits which may be realized from a standard interface to a language are obvious with the high costs of developing software. Although the architectural limitations of the H/Z-100 are not compatible with a full implementation of the GKS standard, the educational benefits that could be realized from even an implementation of a subset of the GKS standard warrants further investigation.

The limited capabilities of the H/Z-100 may limit its suitability for many operational tactical applications, however, it can be a useful system for program development. With the support of the Ada graphics library, the H/Z-100 can assist in performing further research into such tactical programming applications as the Navy Tactical Data System (NTDS). The ability to perform research in this area could be further enhanced by the development of a GKS standard graphics library for the H/Z-100 computer.

## APPENDIX A

### USER'S GUIDE

#### 1. INTRODUCTION

Twelve graphics procedures are available to the user. These procedures are included in **ADAGRAPH.LIB** which is callable from the Ada programming language. Appendices B-E provide four example programs demonstrating the linkage and calling procedures necessary to use the Ada graphics library. Procedures available to the user are:

- (1) **CLS**
- (2) **COLOR(color\_code: in INTEGER)**
- (3) **INQUIRE\_COLOR(x\_coord, y\_coord: in INTEGER;**  
                        **color\_code: out INTEGER)**
- (4) **SET\_PIXEL(x\_coord, y\_coord: in INTEGER)**
- (5) **RESET\_PIXEL(x\_coord, y\_coord: in INTEGER)**
- (6) **DRAW\_LINE(x\_start, y\_start, x\_end, y\_end:**  
                        **in INTEGER)**
- (7) **DRAW\_MLINE(x\_start, y\_start, x\_end, y\_end:**  
                        **in INTEGER)**
- (8) **CIRCLE(x\_center, y\_center, radius: in INTEGER)**
- (9) **BOUNDARY\_FILL(x\_coord, y\_coord, fill\_color,**  
                        **boundary\_color: in INTEGER)**
- (10) **AREA\_FILL(x\_coord, y\_coord, fill\_color: in INTEGER)**
- (11) **SET\_CURS(x\_coord, y\_coord: in INTEGER)**
- (12) **RESET\_CURS(x\_coord, y\_coord: in INTEGER)**

Following the description of each function is an example of the Ada language call to the described procedures. It should be noted that for all procedures that require an (X,Y) coordinate that the allowable range of X is 0-639 and the allowable range of Y is 0-216.

#### 2. CLEARING THE SCREEN

Most graphics programs will require clearing the display screen before displaying graphics data. This is best performed by calling procedure **CLS**. This procedure takes

advantage of a built-in hardware feature which allows resetting all of video RAM in one frame period (approximately 16.7 ms).

-- Clear the screen

CLS;

### 3. COLOR SELECTION

The HZ-100 has the capability of displaying up to eight different colors. Color selection is performed by calling procedure COLOR and passing a color code parameter identifying the desired color. Table 5 lists the colors available and their respective color codes. Black is not listed as a color option since it is the only color which is displayed by resetting a pixel, i.e., writing a "0" to that pixels corresponding addresses in video RAM. All other colors are displayed by writing a "1" in the appropriate relative address of the color planes required to produce the desired color. If a pixel is to be reset to black then the RESET\_PIXEL procedure should be used.

--Set system color to green

COLOR(5);

TABLE 5  
COLOR CODES

<u>COLOR_CODE</u>	<u>COLOR</u>
0	white
1	cyan
2	magenta
3	blue
4	yellow
5	green
6	red

### 4. COLOR TESTING

To determine the color to which any particular pixel has been set, use procedure INQUIRE\_COLOR. Input parameters to this procedure are the (X,Y) coordinate of the selected pixel. The procedure returns the color code (Table 5) of the pixel located at that coordinate.

--Get color of pixel at (X,Y) coordinate (50,60)

```
INQUIRE_COLOR(59, 60, color);
```

## 5. PIXEL SETTING/RESETTING

Procedures SET\_PIXEL and RESET\_PIXEL are provided for controlling individual pixels. Procedure SET\_PIXEL accepts an (X,Y) coordinate as input parameters and sets the corresponding pixel to the current system color. Procedure RESET\_PIXEL accepts an (X,Y) coordinate as input parameters and resets the corresponding pixel to black.

```
--Set pixel at location (70,50) to current system color
```

```
SET_PIXEL(70, 50);
```

```
--Reset pixel at location (50,50) to black
```

```
RESET_PIXEL(50, 50);
```

## 6. LINE DRAWING

Procedures DRAW\_LINE and DRAW\_MLINE are provided for drawing lines. Both procedures accept as input parameters the (X,Y) coordinates of the end points of a line. A line of the current system color is then drawn connecting those end points. If procedure DRAW\_LINE is used, then intersecting lines will be displayed with the last line drawn on top. If procedure DRAW\_MLINE is used for drawing lines then the color at the point of intersection of intersecting lines is the combined color of the individual lines.

```
--Draw a line from coordinate (100,50) to
```

```
--coordinate (200,75). This line will be
```

```
--drawn on top of any line it intersects.
```

```
DRAW_LINE(100, 50, 200, 75);
```

```
--Draw a line from coordinate (100,25) to
```

```
--coordinate (10,15). This line will mix
```

```
--colors at the point of intersection with
```

```
--any lines that it intersects.
```

```
DRAW_MLINE(100, 25, 10, 15);
```

## 7. CIRCLE DRAWING

Procedure circle will draw a circle of the present system color. Input parameters to this procedure include an (X,Y) coordinate identifying the circle's center position and a radius length measured in units based on the number of pixels (640) in the X axis

of the video display. The circle drawing algorithm draws a circle with automatic corrections made based on the x:y linear pixel ratio (2:1) of the color monitor. i.e., the circle radius is twice as many pixels in the X axis as it is in the Y axis.

--Draw a circle of radius 50 units and  
--centered at coordinate (300, 100).  
CIRCLE(300, 100, 50);

## 8. AREA/POLYGON FILLING

Procedures BOUNDARY\_FILL and AREA\_FILL are available to perform filling operations. The user is cautioned that the filling algorithm has an upper limit on the size of an area (approximately seven square inches) which may be filled by a single call to either of the fill procedures. Larger areas may be filled by partitioning the larger area and filling the individual partitions. The user can generally avoid problems by limiting all fills to a contiguous area of not more than 3-4 square inches.

Procedure BOUNDARY\_FILL accepts as input parameters an (X,Y) coordinate identifying the starting point, a fill color code, and a boundary color code (Table 5). The procedure begins filling from the starting (X,Y) coordinate and sets all pixels within the defined boundary to the designated fill color. The boundary must be a single color defined by the boundary color code.

Procedure AREA\_FILL accepts as input parameters an (X,Y) coordinate identifying the starting point and a fill color code (Table 5). The procedure starts at the input (X,Y) coordinate and sets all pixels in a contiguous area which are the same color as the pixel at the (X,Y) starting coordinate to the specified fill color. This procedure can fill an area which is bounded by different colors since filling is based on the color of the area to be filled.

--Beginning at coordinate (50,75), fill an area  
--with blue that has a red boundary.  
BOUNDARY\_FILL(50, 75, 3, 6);  
--Fill a contiguous area with green. An internal  
--point in that area is coordinate (100,100).  
AREA\_FILL(100, 100, 5);

## I. CURSOR CONTROL

Procedures SET\_CURS and RESET\_CURS are provided for cursor control. The graphics cursor controlled by these procedures is a "+". The center of the cursor is

used as a reference point for cursor placement. All management of cursor display is the responsibility of the user. The cursor is simply a special graphics symbol which the user may display and erase. The number of cursor symbols which may be displayed at any point in time is determined solely by the user's program.

Procedure SET\_CURS accepts as input an (X,Y) coordinate and displays a cursor symbol of the present color at that coordinate. Procedure RESET\_CURS accepts as input an (X,Y) coordinate and resets a block of relative memory addresses centered at the corresponding (X,Y) coordinate. The color planes affected are determined by the present system color. It is suggested that if the user desires to use the cursor as a background symbol then the cursor color should be restricted to a single color plane (red, green, or blue) that is dedicated to cursor display. If this is not done then a management scheme must be implemented in the user program to maintain the integrity of non-cursor graphics data when setting resetting the cursor.

--Display a green cursor at coordinate (150,100).

COLOR(5);

SET\_CURS(150, 100);

--Erase a green cursor at coordinate (50,75).

COLOR(5);

RESET\_CURS(50, 75);

## APPENDIX B

### GRAPHICS TEST 1

```
WITH IO, UTIL, ADAGRAPH;
PACKAGE BODY AGTEST1 IS
USE IO, UTIL, ADAGRAPH;
--THIS PROGRAM DRAWS A TEST PATTERN TO TEST COLOR SELECTION,
--CURSOR SETTING, CIRCLE DRAWING, LINE DRAWING, AREA FILLING,
--AND BOUNDARY FILLING
--
x_pos, y_pos : integer;
quit : character;
begin
    CLS;
    x_pos := 320;
    y_pos := 108;
    color(5); --GREEN
    set_curs(300, 135);
    color(3); --BLUE
--DRAW A CIRCLE
    circle(300, 102, 142);
    color(6); --RED
-- DRAW A RECTANGLE
    draw_line(158, 31, 442, 31);
    draw_line(442, 31, 442, 173);
    draw_line(442, 173, 158, 173);
    draw_line(158, 173, 158, 31);
--DRAW A CIRCLE AND FILL IT
    circle(300, 102, 40);
    area_fill(300, 102, 3);
--DRAW AN IRREGULAR POLYGON AND FILL IT
    draw_line(20, 20, 80, 22);
    draw_line(80, 22, 84, 50);
    draw_line(84, 50, 17, 43);
    draw_line(17, 43, 20, 20);
    boundary_fill(50, 35, 6, 6);
--DRAW A TRIANGLE AND FILL IT
    draw_line(50, 100, 80, 130);
    draw_line(80, 130, 20, 130);
    draw_line(50, 100, 20, 130);
    area_fill(50, 120, 5);
    color(2); --MAGENTA
--DRAW A RECTANGLE
    draw_line(10, 10, 590, 10);
    draw_line(590, 10, 590, 205);
    draw_line(590, 205, 10, 205);
    draw_line(10, 205, 10, 10);
    color(5);
--DRAW A RECTANGLE WITH DIAGONAL LINES
    draw_line(200, 52, 400, 52);
    draw_line(400, 52, 400, 152);
    draw_line(400, 152, 200, 152);
    draw_line(200, 152, 200, 52);
    draw_line(200, 52, 400, 152);
    draw_line(200, 152, 400, 52);
    get(quit);
end AGTEST1;
```

## APPENDIX C

### GRAPHICS TEST 2

```
WITH IO, UTIL, ADAGRAPH;
PACKAGE BODY AGTEST2 IS
USE IO, UTIL, ADAGRAPH;
--
--THIS PROGRAM EXERCISES THE LINE DRAWING, CIRCLE,
--AND AREA FILLING PROCEDURES TO PRODUCE A PICTURE
--WITH COLORED CURVES AND A COLOR WHEEL
--
i, x, y, y1, y2, pcol : integer;
quit : character;
begin
  CLS;
  y := 0;
  y1 := 0;
  color(6);
  --LOOP TO DRAW CURVE 1
  for i in 0..63 loop
    x := i * 10;
    y2 := 189 - y1;
    draw_mline(x, y, 0, y2);
    y := y + 2;
    y1 := y1 + 3;
  end loop;
  y := 0;
  y1 := 0;
  color(1);
  --LOOP TO DRAW CURVE 2
  for i in 0..63 loop
    x := 630 - (i * 10);
    y2 := 189 - y1;
    draw_mline(x, y, 630, y2);
    y := y + 2;
    y1 := y1 + 3;
  end loop;
  --DRAW A COLOR WHEEL
  color(0); --WHITE
  circle(320, 150, 100);
  draw_line(320, 100, 320, 200);
  draw_line(220, 150, 420, 150);
  draw_line(249, 115, 391, 185);
  draw_line(391, 115, 249, 185);
  area_fill(355, 115, 0); --COLOR 0 = WHITE
  area_fill(391, 140, 1); --COLOR 1 = CYAN
  area_fill(391, 170, 2); --COLOR 2 = MAGENTA
  area_fill(330, 185, 3); --COLOR 3 = BLUE
  area_fill(310, 185, 4); --COLOR 4 = YELLOW
  area_fill(249, 160, 5); --COLOR 5 = GREEN
  area_fill(249, 130, 6); --COLOR 6 = RED
  get(quit);
end AGTEST2;
```

## APPENDIX D

### GRAPHICS TEST 3

```
WITH IO, UTIL, ADAGRAPH;
PACKAGE BODY AGTEST3 IS
USE IO, UTIL, ADAGRAPH;
--
--THIS PROGRAM IS USED TO TEST SETTING AND RESETTING
--OF A GRAPHICS CURSOR. THE PROGRAM REQUESTS CURSOR
--POSITION INPUTS, ERASES THE PREVIOUS CURSOR, AND
--DRAWS A CURSOR AT THE INPUT (X,Y) COORDINATE
--
i : integer;
x_pos, y_pos, x_old, y_old : integer;
begin
    CLS;
    x_old := 0; --INITIALIZE X & Y
    y_old := 0;
    for i in 1..50 loop
        put("ENTER X POSITION ");
        get(x_pos);
        put("ENTER Y POSITION ");
        get(y_pos);
        color(5); --GREEN
        reset_curs(x_old, y_old);
        set_curs(x_pos, y_pos);
        x_old := x_pos;
        y_old := y_pos - 18;
    end loop;
end AGTEST3;
```

## APPENDIX E

### GRAPHICS TEST 4

```
WITH IO, UTIL, ADAGRAPH;
PACKAGE BODY AGTEST4 IS
USE IO, UTIL, ADAGRAPH;
--THIS PROGRAM IS USED TO DISPLAY A CIRCLE OF THE APPROXIMATE
--MAXIMUM AREA THAT CAN BE FILLED BY A SINGLE CALL TO ONE OF
--THE FILL ROUTINES. IT THEN DEMONSTRATES FILLING AND
--DRAWING OF POLYGONS USING ONLY THE SET_PIXEL AND RESET_PIXEL
--PROCEDURES.
x, y : INTEGER;
quit : character;
begin
    CLS;
    --SELECT COLOR
    color(0);      --WHITE
    --DRAW A CIRCLE
    circle(300, 102, 115);
    --FILL THE CIRCLE WITH RED
    boundary_fill(300, 102, 6, 0);
    color(1);      --CYAN
    --DRAW A RECTANGLE USING SET PIXEL
    for x in 250..350 loop
        set_pixel(x, 77);
        set_pixel(x, 127);
    end loop;
    for y in 77..127 loop
        set_pixel(250, y);
        set_pixel(350, y);
    end loop;
    --FILL THE RECTANGLE
    area_fill(300, 102, 5);  --COLOR 5 = GREEN
    --ERASE A RECTANGLE USING RESET PIXEL
    for x in 280..320 loop
        for y in 92..112 loop
            reset_pixel(x, y);
        end loop;
    end loop;
    area_fill(375, 102, 2);
    color(6);
    get(quit);
end AGTEST4;
```

## APPENDIX F

### SPECIFICATION PACKAGE

```
PACKAGE ADAGRAPH IS
    --RETURN ADDRESS VARIABLES
    RET_ADJ_SL,RET_RVA,RET_LS,RET_IC,RET_XM: INTEGER;
    RET_FILL,RET_AFILL,RET_DL,RET_SPE,RET_CPE:INTEGER;
    RET_DML,RET_RPE:INTEGER;
    --CURSOR ADDRESS VARIABLES
    CURS_0,CURS_1,CURS_2,CURS_3,CURS_4: INTEGER;
    X_LOC: INTEGER;
    --X/Y POSITION AND GENERAL PURPOSE VARIABLES
    X_START,Y_START,X_END,Y_END: INTEGER;
    X_POS,Y_POS,DELTA_X,DELTA_Y,INC_CTR: INTEGER;
    L_ERROR,END_CNT: INTEGER;
    X_CTR,Y_CTR,RADIUS,X_REL,Y_REL,P_VAL:INTEGER;
    --COLOR VARIABLES
    P_COLOR,F_COLOR,B_COLOR:INTEGER;
    --SYSTEM STATUS
    SYS_STAT: INTEGER;
    --SEGMENT E STATUS
    SEGMENT_E,SEGMENT_FE,SEGMENT_IE: INTEGER;
    --COLOR PLANE BASE ADDRESS
    COL_PL_ADDR: INTEGER;
    SAV_COL1_STAT,SAV_COL2_STAT,SAV_COL3_STAT: INTEGER;
    COL_PL1,COL_PL2,COL_PL3: INTEGER;
    --FILL ROUTINE CONTROL VARIABLE
    COL_MIX: INTEGER;
    --GRAPHICS LIBRARY PROCEDURES
    --
    PROCEDURE CLS;
    PROCEDURE COLOR(color_code : in INTEGER);
    PROCEDURE SET_CURS(x_pos, y_pos : in INTEGER);
    PROCEDURE RESET_CURS(x_pos, y_pos : in INTEGER);
    PROCEDURE DRAW_LINE(x_start, y_start, x_end, y_end : in INTEGER);
    PROCEDURE DRAW_MLINE(x_start, y_start, x_end, y_end : in INTEGER);
    PROCEDURE CIRCLE(x_ctr, y_ctr, radius : in INTEGER);
    PROCEDURE INQUIRE_COLOR(x_pos, y_pos : in INTEGER;
                           color : out INTEGER);
    PROCEDURE BOUNDARY_FILL(x_pos, y_pos, f_color, b_color :
                           in INTEGER);
    PROCEDURE AREA_FILL(x_pos, y_pos, f_color : in INTEGER);
    PROCEDURE SET_PIXEL(x_pos, y_pos : in INTEGER);
    PROCEDURE RESET_PIXEL(x_pos, y_pos : in INTEGER);
END ADAGRAPH;
```

## APPENDIX G

### ASSEMBLY CODE LISTING

```

PACKAGE ASSEMBLY ADAGRAPH
JMP      MAIN
;*****PROCEDURE CLS IS USED TO PERFORM A CLEAR SCREEN OPERATION*****
;PROC CLS;
    PUSH    AX
    IN      AL, 0D8H      ;SAVE VIDEO STATUS
    PUSH    AX
    MOV     AL, OFH
    OUT    OD8H, AL
    IN      AL, 0DBH
    AND    AL, OF7H
    OUT    ODBH, AL
    IN      AL, 0D9H
    AND    AL, OF7H
    OUT    OD9H, AL
    MOV     CX, 6680      ;ENABLE CLRSCRN SIGNAL
    MOV     CX, 6680      ;INIT COUNTER FOR TIME DELAY
    NOP
    LOOP   DELAY        ;TIME DELAY TO ALLOW VIDEO PROCESSOR
    IN      AL, 0D9H
    OR     AL, 08H
    OUT    OD9H, AL
    POP     AX
    OUT    OD8H, AL
    POP     AX
    RET
END PROC CLS;
;*****PROCEDURE COLOR IS USED TO ENABLE COLOR PLANES TO PROVIDE THE SELECTED
;COLOR AND THE E SEGMENT REGISTER IS INITIALIZED TO ALLOW WRITING TO
;THE ENABLED COLOR PLANES.
PROC COLOR;
    POP    DX      ;SAVE RETURN ADDRESS
    POP    AX      ;GET COLOR CODE
    PUSH   DX      ;RESTORE RETURN ADDRESS
    AND    AX, 7    ;MASK COLOR CODE TO SET STATUS FLAGS
    JNZ    COLOR1
    MOV    [COL_PL1], 0C000H ;COLOR IS WHITE
    MOV    [COL_PL2], 0D000H
    MOV    [COL_PL3], 0E000H
    JMP    EXIT_COL
    COLOR1:
    SUB    AL, 1
    JNZ    COLOR2
    MOV    [COL_PL1], 0C000H ;COLOR IS CYAN
    MOV    [COL_PL2], 0E000H
    MOV    [COL_PL3], 0D000H
    JMP    EXIT_COL
    COLOR2:
    SUB    AL, 1
    JNZ    COLOR3
    MOV    [COL_PL1], 0C000H ;COLOR IS MAGENTA
    MOV    [COL_PL2], 0D000H
    MOV    [COL_PL3], 0D000H
    JMP    EXIT_COL
    COLOR3:
    SUB    AL, 1
    JNZ    COLOR4
    MOV    [COL_PL1], 0C000H ;COLOR IS BLUE
    MOV    [COL_PL2], 0C000H
    MOV    [COL_PL3], 0C000H
    JMP    EXIT_COL

```

```

COLOR4:    SUB     AL, 1
           JNZ    COLOR5
           MOV    [COL_PL1], 0D000H ;COLOR IS YELLOW
           MOV    [COL_PL2], 0E000H
           MOV    [COL_PL3], 0E000H
           JMP    EXIT_COL
COLOR5:    SUB     AL, 1
           JNZ    COLOR6
           MOV    [COL_PL1], 0E000H ;COLOR IS GREEN
           MOV    [COL_PL2], 0E000H
           MOV    [COL_PL3], 0E000H
           JMP    EXIT_COL
COLOR6:    SUB     AL, 1
           JNZ    EXIT_COL
           MOV    [COL_PL1], 0D000H ;COLOR IS RED
           MOV    [COL_PL2], 0D000H
           MOV    [COL_PL3], 0D000H
           JMP    EXIT_COL
EXIT_COL: MOV    AL, 78H      ;DISABLE SIMULTANEOUS WRITE
           OUT    0D8H, AL
           RET
END PROC COLOR;
;*****PROCEDURE RESET_CURS IS USED TO ERASE THE GRAPHICS CURSOR
;AN (X,Y) POSITION IS INPUT TO THE PROCEDURE AND THE A BLOCK OF
;ADDRESSES IS CLEARED AT THE CURSOR LOCATION
PROC RESET_CURS:
           MOV    [SEGMENT_E], ES ;SAVE SEG E STATUS
           POP   AX             ;SAVE RETURN ADDRESS
           POP   [Y_POS]        ;GET Y POSITION
           POP   [X_POS]        ;GET X POSITION
           PUSH  AX             ;RESTORE RETURN ADDRESS
           PUSH  [X_POS]
           PUSH  [Y_POS]
           CALL  ADJ_SL         ;ADJUST Y POSITION TO A DISPLAYABLE
           CALL  REL_VID_ADDR  ;SCAN LINE & GET VIDEO ADDRESS
           POP   BX
           CALL  BLANK_GCURS
           SUB   BX, 1
           CALL  BLANK_GCURS
           SUB   [Y_POS], 1
           PUSH  [X_POS]
           PUSH  [Y_POS]
           CALL  ADJ_SL
           CALL  REL_VID_ADDR
           POP   BX
           CALL  BLANK_GCURS
           SUB   [Y_POS], 1
           PUSH  [X_POS]
           PUSH  [Y_POS]
           CALL  ADJ_SL
           CALL  REL_VID_ADDR
           POP   BX
           CALL  BLANK_GCURS
           ADD   [Y_POS], 3
           PUSH  [X_POS]
           PUSH  [Y_POS]
           CALL  ADJ_SL
           CALL  REL_VID_ADDR
           POP   BX
           CALL  BLANK_GCURS
           ADD   [Y_POS], 1
           PUSH  [X_POS]
           PUSH  [Y_POS]
           CALL  ADJ_SL
           CALL  REL_VID_ADDR
           POP   BX
           CALL  BLANK_GCURS

```

```

        MOV      ES, [SEGMENT_E] ;RESTORE SEG E
        RET
END PROC RESET_CURS;
;*****
;*****
;PROCEDURE BLANK_GCURS IS USED BY PROCEDURE RESET_CURS TO ERASE A CURSOR
PROC BLANK_GCURS;
        MOV      AX, [COL_PL1]
        MOV      ES, AX
        SEG      ES
        MOV      [BX], 0
        MOV      AX, [COL_PL2]
        MOV      ES, AX
        SEG      ES
        MOV      [BX], 0
        MOV      AX, [COL_PL3]
        MOV      ES, AX
        SEG      ES
        MOV      [BX], 0
        RET
END PROC BLANK_GCURS;
;*****
;*****
;PROCEDURE SET_CURS IS USED TO DISPLAY A CURSOR AT THE INPUT
;(X,Y) POSITION. THE GRAPHICS CURSOR DISPLAYED IS A "+".
PROC SET_CURS;
;CALCULATE MEMORY ADDRESS OF NEW CURSOR POSITION
        MOV      [SEGMENT_E], ES ;SAVE SEG E STATUS
        POP     AX ;SAVE RETURN ADDRESS
        POP     [Y_POS] ;GET Y POSITION FROM STACK
        POP     [X_POS] ;GET X POSITION FROM STACK
        PUSH   AX ;REPLACE RETURN ADDRESS
        MOV      DX, [Y_POS]
        PUSH   [Y_POS]
        CALL   ADJ_SL
        POP     BX ;GET CORRECTED Y LINE NUMBER
;
;THE CURSOR IS MADE UP OF FIVE COMPONENTS LABELED CURS_0 TO CURS_4
        MOV      [CURS_0], DX ;PUT THE LINE NUMBER INTO
        MOV      [CURS_1], DX ;EACH OF THE CURSOR ROWS
        MOV      [CURS_2], BX
        MOV      [CURS_3], DX
        MOV      [CURS_4], DX
        SUB     [CURS_0], 2
        MOV      AX, [CURS_0]
        JNS     C0
        MOV      AX, 3
        ADD     [CURS_0], AX ;ADJUST EACH CURSOR ROW TO REFLECT IT
        CO:    PUSH   [CURS_0] ;DISTANCE FROM CURSOR CENTER POSITION
              CALL   ADJ_SL ;WHICH IS CURS_2
              POP     [CURS_0] ;THEN CALL PROCEDURE ADJ_SL TO ASSURE
              SUB     [CURS_1], 1 ;THAT EACH CURSOR ROW IS LOCATED ON
              MOV     AX, [CURS_1] ;A DISPLAYABLE SCAN LINE
              JNS     C1
              ADD     [CURS_1], 2
              C1:    PUSH   [CURS_1]
              CALL   ADJ_SL
              POP     [CURS_1]
              ADD     [CURS_3], 1
              PUSH   [CURS_3]
              CALL   ADJ_SL
              POP     [CURS_3]
              ADD     [CURS_4], 2
              PUSH   [CURS_4]
              CALL   ADJ_SL
              POP     [CURS_4]
              PUSH   [X_POS]
              BX
              CALL   REL_VID_ADDR

```

```

POP      BX
PUSH    [X_POS]
PUSH    [CURS_0]
CALL    REL_VID_ADDR
POP    [CURS_0]
PUSH    [X_POS]
PUSH    [CURS_1]
CALL    REL_VID_ADDR
POP    [CURS_1]
PUSH    [X_POS]
PUSH    [CURS_2]
CALL    REL_VID_ADDR
POP    [CURS_2]
PUSH    [X_POS]
PUSH    [CURS_3]
CALL    REL_VID_ADDR
POP    [CURS_3]
PUSH    [X_POS]
PUSH    [CURS_4]
CALL    REL_VID_ADDR
POP    [CURS_4]
MOV    AX, [X_POS]      ;GET X POSITION FOR TEST
AND    AX, 07H          ;CALCULATE CURSOR BIT POSITION IN ADDR
;
;DRAW THE CURSOR BASED ON CURSOR CENTER BIT POSITION WITHIN A BYTE
;THIS SPLITS THE CURSOR ACROSS BYTE BOUNDARIES FOR FULL SCREEN COVERAGE
JNZ     BIT1           ;TEST FOR CURSOR IN X PIXEL POS. 0
MOV    AL, 3
MOV    BX, [CURS_2]
SUB    BX, 1
CALL   DISP_GCURS
MOV    AL, 0EOH
ADD    BX, 1
CALL   DISP_GCURS
MOV    AL, 80H
MOV    BX, [CURS_0]
CALL   DISP_GCURS
MOV    BX, [CURS_1]
CALL   DISP_GCURS
MOV    BX, [CURS_3]
CALL   DISP_GCURS
MOV    BX, [CURS_4]
CALL   DISP_GCURS
JMP    EXIT
BIT1:
SUB    AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
JNZ    BIT2           ;TEST FOR CURSOR IN X PIXEL POS. 1
MOV    BX, [CURS_2]
SUB    BX, 1
MOV    AL, 1
CALL   DISP_GCURS
MOV    AL, 0FOH
ADD    BX, 1
CALL   DISP_GCURS
MOV    AL, 40H
MOV    BX, [CURS_0]
CALL   DISP_GCURS
MOV    BX, [CURS_1]
CALL   DISP_GCURS
MOV    BX, [CURS_3]
CALL   DISP_GCURS
MOV    BX, [CURS_4]
CALL   DISP_GCURS
JMP    EXIT
BIT2:
SUB    AL, 1           ;DECREMENT BIT COUNT FOR NEXT TEST
JNZ    BIT3           ;TEST FOR CURSOR IN X PIXEL POS. 2
MOV    AL, 0F8H
MOV    BX, [CURS_2]
CALL   DISP_GCURS
MOV    AL, 20H

```

```

MOV     BX, [CURS_0]
CALL    DISP_GCURS
MOV     BX, [CURS_1]
CALL    DISP_GCURS
MOV     BX, [CURS_3]
CALL    DISP_GCURS
MOV     BX, [CURS_4]
CALL    DISP_GCURS
JMP     EXIT
BIT3:   SUB    AL, 1      ;DECREMENT BIT COUNT FOR NEXT TEST
        JNZ    BIT4      ;TEST FOR CURSOR IN X PIXEL POS. 3
        MOV    AL, 7CH
        MOV    BX, [CURS_2]
        CALL   DISP_GCURS
        MOV    AL, 10H
        MOV    BX, [CURS_0]
        CALL   DISP_GCURS
        MOV    BX, [CURS_1]
        CALL   DISP_GCURS
        MOV    BX, [CURS_3]
        CALL   DISP_GCURS
        MOV    BX, [CURS_4]
        CALL   DISP_GCURS
        JMP     EXIT
BIT4:   SUB    AL, 1      ;DECREMENT BIT COUNT FOR NEXT TEST
        JNZ    BITS5     ;TEST FOR CURSOR IN X PIXEL POS. 4
        MOV    AL, 3EH
        MOV    BX, [CURS_2]
        CALL   DISP_GCURS
        MOV    AL, 8
        MOV    BX, [CURS_0]
        CALL   DISP_GCURS
        MOV    BX, [CURS_1]
        CALL   DISP_GCURS
        MOV    BX, [CURS_3]
        CALL   DISP_GCURS
        MOV    BX, [CURS_4]
        CALL   DISP_GCURS
        JMP     EXIT
BIT5:   SUB    AL, 1      ;DECREMENT BIT COUNT FOR NEXT TEST
        JNZ    BIT6      ;TEST FOR CURSOR IN X PIXEL POS. 5
        MOV    AL, 1FH
        MOV    BX, [CURS_2]
        CALL   DISP_GCURS
        MOV    AL, 4
        MOV    BX, [CURS_0]
        CALL   DISP_GCURS
        MOV    BX, [CURS_1]
        CALL   DISP_GCURS
        MOV    BX, [CURS_3]
        CALL   DISP_GCURS
        MOV    BX, [CURS_4]
        CALL   DISP_GCURS
        JMP     EXIT
BIT6:   SUB    AL, 1      ;DECREMENT BIT COUNT FOR NEXT TEST
        JNZ    BIT7      ;TEST FOR CURSOR IN X PIXEL POS. 6
        MOV    AL, 0FH
        MOV    BX, [CURS_2]
        CALL   DISP_GCURS
        MOV    AL, 80H
        ADD    BX, 1
        CALL   DISP_GCURS
        MOV    AL, 2
        MOV    BX, [CURS_0]
        CALL   DISP_GCURS
        MOV    BX, [CURS_1]
        CALL   DISP_GCURS
        MOV    BX, [CURS_3]
        CALL   DISP_GCURS

```

```

        MOV      BX, [CURS_4]
        CALL    DISP_GCURS
        JMP     EXIT
BIT7:   MOV      AL, 7
        MOV      BX, [CURS_2]
        CALL    DISP_GCURS
        MOV      AL, 0COH
        ADD     BX, 1
        CALL    DISP_GCURS
        MOV      AL, 1
        MOV      BX, [CURS_0]
        CALL    DISP_GCURS
        MOV      BX, [CURS_1]
        CALL    DISP_GCURS
        MOV      BX, [CURS_3]
        CALL    DISP_GCURS
        MOV      BX, [CURS_4]
        CALL    DISP_GCURS
EXIT:   MOV      ES, [SEGMENT_E] ;RESTORE SEG E
        RET

END PROC SET_CURS;
;*****PROCEDURE DISP_GCURS IS USED BY PROCEDURE SET_CURS TO DISPLAY A CURSOR
PROC DISP_GCURS;
        MOV      DX, [COL_PL1]
        MOV      ES, DX
        SEG    ES
        OR     [BX], AL
        MOV      DX, [COL_PL2]
        MOV      ES, DX
        SEG    ES
        OR     [BX], AL
        MOV      DX, [COL_PL3]
        MOV      ES, DX
        SEG    ES
        OR     [BX], AL
        RET

END PROC DISP_GCURS;
;*****PROCEDURE ADJ_SL IS USED TO CORRECT Y POSITION TO INSURE
;THAT IT OCCURS ON A DISPLAYABLE SCAN LINE
PROC ADJ_SL;
        POP     [RET_ADJ_SL] ;SAVE RETURN ADDRESS
        POP     BX             ;GET Y POSITION
TST_Y:   MOV     AX, BX
        SUB     AX, 9
        JNS     ADJ_Y
        JMP     EXIT_SL
ADJ_Y:   ADD     BX, 7
        JMP     TST_Y
EXIT_SL: PUSH   BX             ;RETURN CORRECTED Y POSITION
        PUSH   [RET_ADJ_SL] ;RESTORE RETURN ADDRESS
        RET

END PROC ADJ_SL;
;*****PROCEDURE REL_VID_ADDR ACCEPTS X AND Y SCREEN COORDINATES AND CONVERTS
;THEM TO A BYTE ADDRESS IN MEMORY CORRESPONDING TO THE X Y POSITION
PROC REL_VID_ADDR;
        POP     [RET_RVA] ;SAVE RETURN ADDRESS
        POP     BX             ;GET Y POSITION
        TEST   BX, 8000H ;TEST FOR Y < 0
        JNS     TST_YUPR
        MOV     BX, 0
TST_YUPR: MOV     AX, 376          ;TEST FOR Y > 376
        SUB     AX, BX
        JNS     Y_IN_BND

```

```

Y_IN_BND:    MOV     BX, 376
              MOV     AX, 80H      ;PUT SCALE FACTOR IN AX
              MUL     BX      ;AND SCALE Y BASED ON LINE NUMBER
              POP    BX      ;GET X POSITION
              TEST   BX, 8000H   ;TEST FOR X < 0
              JNS    TST_XUPR
              MOV     BX, 0
TST_XUPR:    MOV     DX, 639      ;TEST FOR X > 639
              SUB    DX, BX
              JNS    X_IN_BND
              MOV     BX, 639
X_IN_BND:    MOV     CL, 3       ;AND DETERMINE BYTE X OFFSET
              SHR    BX, CL      ;BY DIVIDING X POSITION BY 8
              ADD    BX, AX      ;ADD X OFFSET TO GET BYTE ADDRESS
              PUSH   BX
              PUSH   [RET_RVA]   ;RETURN RELATIVE BYTE ADDRESS
              RET
END PROC REL_VID_ADDR;
;*****LINE DRAWING PROCEDURE WITH COLOR MIXING FOR CROSSING LINES
PROC DRAW_MLINE;
    POP    [RET_DML]   ;SAVE RETURN ADDRESS
    MOV    [COL_MIX], 1 ;ENABLE COLOR MIXING
    CALL   DRAWW_LINE  ;GO DRAW THE LINE
    PUSH   [RET_DML]   ;RESTORE RETURN ADDRESS
    RET
END PROC DRAW_MLINE;
;*****LINE DRAWING PROCEDURE WITHOUT COLOR MIXING FOR CROSSING LINES
PROC DRAW_LINE;
    POP    [RET_DML]   ;SAVE RETURN ADDRESS
    MOV    [COL_MIX], 0 ;DISABLE COLOR MIXING
    CALL   DRAWW_LINE  ;GO DRAW THE LINE
    PUSH   [RET_DML]   ;RESTORE RETURN ADDRESS
    RET
END PROC DRAW_LINE;
;*****PROCEDURE DRAWW_LINE PROVIDES PRIMITIVE LINE DRAWING CAPABILITIES
;THE SUBROUTINE ACCEPTS AS INPUT A PAIR OF ENDPOINTS IDENTIFIED BY
;(X, Y) COORDINATES
PROC DRAWW_LINE;
    MOV    BP, SP
    PUSH  DS
    MOV    BX, [BP+8]
    MOV    [X_START], BX ;GET X START FROM STACK
    MOV    BX, [BP+6]
    MOV    [Y_START], BX ;GET Y START FROM STACK
    MOV    BX, [BP+4]
    MOV    [X_END], BX   ;GET X END FROM STACK
    MOV    AX, [BP+2]
    MOV    [Y_END], AX   ;GET Y END FROM STACK
    MOV    [Y_END], AX

;TEST ORDERING OF Y COORDINATES. THE ALGORITHM EXPECTS TO FIND THE Y
;COORDINATE IN INCREASING ORDER OR 0.
    MOV    AX, [Y_END]
    SUB    AX, [Y_START]
    JNS    STO_DY        ;JUMP IF Y ORDERING OK
    MOV    AX, [X_START]
    MOV    BX, [X_END]    ;ELSE SWAP START AND END COORD.
    MOV    [X_START], BX  ;SO Y START VALUE IS LTE Y END
    MOV    [X_END], AX    ;VALUE. THEN CALCULATE DELTA Y.
    MOV    AX, [Y_START]
    MOV    BX, [Y-END]
    MOV    [Y_START], BX
    MOV    [Y_END], AX
    SUB    AX, BX
    MOV    [DELTA_Y], AX

STO_DY:

```

```

MOV      AX, [X_END]          ;CALCULATE DELTA X
SUB      AX, [X_START]
MOV      [DELTA_X], AX
MOV      [INC_CTR], 1
MOV      [L_ERROR], 0
MOV      AX, [X_START]
MOV      [X_POS], AX
MOV      AX, [Y_START]
MOV      [Y_POS], AX
PUSH    [X_POS]
PUSH    [Y_POS]
CALL    LINE_SEG             ;PLOT FIRST POINT
TEST   [DELTA_X], 8000H       ;TEST FOR NEGATIVE SLOPE
JNS    TST_DY
JMP    TST_DYZ
TST_DY: TEST   [DELTA_Y], 7FFFH ;TEST FOR DELTA Y = 0
JNZ    C_2_OR_3
SUB    [DELTA_X], 1
CASE_1: ADD    [X_POS], 1      ;DRAW LINE FOR SPECIAL CASE WHERE
PUSH    [X_POS]                ;DX > 0 AND DY = 0
PUSH    [Y_POS]
CALL    LINE_SEG
SUB    [DELTA_X], 1
JNS    CASE_2
CASE_2: JMP    EXIT_DL
C_2_OR_3: MOV    AX, [DELTA_X] ;DX > 0 AND DY > 0
SUB    AX, [DELTA_Y]
JNS    CASE_2
JMP    CASE_3
CASE_3: MOV    AX, [DELTA_X] ;DX >= DY
MOV    [END_CNT], AX
;
MOV    BX, [DELTA_Y]           ;ADD IN CORRECTION FACTOR FOR
ADD    BX, 1                  ;SMOOTHING
JNZ    C_CASE2               ;CORR = DX/(DY+1)
C_CASE2: JMP    DR_C2
DR_C2:  MOV    AX, [DELTA_X]
MOV    DX, 0
DIV    BX
SUB    [L_ERROR], AX          ;INIT ERROR VAL. WITH CORR. FACT.
;
DR_C2:  MOV    AX, [END_CNT] ;TEST INCREMENT COUNTER
SUB    AX, [INC_CTR]
JNS    DR_C2C
JMP    EXIT_DL
DR_C2C: TEST  [L_ERROR], 8000H ;TEST IF ERROR < 0
CASE_2C: JNS    CASE_2C
ADD    [X_POS], 1              ;ERROR < 0
PUSH    [X_POS]
PUSH    [Y_POS]
CALL    LINE_SEG
MOV    AX, [L_ERROR]
ADD    AX, [DELTA_Y]
MOV    [L_ERROR], AX
ADD    [INC_CTR], 1
JMP    DR_C2
CASE_2C: ADD    [X_POS], 1      ;ERROR >= 0
ADD    [Y_POS], 1
PUSH    [X_POS]
PUSH    [Y_POS]
CALL    LINE_SEG
MOV    AX, [L_ERROR]
ADD    AX, [DELTA_Y]
SUB    AX, [DELTA_X]
MOV    [L_ERROR], AX
ADD    [INC_CTR], 1
JMP    DR_C2
CASE_3: MOV    AX, [DELTA_Y] ;DY > DX
MOV    [END_CNT], AX

```

```

;
MOV BX, [DELTA_X] ;ADD IN CORRECTION FACTOR FOR
ADD BX, 1 ;SMOOTHING
JNZ C_CASE3 ;CORR = DY/(DX+1)
C_CASE3:
JMP DR_C3
MOV AX, [DELTA_Y]
MOV DX, 0
DIV BX
MOV [L_ERROR], AX ;INIT ERROR VAL. WITH CORR. FACT.
;
DR_C3:
MOV AX, [END_CNT] ;TEST INCREMENT COUNTER
SUB AX, [INC_CTR]
JNS DR_C3C
JMP EXIT_DL
TEST [L_ERROR], 8000H ;TEST FOR ERROR < 0
CASE_3C:
JNS ADD [X_POS], 1 ;ERROR < 0
ADD [Y_POS], 1
PUSH [X_POS]
PUSH [Y_POS]
CALL LINE_SEG
MOV AX, [L_ERROR]
SUB AX, [DELTA_X]
ADD AX, [DELTA_Y]
MOV [L_ERROR], AX
ADD [INC_CTR], 1
JMP DR_C3
CASE_3C:
ADD [Y_POS], 1 ;ERROR >= 0
PUSH [X_POS]
PUSH [Y_POS]
CALL LINE_SEG
MOV AX, [L_ERROR]
SUB AX, [DELTA_X]
MOV [L_ERROR], AX
ADD [INC_CTR], 1
JMP DR_C3
TST_DYZ:
TEST [DELTA_Y], 7FFFH ;TEST FOR DY > 0
C_5_OR_6:
MOV AX, OFFFFFH ;PROCESS SPECIAL CASE WHERE DX < 0
SUB AX, [DELTA_X] ;AND DY = 0
MOV [DELTA_X], AX
;
CASE_4:
SUB [X_POS], 1
PUSH [X_POS]
PUSH [Y_POS]
CALL LINE_SEG
SUB [DELTA_X], 1
JNS CASE_4
JMP EXIT_DL
;
CASE_4:
SUB [X_POS], 1
PUSH [X_POS]
PUSH [Y_POS]
CALL LINE_SEG
SUB [DELTA_X], 1
JNS CASE_4
JMP EXIT_DL
C_5_OR_6:
MOV AX, 0 ;CASE 3 OR 4. DX < 0 & DY > 0
SUB AX, [DELTA_X]
SUB AX, [DELTA_Y]
JNS CASE_5
JMP CASE_6
CASE_5:
MOV AX, 0 ;DY <= ABS(DX)
SUB AX, [DELTA_X]
MOV [END_CNT], AX
;
MOV BX, [DELTA_Y] ;ADD IN CORRECTION FACTOR FOR
ADD BX, 1 ;SMOOTHING
JNZ C_CASE5 ;CORR = DX/(DY+1)
C_CASE5:
JMP DR_C5
MOV AX, 0
SUB AX, [DELTA_X]
MOV DX, 0
DIV BX
MOV [L_ERROR], AX ;INIT ERROR WITH CORR. FACT.
;
DR_C5:
MOV AX, [END_CNT] ;TEST INCREMENT COUNTER
SUB AX, [INC_CTR]

```

```

JNS      DR_C5C
JMP
DR_C5C: TEST    EXIT_DL
          [L_ERROR], 8000H ;TEST IF ERROR < 0
JNS      CASE_5C
SUB     [X_POS], 1      ;ERROR < 0
PUSH    [X_POS]
PUSH    [Y_POS]
CALL    LINE_SEG
MOV     AX, [L_ERROR]
ADD     AX, [DELTA_Y]
MOV     [L_ERROR], AX
ADD     [INC_CTR], 1
JMP    DR_C5
CASE_5C: SUB     [X_POS], 1      ;ERROR >= 0
ADD     [Y_POS], 1
PUSH    [X_POS]
PUSH    [Y_POS]
CALL    LINE_SEG
MOV     AX, [L_ERROR]
ADD     AX, [DELTA_X]
ADD     AX, [DELTA_Y]
MOV     [L_ERROR], AX
ADD     [INC_CTR], 1
JMP    DR_C5
CASE_6:  MOV     AX, [DELTA_Y]   ;ABS(DX) < DY
          MOV     [END_CNT], AX
;
          MOV     BX, 1      ;ADD IN CORRECTION FACTOR FOR
          SUB     BX, [DELTA_X] ; SMOOTHING
          JNZ     C_CASE6   ;CORR = DY/(DX+1)
C_CASE6: MOV     AX, [DELTA_Y]
          MOV     DX, 0
          DIV     BX
          MOV     [L_ERROR], AX ;INIT ERROR WITH CORR. FACT.
;
DR_C6:   MOV     AX, [END_CNT]  ;TEST INCREMENT COUNTER
          SUB     AX, [INC_CTR]
          JNS     DR_C6C
          JMP    EXIT_DL
DR_C6C:  TEST    [L_ERROR], 8000H ;TEST FOR ERROR < 0
          CASE_6C
          SUB     [X_POS], 1      ;ERROR < 0
          ADD     [Y_POS], 1
          PUSH   [X_POS]
          PUSH   [Y_POS]
          CALL    LINE_SEG
          MOV     AX, [L_ERROR]
          ADD     AX, [DELTA_X]
          ADD     AX, [DELTA_Y]
          MOV     [L_ERROR], AX
          ADD     [INC_CTR], 1
          JMP    DR_C6
CASE_6C: ADD     [Y_POS], 1      ;ERROR >= 0
          PUSH   [X_POS]
          PUSH   [Y_POS]
          CALL    LINE_SEG
          MOV     AX, [L_ERROR]
          ADD     AX, [DELTA_X]
          MOV     [L_ERROR], AX
          ADD     [INC_CTR], 1
          JMP    DR_C6
EXIT_DL: POP    DS      ;PREPARE TO EXIT PROCEDURE BY
          POP    AX      ;RESTORING REGISTERS AND THEN
          POP    BX      ;REMOVE INPUT PARAMETERS
          POP    BX      ;FROM STACK
          POP    BX
          POP    AX

```

```

        RET
END PROC DRAWW_LINE;
;*****PROCEDURE LINE_SEG ACCEPTS AS INPUT AN X AND Y POSITION AND CONVERTS
;THE POSITION INTO DISPLAYABLE PIXEL DATA
PROC LINE_SEG,
        MOV      [SEGMENT_E], ES    ;SAVE SEG E STATUS
        MOV      ES, [COL_PL_ADDR] ;ENABLE SELECTED COLOR
        POP      [RET_LS]          ;SAVE RETURN ADDRESS
        CALL    ADJ_SL             ;CONVERT Y POS. TO DISPLAYABLE S.L.
        CALL    REL_VID_ADDR      ;USE X & Y TO CALC REL. BYTE ADDR.
        POP      BX                ;BX REGISTER HOLDS REL. BYTE ADDR.
        MOV      AX, [X_POS]        ;MOV X POSITION TO AX REGISTER AND
        AND      AX, 7              ;CALCULATE X BIT POSITION WITHIN A
        JNZ      XBIT1             ;BYTE FOR DISPLAY PURPOSES
        MOV      DL, 80H
        MOV      CL, 7FH
        JMP      OUT_LINE
XBIT1:
        SUB      AL, 1
        JNZ      XBIT2
        MOV      DL, 40H
        MOV      CL, 0BFH
        JMP      OUT_LINE
XBIT2:
        SUB      AL, 1
        JNZ      XBIT3
        MOV      DL, 20H
        MOV      CL, ODFH
        JMP      OUT_LINE
XBIT3:
        SUB      AL, 1
        JNZ      XBIT4
        MOV      DL, 10H
        MOV      CL, OEFH
        JMP      OUT_LINE
XBIT4:
        SUB      AL, 1
        JNZ      XBIT5
        MOV      DL, 8
        MOV      CL, OF7H
        JMP      OUT_LINE
XBIT5:
        SUB      AL, 1
        JNZ      XBIT6
        MOV      DL, 4
        MOV      CL, OFBH
        JMP      OUT_LINE
XBIT6:
        SUB      AL, 1
        JNZ      XBIT7
        MOV      DL, 2
        MOV      CL, OFDH
        JMP      OUT_LINE
XBIT7:
        MOV      DL, 1
        MOV      CL, OFEH
OUT_LINE:
        CMP      [COL_MIX], 1      ;TEST IF MIXING ENABLED
        JNS      LSC_MIX
        MOV      AX, 0C000H          ;CLEAR SELECTED LOCATION IN ALL
        MOV      ES, AX              ;COLOR PLANES IF NO MIXING
        SEG      ES
        AND      [BX], CL
        MOV      AX, 0D000H
        MOV      ES, AX
        SEG      ES
        AND      [BX], CL
        MOV      AX, 0E000H
        MOV      ES, AX
        SEG      ES
        AND      [BX], CL
LSC_MIX:
        MOV      AX, [COL_PL1]
        MOV      ES, AX
        SEG      ES
        OR      [BX], DL            ;SELECT E SEGMENT FOR ADDRESSING OF
                                ;VIDEO OUTPUT THEN OUTPUT A BYTE

```

```

MOV      AX, [COL_PL2]
MOV      ES, AX
SEG     ES
OR      [BX], DL
MOV      AX, [COL_PL3]
MOV      ES, AX
SEG     ES
OR      [BX], DL
PUSH    [RET_LS] ;RESTORE RETURN ADDRESS
MOV      ES, [SEGMENT_E] ;RESTORE SEG E
RET

END PROC LINE_SEG;
;*****PROCEDURE LINE SEGMENT*****
;PROCEDURE CIRCLE INPUTS X & Y COORDINATES OF THE CIRCLE CENTER
;AND A RADIUS VALUE. IT THEN DRAWS A CIRCLE.
PROC CIRCLE;
MOV      BP, SP
MOV      AX, [BP+6]
MOV      AX, [X_CTR], AX ;GET X CENTER COORDINATE OFF STACK
MOV      AX, [BP+4]
MOV      AX, [Y_CTR], AX ;GET Y CENTER COORDINATE OFF STACK
MOV      DX, [BP+2]
MOV      [Y_REL], DX ;GET RADIUS VALUE AND SET
MOV      [X_REL], 0 ;INITIAL VALUES FOR X AND Y COORD.
MOV      CL, 1
SHL     DX, CL
MOV      AX, 3
SUB     AX, DX
MOV      [P_VAL], AX
CIRC_LP: MOV      AX, [Y_REL] ;TEST IF FINISHED DRAWING CIRCLE
SUB     AX, [X_REL]
JNS     DR_CIRC
POP     AX
POP     BX ;REMOVE INPUT PARAMETERS FROM STACK
POP     BX
POP     BX
PUSH    AX
RET      ;EXIT SUBROUTINE

;POINTS ON CIRCLE ARE PLOTTED IN GROUPS OF 8 WITH THE Y COORDINATE
;SCALED BY 1/2 TO COMPENSATE FOR X:Y RATIO IN THE DISPLAY
DR_CIRC: MOV      AX, [X_CTR] ;CALCULATE POINT 1
MOV      DX, [X_REL]
ADD     AX, DX
MOV      [X_POS], AX
PUSH    AX
MOV      AX, [Y_REL]
MOV      CL, 1
SHR     AX, CL
ADD     AX, [Y_CTR]
PUSH    AX
CALL    ADJ_SL
POP     [Y_POS]
PUSH    [Y_POS]
CALL    REL_VID_ADDR
PUSH    [X_POS]
CALL    CIR_PIXEL ;PLOT (X_CENTER+X, Y_CENTER+Y)
MOV      AX, [X_CTR] ;CALCULATE POINT 2
MOV      DX, [X_REL]
SUB     AX, DX
MOV      [X_POS], AX
PUSH    AX
PUSH    [Y_POS]
CALL    REL_VID_ADDR
PUSH    [X_POS]
CALL    CIR_PIXEL ;PLOT (X_CENTER-X, Y_CENTER+Y)
PUSH    [X_POS]
MOV      BX, [Y_REL] ;CALCULATE POINT 3

```

```

MOV CL, 1
SHR BX, CL
MOV AX, [Y_CTR]
SUB AX, BX
PUSH AX
CALL ADJ_SL
POP [Y_POS]
PUSH [Y_POS]
CALL REL_VID_ADDR
PUSH [X_POS]
CALL CIR_PIXEL
MOV AX, [X_CTR]
MOV DX, [X_REL]
ADD AX, DX
MOV [X_POS], AX
PUSH AX
PUSH [Y_POS]
CALL REL_VID_ADDR
PUSH [X_POS]
CALL CIR_PIXEL
MOV AX, [X_CTR]
MOV DX, [Y_REL]
ADD AX, DX
MOV [X_POS], AX
PUSH AX
MOV AX, [X_REL]
MOV CL, 1
SHR AX, CL
ADD AX, [Y_CTR]
PUSH AX
CALL ADJ_SL
POP [Y_POS]
PUSH [Y_POS]
CALL REL_VID_ADDR
PUSH [X_POS]
CALL CIR_PIXEL
MOV AX, [X_CTR]
MOV DX, [Y_REL]
SUB AX, DX
MOV [X_POS], AX
PUSH AX
PUSH [Y_POS]
CALL REL_VID_ADDR
PUSH [X_POS]
CALL CIR_PIXEL
MOV AX, [X_CTR]
SUB BX, [X_REL]
MOV CL, 1
SHR BX, CL
MOV AX, [Y_CTR]
SUB AX, BX
PUSH AX
CALL ADJ_SL
POP [Y_POS]
PUSH [Y_POS]
CALL REL_VID_ADDR
PUSH [X_POS]
CALL CIR_PIXEL
MOV AX, [X_CTR]
MOV DX, [Y_REL]
ADD AX, DX
MOV [X_POS], AX
PUSH AX
PUSH [Y_POS]
CALL REL_VID_ADDR
PUSH [X_POS]
CALL CIR_PIXEL
;PLOT (X_CENTER-X, Y_CENTER-Y)
;CALCULATE POINT 4
;PLOT (X_CENTER+X, Y_CENTER-Y)
;CALCULATE POINT 5
;PLOT (X_CENTER+Y, Y_CENTER-X)
;CALCULATE POINT 6
;PLOT (X_CENTER-Y, Y_CENTER+X)
;CALCULATE POINT 7
;PLOT (X_CENTER-Y, Y_CENTER-X)
;CALCULATE POINT 8
;PLOT (X_CENTER+Y, Y_CENTER-X)
;TEST P FOR NEGATIVE VALUE
;
TEST [P_VAL], 8000H

```

```

JNS      P_DECY
MOV     CL, 2          ;P := P + (4 * X) + 6
MOV     AX, [X_REL]
SHL     AX, CL
ADD     AX, 6
ADD     [P_VAL], AX
ADD     [X_REL], 1      ;INCREMENT X COUNT
JMP     CIRC_LP
P_DECY: MOV     CL, Z          ;P := P + 4 * (X - Y) + 10
MOV     AX, [X_REL]
SUB     AX, [Y_REL]
SHL     AX, CL
ADD     AX, 10
ADD     [P_VAL], AX
SUB     [Y_REL], 1      ;DECREMENT Y COUNT
ADD     [X_REL], 1      ;INCREMENT X COUNT
JMP     CIRC_LP
END PROC CIRCLE;
;*****
;*****
;PROCEDURE CIR_PIXEL ACCEPTS AS INPUT A RELATIVE BYTE ADDRESS AND AN
;X COORDINATE POSITION AND SETS THE CORRESPONDING PIXEL
PROC CIR_PIXEL;
    MOV     [SEGMENT_E], ES ;SAVE SEG E STATUS
    POP    [RET_CPE]        ;SAVE RETURN ADDRESS
    POP    DX              ;GET X POSITION
    POP    BX              ;GET RELATIVE BYTE ADDRESS
    AND   DX, 7
    JNZ   CPBIT1
    MOV   AL, 80H
    MOV   CL, 7FH
    JMP   CPIX_ON
CPBIT1: SUB   DL, 1
    JNZ   CPBIT2
    MOV   AL, 40H
    MOV   CL, 0BFH
    JMP   CPIX_ON
CPBIT2: SUB   DL, 1
    JNZ   CPBIT3
    MOV   AL, 20H
    MOV   CL, 0DFH
    JMP   CPIX_ON
CPBIT3: SUB   DL, 1
    JNZ   CPBIT4
    MOV   AL, 10H
    MOV   CL, 0EFH
    JMP   CPIX_ON
CPBIT4: SUB   DL, 1
    JNZ   CPBIT5
    MOV   AL, 8
    MOV   CL, 0F7H
    JMP   CPIX_ON
CPBIT5: SUB   DL, 1
    JNZ   CPBIT6
    MOV   AL, 4
    MOV   CL, 0FBH
    JMP   CPIX_ON
CPBIT6: SUB   DL, 1
    JNZ   CPBIT7
    MOV   AL, 2
    MOV   CL, 0FDH
    JMP   CPIX_ON
CPBIT7: MOV   AL, 1
    MOV   CL, 0FEH
CPIX_ON: MOV   DX, 0C000H      ;CLEAR ALL COLOR PLANES AT SELECTED
    MOV   ES, DX          ;PIXEL LOCATION BEFORE SETTING
    SEG   ES              ;PIXEL TO DESIRED COLOR
    AND   [BX], CL
    MOV   DX, 0D000H

```

```

MOV     ES, DX
SEG    ES
AND    [BX], CL
MOV    DX, 0E000H
MOV    ES, DX
SEG    ES
AND    [BX], CL
MOV    DX, [COL_PL1] ;SET PIXEL TO DESIRED COLOR
MOV    ES, DX
SEG    ES
OR     [BX], AL
MOV    DX, [COL_PL2]
MOV    ES, DX
SEG    ES
OR     [BX], AL
MOV    DX, [COL_PL3]
MOV    ES, DX
SEG    ES
OR     [BX], AL
PUSH   [RET_CPE]
MOV    ES, [SEGMENT_E] ;RESTORE SEG E
RET

END PROC CIR_PIXEL;
;*****PROCEDURE SET_PIXEL ACCEPTS AS INPUT AN (X,Y) COORDINATE AND SETS THE
;CORRESPONDING_PIXEL TO THE SYSTEM COLOR
PROC SET_PIXEL;
    MOV    BP, SP
    MOV    [SEGMENT_E], ES ;SAVE ES STATUS
    POP    [RET_SPE] ;SAVE RETURN ADDRESS
    MOV    AX, [BP+4] ;GET X POSITION
    MOV    [X_POS], AX
    CALL   ADJ_SL
    CALL   REL_VID_ADDR
    POP    BX ;GET RELATIVE BYTE ADDRESS
    MOV    DX, [X_POS]
    AND    DX, 7 ;MAKE A BIT MASK
    JNZ    PBIT1
    MOV    AL, 80H
    MOV    CL, 7FH
    JMP    PIX_ON
    SUB    DL, 1
    JNZ    PBIT2
    MOV    AL, 40H
    MOV    CL, 0BFH
    JMP    PIX_ON
    SUB    DL, 1
    JNZ    PBIT3
    MOV    AL, 20H
    MOV    CL, 0DFH
    JMP    PIX_ON
    SUB    DL, 1
    JNZ    PBIT4
    MOV    AL, 10H
    MOV    CL, 0EFH
    JMP    PIX_ON
    SUB    DL, 1
    JNZ    PBIT5
    MOV    AL, 8
    MOV    CL, 0F7H
    JMP    PIX_ON
    SUB    DL, 1
    JNZ    PBIT6
    MOV    AL, 4
    MOV    CL, 0FBH
    JMP    PIX_ON
    SUB    DL, 1
    JNZ    PBIT7

```

```

    MOV     AL, 2
    MOV     CL, OFDH
    JMP     PIX_ON
PBIT7:   MOV     AL, 1
    MOV     CL, OFEH
PIX_ON:  MOV     DX, OC000H      ;CLEAR ALL COLOR PLANES AT SELECTED
    MOV     ES, DX      ;PIXEL LOCATION BEFORE SETTING
    SEG     ES          ;PIXEL TO NEW COLOR
    AND    [BX], CL
    MOV     DX, OD000H
    MOV     ES, DX
    SEG     ES
    AND    [BX], CL
    MOV     DX, OE000H
    MOV     ES, DX
    SEG     ES
    AND    [BX], CL
    MOV     DX, [COL_PL1] ;SET PIXEL TO DESIRED COLOR
    MOV     ES, DX
    SEG     ES
    OR     [BX], AL
    MOV     DX, [COL_PL2]
    MOV     ES, DX
    SEG     ES
    OR     [BX], AL
    MOV     DX, [COL_PL3]
    MOV     ES, DX
    SEG     ES
    OR     [BX], AL
    PUSH   [RET_SPE]
    MOV     ES, [SEGMENT_E] ;RESTORE RETURN ADDRESS
    RET
END PROC SET_PIXEL;
;*****PROCEDURE RESET_PIXEL ACCEPTS AS INPUT AN (X,Y) COORDINATE AND RESETS
;THE CORRESPONDING PIXEL BY WRITING "0" TO ALL COLOR PLANES
PROC RESET_PIXEL;
    MOV     BP, SP
    MOV     [SEGMENT_E], ES ;SAVE ES STATUS
    POP    [RET_RPE]        ;SAVE RETURN ADDRESS
    MOV     AX, [BP+4]       ;GET X POSITION
    MOV     [X_POS], AX
    CALL   ADJ_SL
    CALL   REL_VID_ADDR
    POP    BX                ;GET RELATIVE BYTE ADDRESS
    MOV     DX, [X_POS]
    AND    DX, 7             ;MAKE A BIT MASK
    JNZ    RBIT1
    MOV     AL, 7FH
    JMP    PIX_OFF
RBIT1:   SUB    DL, 1
    JNZ    RBIT2
    MOV     AL, OBFH
    JMP    PIX_OFF
RBIT2:   SUB    DL, 1
    JNZ    RBIT3
    MOV     AL, ODFH
    JMP    PIX_OFF
RBIT3:   SUB    DL, 1
    JNZ    RBIT4
    MOV     AL, OEOFH
    JMP    PIX_OFF
RBIT4:   SUB    DL, 1
    JNZ    RBIT5
    MOV     AL, OF7H
    JMP    PIX_OFF
RBIT5:   SUB    DL, 1
    RBIT6

```

```

        MOV      AL, OFBH
        JMP      PIX_OFF
RBIT6:   SUB      DL, 1
        JNZ      RBIT7
        MOV      AL, OFDH
        JMP      PIX_OFF
RBIT7:   MOV      AL, OFEH
PIX_OFF: MOV      DX, OC000H
        MOV      ES, DX
        SEG      ES
        AND      [BX], AL
        MOV      DX, ODOOOH
        MOV      ES, DX
        SEG      ES
        AND      [BX], AL
        MOV      DX, OE000H
        MOV      ES, DX
        SEG      ES
        AND      [BX], AL
        PUSH    [RET_RPE]      ;RESTORE RETURN ADDRESS
        MOV      ES, [SEGMENT_E] ;RESTORE SEGMENT E
        RET

END PROC RESET_PIXEL;
;*****PROCEDURE INQUIRE_COLOR IS USED TO INTERFACE WITH HIGHER LEVEL ADA
;PROGRAMS IN ORDER TO HANDLE I/O PARAMETER PASSING
PROC INQUIRE_COLOR,
        MOV      BP, SP
        PUSH    BP
        PUSH    [BP+6]          ;PUSH X POSITION
        PUSH    [BP+4]          ;PUSH Y POSITION
        CALL    INQ_COLOR        ;GET PIXEL COLOR
        POP     AX              ;COLOR VAL RETURNED
        POP     BP
        MOV     BX, [BP+2]
        MOV     [BX], AX          ;RETURN PIXEL COLOR
        RET

END PROC INQUIRE_COLOR;
;*****PROCEDURE INQ_COLOR ACCEPTS X & Y COORDINATES AS AN INPUT AND
;RETURNS THE PIXEL COLOR CODE OF THAT LOCATION
PROC INQ_COLOR,
        MOV      BP, SP
        MOV      AX, [BP+4]
        MOV      [X_POS], AX
        POP     [RET_IC]          ;SAVE RETURN ADDRESS
        CALL    ADJ_SL
        CALL    REL_VID_ADDR
        POP     BX
        PUSH    [X_POS]
        CALL    X_MASK
        POP     CX              ;READ MASK
        PUSH    ES              ;SAVE ES STATUS
        MOV     AX, OC000H
        MOV     ES, AX
        SEG      ES
        MOV     DL, [BX]          ;READ DATA IN BLUE BIT PLANE
        AND     DL, CL          ;TEST IF BIT SET
        JNZ     B1
        JMP     NO_B
B1:      MOV     AX, ODOOOH
        MOV     ES, AX
        SEG      ES
        MOV     DL, [BX]          ;READ DATA IN RED BIT PLANE
        AND     DL, CL          ;TEST IF BIT SET
        JNZ     B2
        JMP     B_NO_R

```

```

B2:    MOV     AX, 0E000H      ;RED IS SET, TEST GREEN
       MOV     ES, AX
       SEG     ES
       MOV     DL, [BX]      ;READ DATA IN GREEN BIT PLANE
       AND     DL, CL        ;TEST IF BIT IS SET
       JNZ     B3
       JMP     BR_NO_G
B3:    MOV     AX, 0           ;COLOR IS WHITE
       JMP     EXIT_IC
BR_NO_G: MOV     AX, 2           ;COLOR IS MAGENTA
       JMP     EXIT_IC
B_NO_R: MOV     AX, 0E000H      ;BLUE IS SET, RED IS NOT, TEST GREEN
       MOV     ES, AX
       SEG     ES
       MOV     DL, [BX]      ;READ DATA IN GREEN BIT PLANE
       AND     DL, CL
       JNZ     B4
       JMP     B_NO_RG
B4:    MOV     AX, 1           ;COLOR IS CYAN
       JMP     EXIT_IC
B_NO_RG: MOV     AX, 3           ;COLOR IS BLUE
       JMP     EXIT_IC
NO_B:  MOV     AX, 0D000H      ;NO BLUE, TEST RED
       MOV     ES, AX
       SEG     ES
       MOV     DL, [BX]      ;READ DATA IN RED BIT PLANE
       AND     DL, CL
       JNZ     B5
       JMP     NO_BR
B5:    MOV     AX, 0E000H      ;RED IS SET, NO BLUE, TEST GREEN
       MOV     ES, AX
       SEG     ES
       MOV     DL, [BX]      ;READ DATA IN GREEN BIT PLANE
       AND     DL, CL
       B6
       JMP     R_NO_BG
B6:    MOV     AX, 4           ;COLOR IS YELLOW
       JMP     EXIT_IC
R_NO_BG: MOV     AX, 6           ;COLOR IS RED
       JMP     EXIT_IC
NO_BR:  MOV     AX, 0E000H      ;NO BLUE, NO RED, TEST GREEN
       MOV     ES, AX
       SEG     ES
       MOV     DL, [BX]      ;READ DATA IN GREEN BIT PLANE
       AND     DL, CL
       B7
       JMP     NO_RGB
B7:    MOV     AX, 5           ;COLOR IS GREEN
       JMP     EXIT_IC
NO_RGB: MOV     AX, 7           ;COLOR IS BLACK
       POP     ES            ;RESTORE ES
       PUSH   AX
       PUSH   [RET_IC]       ;RESTORE RETURN ADDRESS
       RET
END PROC INQ_COLOR;
;*****
;*****
;PROCEDURE X_MASK ACCEPTS AN X COORDINATE POSITION AS INPUT
;AND RETURNS A BIT MASK BASED ON THE X COORDINATE
PROC X_MASK;
       POP     DX            ;SAVE RETURN ADDRESS
       POP     AX            ;GET X POSITION
       AND     AX, 7
       JNZ     MBIT1
       MOV     AX, 80H
       JMP     EXIT_XM
MBIT1:  SUB     AX, 1
       JNZ     MBIT2
       MOV     AX, 40H

```

```

MBIT2:
    JMP EXIT_XM
    SUB AX, 1
    JNZ MBIT3
    MOV AX, 20H
    JMP EXIT_XM
MBIT3:
    SUB AX, 1
    JNZ MBIT4
    MOV AX, 10H
    JMP EXIT_XM
MBIT4:
    SUB AX, 1
    JNZ MBIT5
    MOV AX, 8
    JMP EXIT_XM
MBIT5:
    SUB AX, 1
    JNZ MBIT6
    MOV AX, 4
    JMP EXIT_XM
MBIT6:
    SUB AX, 1
    JNZ MBIT7
    MOV AX, 2
    JMP EXIT_XM
MBIT7:
    MOV AX, 1
EXIT_XM:
    PUSH AX           ;RETURN X MASK
    PUSH DX           ;RESTORE RETURN ADDRESS
    RET

END PROC X_MASK;
;*****PROCEDURE X_MASK TAKES AS INPUT A X POSITION AND A MASK COLOR AND
;*****PERFORMS A SCREEN FILL WITH THE SPECIFIED MASK COLOR UP TO THE
;*****SPECIFIED BOUNDARY
PROC BOUNDARY_FILL;
    POP [RET_FILL]
    POP [B_COLOR]
    POP [F_COLOR]
    MOV [SEGMENT_FE], ES
    MOV AX, [COL_PL1]
    MOV AX, [SAV_COL1_STAT], AX
    MOV AX, [COL_PL2]
    MOV AX, [SAV_COL2_STAT], AX
    MOV AX, [COL_PL3]
    MOV AX, [SAV_COL3_STAT], AX
    CALL B_FILL
    PUSH [RET_FILL]
    MOV ES, [SEGMENT_FE]
    MOV AX, [SAV_COL1_STAT]
    MOV AX, [COL_PL1], AX
    MOV AX, [SAV_COL2_STAT]
    MOV AX, [COL_PL2], AX
    MOV AX, [SAV_COL3_STAT]
    MOV AX, [COL_PL3], AX
    RET

END PROC BOUNDARY_FILL;
;*****PROCEDURE BOUNDARY_FILL IS THE RECURSIVE PART OF THE BOUNDARY FILL PROCEDURE.
;*****IT IS USED TO AVOID UNNECESSARY PASSING OF THE COLOR PARAMETERS WHICH
;*****DO NOT CHANGE ON SUCCESSIVE RECURRSIVE CALLS.
PROC B_FILL;
    POP DX           ;SAVE RETURN ADDRESS
    MOV CX, [X_POS]
    MOV BX, [Y_POS]
    POP [Y_POS]        ;GET NEXT Y POSITION OFF STACK
    POP [X_POS]        ;GET NEXT X POSITION OFF STACK
    PUSH DX
    PUSH CX
    PUSH BX
    PUSH [X_POS]       ;SAVE PRESENT X POSITION
    PUSH [Y_POS]       ;SAVE PRESENT Y POSITION

```

```

CALL INQ_COLOR
POP AX
MOV [P_COLOR], AX ;COMPARE COLOR AT PRESENT LOCATION
CMP AX, [B_COLOR] ;WITH BOUNDARY COLOR
JNZ TEST_FC
JMP EXIT_F
TEST_FC:
MOV AX, [P_COLOR] ;COMPARE COLOR AT PRESENT LOCATION
CMP AX, [F_COLOR] ;WITH FILL COLOR
JNZ F_PIX
JMP EXIT_F
F_PIX:
PUSH [X_POS]
PUSH [Y_POS]
CALL ADJ_SL
CALL REL_VID_ADDR
PUSH [X_POS]
PUSH [F_COLOR]
CALL COLOR
CALL CIR_PIXEL ;SET LOCATION (X,Y) TO FILL COLOR
MOV AX, [X_POS]
ADD AX, 1
PUSH AX
PUSH [Y_POS]
CALL B_FILL ;CALL B_FILL PASSING (X+1,Y)
MOV AX, [X_POS]
SUB AX, 1
PUSH AX
PUSH [Y_POS]
CALL B_FILL ;CALL B_FILL PASSING (X-1,Y)
MOV AX, [Y_POS]
ADD AX, 1
PUSH AX
PUSH [X_POS]
PUSH AX
CALL B_FILL ;CALL B_FILL PASSING (X,Y+1)
MOV AX, [Y_POS]
SUB AX, 1
PUSH AX
PUSH [X_POS]
PUSH AX
CALL B_FILL ;CALL B_FILL PASSING (X,Y-1)
POP [Y_POS]
POP [X_POS] ;RESTORE POSITION (X,Y)
RET

```

END PROC B\_FILL;

;\*\*\*\*\*

;PROCEDURE AREA\_FILL ACCEPTS AS INPUT AN (X,Y) POSITION AND A  
;FILL COLOR. IT FILLS AN AREA WHOSE BOUNDARY IS DETERMINED BY THE  
;PRESENT COLOR OF THE INPUT (X,Y) POSITION.

PROC AREA\_FILL;

```

POP [RET_AFILL] ;SAVE RETURN ADDRESS
MOV [SEGMENT_FE], ES
MOV AX, [COL_PL1]
MOV [SAV_COL1_STAT], AX
MOV AX, [COL_PL2]
MOV [SAV_COL2_STAT], AX
MOV AX, [COL_PL3]
MOV [SAV_COL3_STAT], AX
POP [F_COLOR] ;GET FILL COLOR OFF OF STACK
POP [Y_POS]
POP [X_POS]
PUSH [X_POS]
PUSH [Y_POS]
CALL INQ_COLOR ;GET COLOR OF INPUT POSITION
POP [B_COLOR] ;SAVE REFERENCE COLOR
PUSH [X_POS]
PUSH [Y_POS]
CALL A_FILL ;CALL RECURSIVE FILL PROCEDURE
PUSH [RET_AFILL] ;RESTORE RETURN ADDRESS
MOV ES, [SEGMENT_FE]
MOV AX, [SAV_COL1_STAT]

```

```

MOV      [COL_PL1], AX
MOV      AX, [SAV_COL2_STAT]
MOV      [COL_PL2], AX
MOV      AX, [SAV_COL3_STAT]
MOV      [COL_PL3], AX
RET
END PROC AREA_FILL;
;*****
;*****
;PROCEDURE A_FILL IS THE RECURSIVE PART OF THE AREA FILL PROCEDURE.
;IT IS USED TO AVOID UNNECESSARY PASSING OF THE COLOR PARAMETERS WHICH
;DO NOT CHANGE ON SUCCESSIVE RECURRSIVE CALLS.
PROC A_FILL;
    POP      DX          ;SAVE RETURN ADDRESS
    MOV      CX, [X_POS]
    MOV      BX, [Y_POS]
    POP      [Y_POS]      ;GET NEXT Y POSITION OFF STACK
    POP      [X_POS]      ;GET NEXT X POSITION OFF STACK
    PUSH   DX
    PUSH   CX
    PUSH   BX
    PUSH   [X_POS]      ;SAVE PRESENT X POSITION
    PUSH   [Y_POS]      ;SAVE PRESENT Y POSITION
    CALL   INQ_COLOR
    POP      AX
    MOV      [P_COLOR], AX
    CMP      AX, [B_COLOR]
    JNZ      EXIT_AF
    PUSH   [X_POS]
    PUSH   [Y_POS]
    CALL   ADJ_SL
    CALL   REL_VID_ADDR
    PUSH   [X_POS]
    PUSH   [F_COLOR]
    CALL   COLOR
    CALL   CIR_PIXEL
    MOV      AX, [X_POS]
    ADD      AX, 1
    PUSH   AX
    PUSH   [Y_POS]
    CALL   A_FILL
    MOV      AX, [X_POS]
    SUB      AX, 1
    PUSH   AX
    PUSH   [Y_POS]
    CALL   A_FILL
    MOV      AX, [Y_POS]
    ADD      AX, 1
    PUSH   [X_POS]
    PUSH   AX
    CALL   A_FILL
    MOV      AX, [Y_POS]
    SUB      AX, 1
    PUSH   [X_POS]
    PUSH   AX
    CALL   A_FILL
    POP      [Y_POS]
    POP      [X_POS]
    RET
EXIT_AF:
END PROC A_FILL;
;*****
;*****
MAIN:
END ADAGRAPH;

```

## LIST OF REFERENCES

1. *Technical Manual, Hardware, Z-100 Series Computers*, Zenith Data Systems Corporation, 1983.
2. Draft Department of Defense Directive 5000.31, *Computer Language Programming Policy*, Computer Software & Systems (OUSD&AT), The Pentagon, Washington, DC, 1983.
3. Wagner, Patrice M., "Ada and Graphics, Implications of the DOD Directive," *Computer Graphics World*, February 1985.
4. *American National Standard, X3.124.3-198X, Graphical Kernel System*, by Technical Committee X3H3 - Computer Graphics, American National Standards Committee X3 - Information Processing Systems, Computer and Business Equipment Manufacturers Association, June 1986.
5. *JANUS/Ada Package, User Manuals*, Software, Inc., 1983.
6. *CP/M-86 Operating System User's Guide*, Digital Research, 1982.
7. Berger, Marc, *Computer Graphics with Pascal*, The Benjamin Cummings Publishing Company, Inc., 1986.
8. Hearn, Donald and Baker, M. Pauline, *Computer Graphics*, Prentice-Hall, 1986.

## BIBLIOGRAPHY

- Barnes, J. G. P., *Programming in Ada*, Addison-Wesley Publishing Company, 1984.
- Booch, Grady, *Software Engineering with Ada*, The Benjamin/Cummings Publishing Company, Inc., 1983.
- Bray, Gary and Pokrass, David, *Understanding Ada*, John Wiley & Sons, 1985.
- Coomes, Kenneth W., *Tactical Display Simulation on the HZ-100*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1986.
- Foley, J. D. and Van Dam, A., *Fundamentals of Interactive Computer Graphics*, Addison-Wesley Publishing Company, 1982.
- Rector, Russell and Alexy, George, *The 8086 Book*, Osborne-McGraw-Hill, 1980.
- United States Department of Defense, *Reference Manual for the Ada Programming Language*, ANSI MIL-STD-1815A-1983, Springer-Verlag, 1983.

## INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2. Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
3. Department Chairman, Code 52 Department of Computer Science Naval Postgraduate School Monterey, California 93943	1
4. Dr. Uno R. Kodres, Code 52Kr Department of Computer Science Naval Postgraduate School Monterey, California 93943	3
5. Dr. Michael J. Zvoda, Code 52Zk Department of Computer Science Naval Postgraduate School Monterey, California 93943	1
6. Daniel Green, Code 20F Naval Surface Weapons Center Dahlgren, Virginia 22449	1
7. CAPT. J. Hood, USN PMS 400B5 Naval Sea Systems Command Washington, D.C. 20362	1
8. RCA AEGIS Repository RCA Corporation Government Systems Division Mail Shop 127-327 Moorestown, New Jersey 08057	1
9. Library (Code E33-05) Naval Surface Weapons Center Dahlgren, Virginia 22449	1
10. Dr. M. J. Gralia Applied Physics Laboratory John Hopkins Road Laurel, Maryland 20707	1
11. Dana Small, Code 8242 NOSC San Diego, California 92152	1
12. Thomas R. Brown Jr. 409 Essex Dr. Lexington Park, Maryland 20653	2





DUDLEY LIBRARY  
NAVAL POSTGRADUATE SCHOOL  
MONTEREY, CALIFORNIA 93943-5002

220957

Thesis

B82275 Brown

c.1 A general purpose graphics support library for the Ada programming language hosted on the Zenith H/Z-100 computer.

220957

Thesis

B82275 Brown

c.1 A general purpose graphics support library for the Ada programming language hosted on the Zenith H/Z-100 computer.

thesB82275  
A general purpose graphics support libra



3 2768 000 75821 3  
DUDLEY KNOX LIBRARY