Graphics software and hardware for RT-11 systems

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A general-purpose graphics package is described that allows the user to generate figures with a superset of the basic CalComp plotting subroutines. The software runs under RT-11 on an LSI-11 with 28K words of memory. The graphics subroutine library is approximately 200 blocks long. The plotting tasks are passed over an RS 232 line to a simple extension of an inexpensive and commercially available graphics controller. The controller implements these tasks as plotting instructions to a color television, a vector display, and a digital plotter. The graphics subroutines are written in FORTRAN and are invoked by the user as subroutine calls from a FORTRAN program. The graphics controller is a modified Motorola "Micro Chroma 68 Kit." The board is based on the 6808 microprocessor and 6847 video controller. It provides eight graphic modes from 64 by 32 eight-color graphics to 128 by 192 four-color graphics to 256 by 192 two-color graphics. The present software and hardware implements the graphics subroutines as 256 by 192 two-color graphics, as 512 by 512 vector graphics, and as stepping instructions for a digital plotter.

A laboratory graphics capability was developed by modifying an inexpensive, commercially available, video graphics controller and writing the software required to enable a user to easily generate and output desired figures. The software and hardware were developed for use on Digital Equipment Corporation (DEC) PDP-11 family computers with the real-time (RT-11) operating system. However, the software was written in a relatively standard FORTRAN, and the graphics controller was designed to receive input over an RS 232 channel. As a result, the graphics software can be modified to run in other environments and the controller can be used with other host computers. The graphics package presently provides for output to black-and-white or color televisions, a vector controller, and a digital plotter. A somewhat straightforward modification would provide the capability to directly drive an X-Y plotter or a vector display.

COMMERCIAL HARDWARE

Figure 1 provides a block diagram of the graphics hardware. The main computer system is based on an LSI-11 (Doyle & Palya, 1980; Palya & Doyle, 1980). We are currently using an unmodified color television as a display device, a Megatek BP 734 vector controller with a Fairchild 737A display, and a Houston Instruments DP 7 digital plotter. The graphics software requires

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Figure 1. A block diagram of the basic graphics hardware.

about 28K words of memory to run, and the library requires about 200 blocks of disk storage.

The graphics controller is a modified Motorola "Micro Chroma 68 Kit." The board is based on the 6847 video controller and provides eight graphic modes from 64 by 32 eight-color graphics, to 128 by 192 four-color graphics, to 256 by 192 two-color graphics. Figure 2 provides a block diagram of the Micro Chroma 68 board. This commercial board is a stand-alone system and contains a 6808 microprocessor, a 2K monitor, 8K user RAM, a keyboard port, a "Kansas City standard" tape port, 6K video display RAM, and circuitry to connect to an unmodified color television. Motorola provides the printed circuit board and major chip set to universities for \$89. The additional parts needed to complete the kit cost approximately \$150.

Figure 2. A block diagram of the commercially available Micro Chroma 68 board.

CUSTOM HARDWARE

The present system did not implement the monitor, the tape port, or the keyboard port that were available on the Micro Chroma 68 board. Rather, the present implementation uses the board as a dedicated peripheral controller that is downline loaded through an RS 232 port. Figure 3 provides a block diagram of the graphics controller. A 1K communications monitor in PROM, interfaces for the vector display (RS 232), and the digital plotter (parallel I/O adapter and one shots) were implemented on the "kluge" area provided on the Micro Chroma board. With the addition of parallel adapters, digital-to-analog converters, and task software, a vector display or an X-Y plotter can be directly interfaced.

COMMERCIAL SOFTWARE

The graphics subroutines are invoked by the user as subroutine calls from a FORTRAN program running under DEC's RT-11 operating system. Figure 4 illustrates the overall architecture of the commercial software used in displaying graphics. The user writes the program in FORTRAN, including the calls to the graphics subroutines. This program is compiled and then linked with the COMLIB library, which produces the machine-runnable program. The graphics library, COMLIB, emulates the CalComp "Host Computer Basic Software," or HCBS (Calcomp Computer Products, 1976, 1977). In addition, it also includes other graphic subroutines that provide for the more convenient generation of the type of figures that are typically used in psychology.

CUSTOM SOFTWARE

The custom software consists of three main groups: the initialization and utility software, which sets up and carries out the interprocessor communication; the graphics processor software, which receives the informa-

tion from the main system, processes it, and controls the appropriate display device; and the library of graphics subroutines. Figure 5 illustrates these custom software elements in the graphics package.

The initialization and utility software is invoked by a subroutine call to PLOTS, which must be called before any other graphic subroutine. It is a FORTRAN routine that determines the display device requested by the user, obtains and downline loads the appropriate software for the graphics controller, obtains and installs the appropriate data passing software for the LSI-11, and initializes the graphics software.

The graphics controller monitor contains an input routine in PROM that loads in the task-specific software to control the requested display device from the RS 232 channel. The graphic controller then inputs graphics commands into a 6K input buffer. This typically releases the main processor from a graphics tasks almost immediately. The task-specific software in the controller imple-

Figure 3. A block diagram of the Micro Chroma 68 board as modified for use as a graphics controller.

Figure 4. Architecture of the commercial software used in displaying graphics.

Figure 5. Overall architecture of the software used in displaying graphics.

ments the graphics input as 256 by 192 two-color raster graphics, as 512 by 512 vector graphics to a Megatek graphics controller, or as stepping instructions for a Houston Instruments DP 7 plotter.

The library of graphics subroutines is detailed in the Appendix. They are for the most part hierarchical, with PLOT as the kernel or basic HCBS subroutine. PLOT either simply moves the "pen" to some x,y coordinate or draws a line while moving the pen. Virtually all other subroutines call PLOT to implement their specific functions. We have supplemented PLOT with MOVE, which also allows control of the line type while moving the pen.

AXIS is the CalComp HCBS subroutine that draws axes, adds tic marks, numbers the tics, and labels the axes. Unfortunately, it provides only a very restricted

and generally unacceptable format. The present library superseded AXIS with AXSLIN (draw axis line), TICS (draw tic marks), TICLBL (label the tic marks), and AXSLBL (label the axis). These routines provide complete and convenient control of each element and allow the user to create figures with a satisfactory appearance.

SYMBOL and NUMBER are the CalComp subroutines for drawing symbols and numbers. SYMBOL draws designated characters, and NUMBER draws the characters that specify the value of a number. SYMBOL has been modified to contain a character set with a better appearance, as well as a character set for the vector display. TEXT has been added to the library. It centers a string of characters between specified points and provides any desired character rotation.

The HCBS library also contains several utility subroutines. LINE is the CalComp subroutine that draws a line. It has been expanded with ILINE (draw an interrupted line), DRAWLN (draw a line with data from the disk), NEWLIN (change line type), PENUP, PENDN, and HOME (return to current origin). Several other HCBS support subroutines are included in the library, such as NEWPEN (change pens), SCALE (scale data to fit axis), WHERE (returns x,y coordinate of current pen location), and FACTOR (draws figure to specified scale). Calling FACTOR (.5) reduces the entire figure by 50%.

REFERENCES

- CALCOMP COMPUTER PRODUCTS. *CalComp software reference manual*. Anaheim, Calif: Author, 1976.
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- DOYLE, A. F., & PALYA, W. L. A hierarchical LSI-11 system for real-time control, interevent time storage, and data analysis. *Behavior Research Methods & Instrumentation*, 1980, 12, 221-231.
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APPENDIX

PLOTS

INITIALIZES GRAPHICS SYSTEM

DEVICE
CHARACTER SET

PLOT

MOVES PEN - MANIPULATES ORIGIN

X.Y COORDINATE OF DESTINATION
PEN UP / PEN DOWN
REESTABLISH ORIGIN
RETURN CURRENT LOCATION
CLEAR SCREEN

NEWLIN

CHANGES LINE TYPE

SOLID
DOTTED
DASHED
BROKEN
DOT/DASH

NEWPEN

CHANGES PEN

PEN 1. 2. OR 3

MOVE

MOVES PEN - MANIPULATES ORIGIN

X.Y COORDINATE OF DESTINATION
PEN UP / PEN DOWN
REESTABLISH ORIGIN
RETURN CURRENT LOCATION
DESIRED PEN
LINE TYPE (SOLID, DOTTED, DASHED,
BROKEN, DOT-DASH)

WHERE

RETURNS CURRENT X.Y LOCATION

HOME

MOVES PEN TO CURRENT ORIGIN

FACTOR

CHANGES SIZE OF FIGURE

PROPORTION OF ORIGINAL

AXSL IN

DRAWS AXIS LINE

AXIS ANGLE
AXIS LENGTH
NUMBER OF OFFSET RETRACES
CENTERED / ONE SIDE
DISTANCE BETWEEN RETRACES

TICS

DRAWS TIC MARKS

AXIS ANGLE
AXIS LENGTH
DISTANCE TO FIRST TIC
SPACE BETWEEN TICS (MANUAL)
HOW MANY TICS (AUTO)
LENGTH OF TICS
WIDTH OF TICS

TICLBL

LABELS TIC MARKS

AXIS ANGLE
AXIS LENGTH
DISTANCE TO FIRST NUMBER
SPACE BETWEEN NUMBERS (MANUAL)
HOW MANY NUMBERS (AUTO)
VALUE OF FIRST TIC
VALUE INCREMENT PER TIC
NUMBER OF DECIMAL PLACES
HEIGHT OF NUMBERS
ROTATION OF NUMBERS
DISTANCE FROM AXIS

AXSLBL

LABELS THE AXIS

AXIS ANGLE
AXIS LENGTH
NUMBER OF CHARACTERS
DESIRED TEXT
CHARACTER SIZE
CHARACTER ROTATION
DISTANCE FROM AXIS
OFFSET FROM CENTERED

LINE

DRAWS A LINE

ARRAY OF X COORDINATES
ARRAY OF Y COORDINATES
NUMBER OF DATA POINTS
ARRAY INDEX
LINE TYPE
CONNECTED / NOT CONNECTED POINTS
SYMBOLS / NO SYMBOLS
FREQUENCY OF SYMBOLS
DESIRED SYMBOL

SCALE

PREPROCESSES DATA

FIRST ELEMENT IN ARRAY
NUMBER OF ELEMENTS IN ARRAY
ARRAY INDEX
LENGTH OF AXIS ON TO WHICH ARRAY MUST FIT

AXIS

DRAWS AXIS, TIC MARKS, AND LABEL

X,Y COORDINATE OF AXIS ORIGIN
AXIS ANGLE
AXIS LENGTH
VALUE OF FIRST TIC
VALUE INCREMENT PER TIC
DESIRED TEX
NUMBER OF CHARACTERS

NUMBER

DRAWS A NUMBER

X,Y COORDINATE OF START OF NUMBER
HEIGHT OF NUMBER
VALUE OF NUMBER
ANGLE OF NUMBER STRING
FORMAT
NUMBER OF DECIMAL PLACES
INTEGER / REAL
TRUNCATION

TEXT

SYMBOL

DRAWS CENTERED TEXT

PAIR OF X,Y COORDINATES
NUMBER OF CHARACTERS
DESIRED TEXT
HEIGHT OF CHARACTERS
ROTATION OF CHARACTERS
OFFSET FROM CENTERED

ABCDEFGHIJKLMN
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
. , : ; ! ? ' " # \$ % & * + - =
0 1 2 3 4 5 6 7 8 9 Σ o f - f j n
> < = + - * / \ () [] { }
◇ ◆ ○ ● □ ■ △ ▲ ☆ ★
AB<D<F<H I J K L M N O P Q R S T U V W X Y Z

DRAWS SYMBOL

X,Y COORDINATE OF START OF TEXT
ANGLE OF TEXT STRING
NUMBER OF CHARACTERS
DESIRED TEXT
HEIGHT OF CHARACTERS
PLOTTER / CRT SYMBOL SET