THE GRAPHICS SUBSYSTEM OF THE VERTICAL WORKSTATION
OF THE AUTOMATED MANUFACTURING RESEARCH FACILITY
AT THE NATIONAL BUREAU OF STANDARDS

Dr. Thomas R. Kramer
Guest Researcher, National Bureau of Standards, &
Research Associate, Catholic University

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THE GRAPHICS SUBSYSTEM OF THE VERTICAL WORKSTATION
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I. INTRODUCTION

1. CONTENTS

This paper discusses the graphics subsystem of the Vertical Workstation (VWS) of the Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards. The descriptions pertain to the system in use during the summer of 1987.

Chapter II gives an overview of the graphics subsystem, its appearance, uses, strong points, and weak points.

Chapter III describes the arrangement of the drawing window, the appearance of the drawing of a feature, how the drawing is covered with a grey mask, how finding part locations is done, how the picture of a feature may be flashed, how the feature number of a feature may be found from the picture of the feature, how the drawing may be refreshed, and how the drawing may be wiped out.

Chapter IV presents other graphics capabilities that are available only from certain parts of the system, namely, the Part Design Editor, the Data Execution module, and the vws_cadm user interface.

Chapter V discusses several software techniques and issues: the database needed by the graphics subsystem, the relative merits of masking vs. clipping, how function switches are used for scaling and translation, how using polygons compares with using lines in SunCore, when images are saved on disk or restored from disk, the pros and cons of SunCore, and the use of segment indexes. This chapter also makes brief mention of some capabilities which were developed but are not currently in use. Finally, it discusses alterations to three pairs of SunCore functions.

Chapter VI gives a brief description of the software of the graphics subsystem.

2. AUDIENCE

The paper is intended to be useful to people interested in concepts and technical details of the VWS, particularly AMRF personnel who are running the VWS or maintaining or improving the software for the VWS. The paper is intended to be useful also to other researchers in automated manufacturing. Knowledge of the computer language LISP and familiarity with computer graphics are useful but not essential to reading this paper. Detailed documentation of the LISP functions that are involved with the systems described here is being prepared separately.

3. BRIEF VWS DESCRIPTION

The VWS is a computer-integrated automated machining workstation. It includes a control system, a computer-aided design system, an automatic process planning system, and an automatic NC-code generator. The principal machinery is a milling center (Monarch VMC-75 with a GE2000 controller) and a robot (Unimate 4070 with a Val II controller) to tend the milling center. There is quite a bit of ancillary hardware. The system is controlled from a microcomputer (Sun 3/160 with 6Mb memory, BW monitor). Running in stand-alone mode, it is possible to design and machine a simple metal part within an hour. The VWS may also be run as an integrated part of the AMRF. The workstation is described in more detail in [K&J1].

The software for the VWS is written in Franz LISP dialect of the computer language LISP. A national standard graphics package named "Core" has been implemented for the Sun computer by Sun Microsystems and named "SunCore". An interface between Franz LISP and SunCore was written by Franz, Inc. In this paper the VWS software is called the VWS2 system. SunCore (via the Franz interface) is the graphics package on which the VWS2 Graphics Subsystem is built. Six principal modules comprise the VWS2 system: the Production Management Operating System (the control system), the State Table Editor, the Equipment Program Generator, the Part Design Editor, the Process Planner, and the Data Execution module.

The Part Design Editor, Process Planning and Data Execution modules, as well as other system capabilities, may be accessed by the user through a small user interface called vws_cadm. Vws_cadm asks the user questions about what the user wants to do and then activates the appropriate module or other capability accordingly.

To produce a part from scratch, the user sits at the Sun workstation and creates a design using the Part Design Editor. The Process Planner is then called to write a plan for how to machine a part of that design. Next NC-code is generated automatically from the design and the plan by the Data Execution module. Finally the user tells the control system to make the part. The control system coordinates the activities of the workstation equipment so that the part blank is loaded onto the milling machine, the NC-code is sent to the milling machine and executed (making the part), and the finished part is unloaded.

To make a part using existing data, the VWS controller calls on the local database manager to retrieve several types of data: tray contents, VWS process plan, and NC-code. Following the process plan, the VWS controller directs workstation activity so that the robot loads the part onto the milling machine, the NC-code is sent to the milling machine and executed, and the finished part is unloaded.

4. RELATED READING

This paper is one of about a dozen papers being prepared as part of the AMRF documentation to describe all aspects of the VWS. The others are [JUN], [KRA1], [KRA3], [KRA4], [K&J2], [K&S2], [KR&W], [LOVE], [NA&J], and [RUDD]. Other papers, prepared for professional meetings, also describe the VWS [KRA2], [K&J1], and [K&S1].

II. OVERVIEW

1. USES

The graphics subsystem of the VWS2 system is used to display designs and workpieces. The graphics subsystem is used by the Part Design Editor module to display designs, by the Data Execution Module to display workpieces, and directly from the vws_cadm user interface to display designs and workpieces. The graphics subsystem provides a few other capabilities, as well: displaying the appearance of text fonts, displaying the position of a cursor, and drawing the path of the tools used to machine a part.

The graphics subsystem is not under direct user control. Rather, the user interacts with the Design Editor or vws_cadm, and they control the graphics subsystem.

Hard copies of pictures made by the graphics subsystem may be made by screen dumps or by using an advanced desktop publishing system such as Frame Maker or Interleaf to capture pictures directly from the computer screen. All such hard copies are bit images.

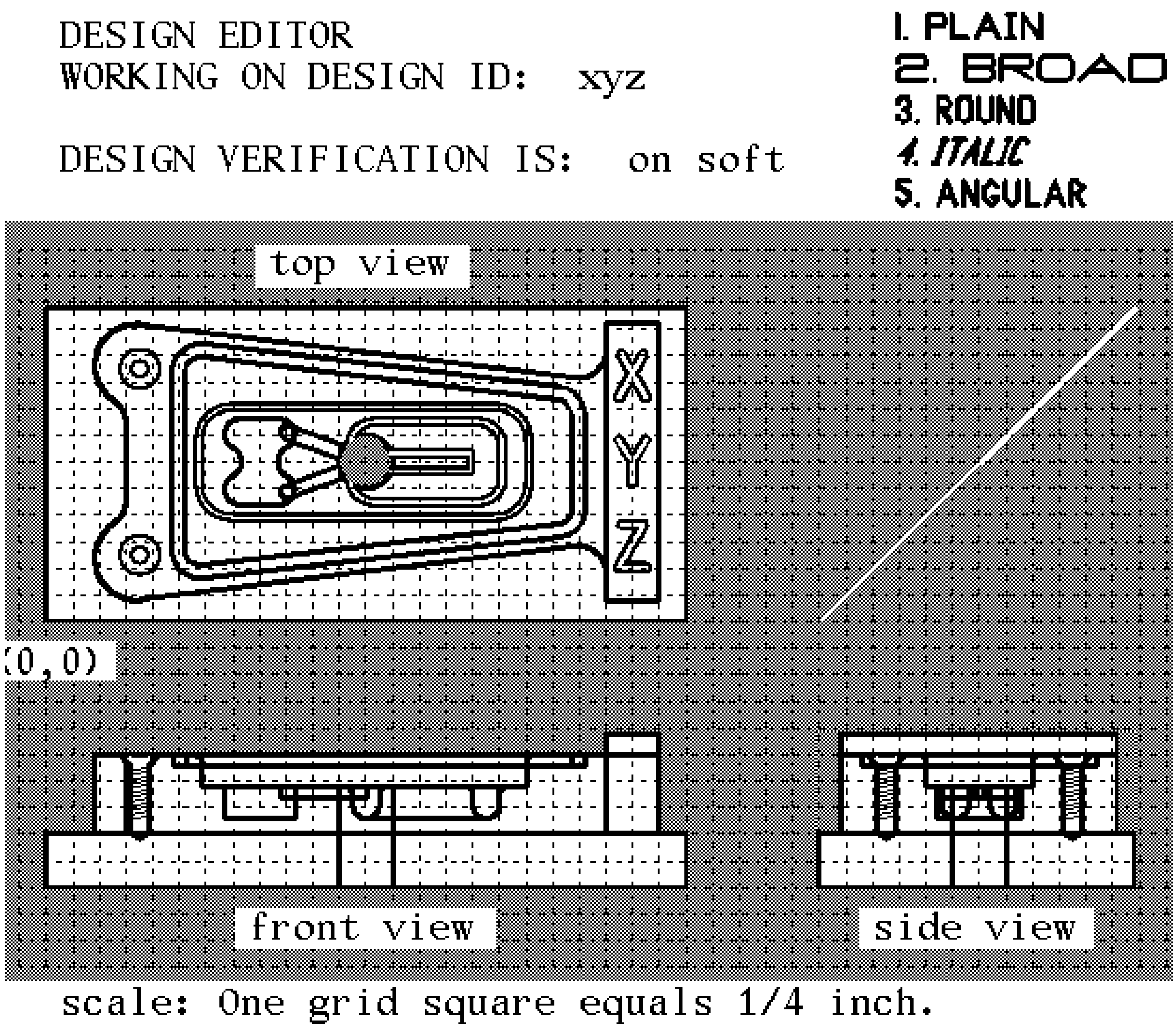
An expert user can make additional uses of the subsystem, such as drawing figures. In these uses the subsystem is under direct user control. The additional uses require detailed knowledge of LISP and SunCore and are not discussed further in this paper.

2. APPEARANCE

In all of its uses, the graphics subsystem shows three orthographic views of the item being displayed, as on a conventional mechanical drawing. The drawing is done in a window on the screen of the Sun computer terminal. The drawing is scaled automatically according to the size of the item being displayed. The scale of the drawing is not under control of the user, except that the user may use the standard Sun window manipulation facilities to make the window bigger or smaller, move it around, etc.

Figure 1 shows the graphics window as it appears in the design editor. A demonstration part called the XYZ part is drawn in the figure.

Figure 1. Drawing of XYZ Part



3. STRONG POINTS

The graphics subsystem provides a decent representation of a design or workpiece for the user. It draws quickly enough not to irritate the user. It requires comparatively little user input to produce a fairly complicated picture. It is easy to get a hard copy.

When used in the Data Execution module, the graphics subsystem provides a good simulation of the machining process.

The subsystem provides the user with useful information. It can respond quickly and accurately to questions like:

What change to the workpiece was made in step 10 of the process plan just executed?
What is the feature number of the feature I am pointing at?
What does feature 6 look like?
What are the part coordinates of the point I am pointing at?
What does the XYZ part look like?

4. WEAK POINTS

The graphics subsystem does not provide much user control of the picture. No three-dimensional pictures, alternate views, cutaways, zooming, coloring, labelling with text, arrows, etc., or layering (features found on commercial CAD systems) are available.

The subsystem does not provide a true picture of the part when features intersect. The entire picture of each feature is drawn even if some or all of the feature is eaten away by some other feature.

The VWS2 system does not provide device drivers for pen plotters or laser printers to make high-quality images.

III. GENERAL APPEARANCE AND USE

1. ARRANGEMENT OF THE DRAWING WINDOW

The graphics subsystem, is part of a LISP process running in a window under the "Suntools" window environment. When a picture is to be created, the LISP process creates a new core tool covered by a graphics window in the upper left-hand corner of the screen. All the drawing commands given from the LISP process are directed to this window. Figure 1 shows the normal screen layout and should be used for reference in reading the rest of this section.

The initial window size is 746 by 670 pixels. The subsystem is tuned to this window size, in the sense that the best picture is made when the window is that size. The window size was selected several years ago as a convenient size to fit in an overall window layout. This size does not optimize anything, but it does not present any particular difficulties, either. The window may be made about 50 percent larger or 10 percent smaller (by using the Suntools window manipulation facilities) without creating any glaring defects in the picture.

The reason that changing the window size changes more than the size of the picture is that for a fixed linewidth setting, the number of pixels in the width of a line varies with the size of the window. The most common linewidth used in the subsystem results in lines that are three pixels wide in the 746 by 670 window. If the size of the window is increased, some lines will jump to five pixels wide, depending upon the angle of the line with the horizontal, while other lines will remaing at three pixels wide. This degrades the quality of the picture.

The scale of the picture is calculated automatically. A fixed space is allotted into which the picture of the part must fit. The subsystem determines how to fit the block on which the part is based into the allotted space so as to make the largest possible picture. First, the block is fitted so as to use up all the horizontal space. If this makes a picture that is too tall to fit vertically, it scraps the horizontal fit and fits the block vertically, instead. The scale of graphics coordinate units per inch is determined according to the fit.

A grid of dotted lines somewhat like a piece of graph paper is drawn next. The area covered by the grid is held within narrow limits, but the size of a single grid square (and hence the number of grid lines), varies with the size of the block so as to keep the number of pixels per grid square in a reasonable range. The scale of inches per grid line also varies, but is always a multiple of 2. In other words, acceptable values for inches per grid line are chosen from the sequence (. . . 4, 2, 1, 1/2, 1/4, 1/8 . . .). There is no maximum or minimum.

Three views of the blank block from which the part will be made are placed on the grid, and the scene is labelled. The three views are placed so that the top view is directly above the front view and the side view is directly to the right of the front view. Thus, the grid lines may be used to match corresponding views of the same feature. A 45 degree oblique line is drawn directly to the right of the top view of the block and directly above the side view. The oblique line is used along with the grid lines to match corresponding views of a feature on the top view and the side view.

At the top of the window on the left, three to five lines of text identify:

A. The module or facility using the subsystem ("Design Editor" in Figure 1).
B. The name of the design or workpiece ("XYZ" in Figure 1) - both if the Data Execution Module is in charge.
C. The current setting of the verification system ("on soft" in Figure 1).
D. The name of the file to which NC-code is being written, when the Data Execution Module is run with graphics and NC-coding turned on.

At the top right of the picture in the Design Editor, either pictures of fonts or position information appear from time to time. Fonts are showing in Figure 1.

2. APPEARANCE OF A FEATURE

2.1. Introduction

The graphics subsystem makes a picture by drawing features and subfeatures on the three views of the block (the one exception being the thread subfeature, which does not appear on the top view). This is followed in some cases by masking out portions of the block which have been completely milled away. Each view of a feature is a silhouette of the feature, in which just the outline of the feature is visible.

Except for three subfeatures (countersink, chamfer_in, and chamfer_out), the drawing of which modifies the appearance of the parent feature, each feature is drawn as though it were the only feature on the part. The lines created by the intersection of features are not drawn, and the lines destroyed by machining over an existing feature are not removed.

All features that are legitimate (in the sense that the verification system says they are OK), will be drawn correctly. Features that fail verification may be incorrectly drawn. Pockets whose right side is to the left of the left side look quite peculiar, for example.

Dozens of examples of the appearance of features and subfeatures are given in Chapter II of [K&J2].

2.2. Drawing Text and Contour_Grooves

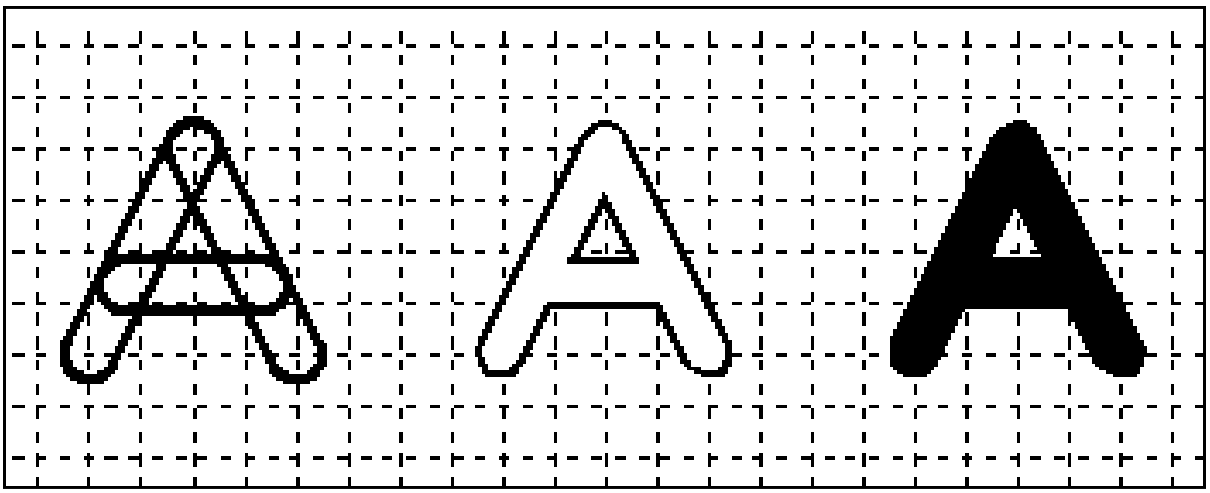
All but two features are drawn with thin (1 to 3 pixel wide) lines. The two exceptions are the text and contour_groove features, which are drawn with polygons. Text and contour_groove features are likely to overlap themselves. Determining the actual outline of an arbitrary contour_groove is a formidable task that has not been undertaken in the VWS2 system.

Fortunately, a little drawing trickery makes an accurate picture of the outline without any calculation of the outline required. The technique is to draw the feature twice, first with a set of black polygons, and then again with a set of slightly narrower white polygons. The black that remains at the end is a correct outline.

The technique is illustrated in Figure 2. In Figure 2 the letter A is drawn three times. On the left, it is drawn as it would appear if the outlines of all three parts of it were drawn separately. On the right it is shown in black as it appears after the first stage of the actual drawing. In the middle it is shown as appears when the drawing is finished. Notice that since the drawing is made with polygons, the grid lines that pass behind the middle view are covered up by the interior of the A.

The grid lines can be restored by refreshing the picture, but if there were outlines of any other features underneath the middle A, they would have been covered up, also, even if they should appear. This is a slight drawback of this method of outline drawing.

Figure 2. Drawing Text



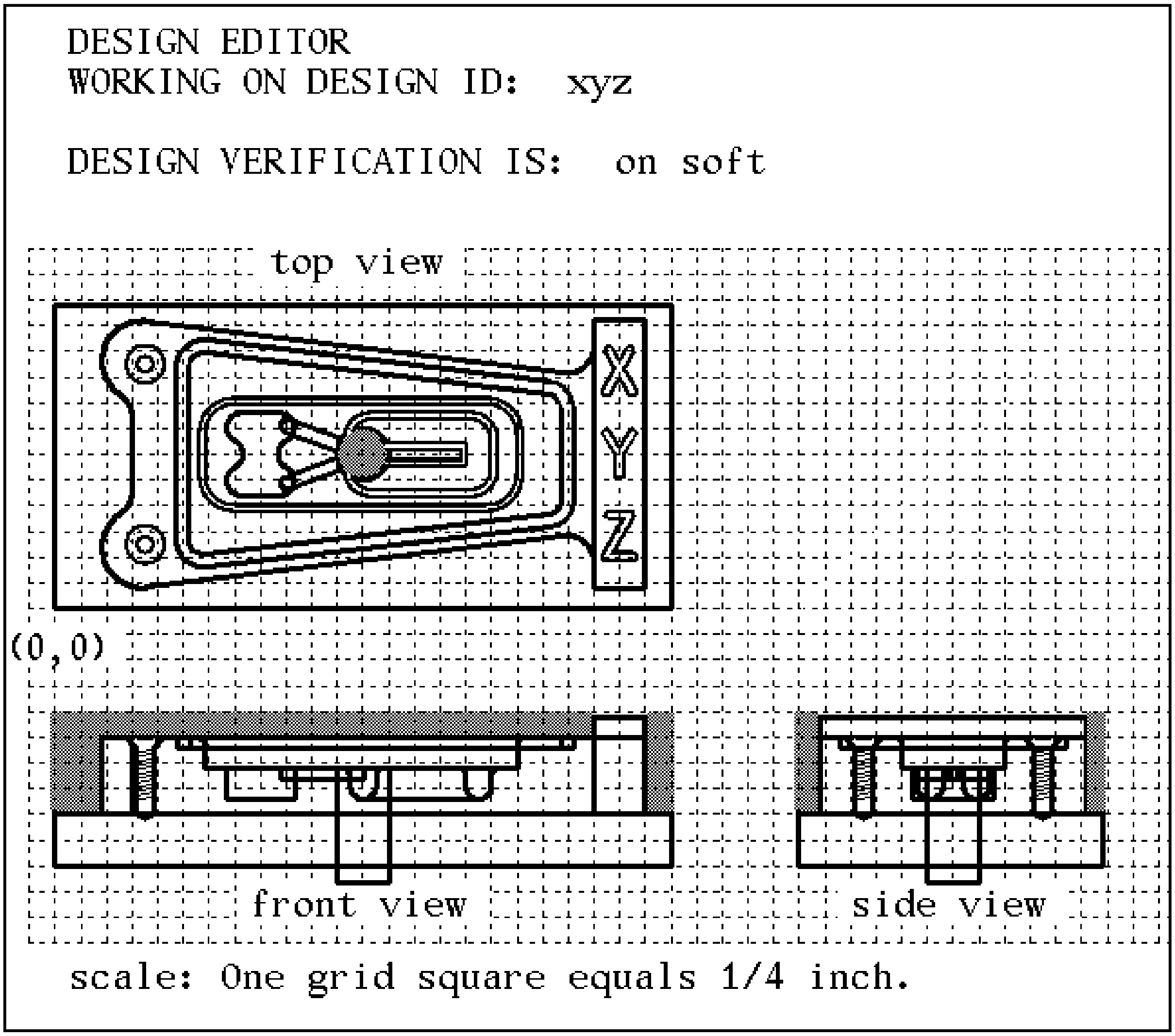
3. MASKING

As may be seen from Figure 1, the three views of a part appear to be drawn against a grey background. This appearance is an illusion. The grey is actually drawn over the top of the part. The grey areas of a picture form a mask that covers up portions of features. The grid and the labels are drawn on top of the mask.

When the picture of a block with no features is generated (this is the first step in all pictures), a "main mask" is generated. The main mask appears to be a rectangular polygon with three holes in it, one for each of the three views of the block. Actually, the main mask is an odd-shaped polygon with no holes (SunCore does not include the ability to draw polygons with holes).

When features are added that go all the way through the block or cut all the way across it on the front or side view, additional grey polygons are generated which cover up more sections of the block. The grey circle on the top view of the part in Figure 1 is an example. It indicates a through hole. When these additional bits of mask are on the periphery in any of the views, they blend (almost) seamlessly with the main mask and with each other to give a clear picture of the new outline of the part. Figure 3 shows the same part as Figure 1, but the main mask has been deleted. The grey patches on Figure 3 are the extra bits of mask required by this drawing.

Figure 3. Bits of Mask



This figure shows the same part as Figure 1, but the main mask has been removed, leaving the six mask bits in clear view. There is one mask bit on the top view, two on the side view, and three on the front view. Note how the two rectangular mask bits at the upper left of the front view merge together seamlessly to form an L-shaped mask bit.

Constructing the extra pieces of mask is painstaking, since the portion of the outline of each mask piece that touches the part should not cover up any part of the three-pixel outline of the part and the portion that touches the main mask should overlap the main mask a little, so that there are no white spaces between the main mask and the extra bits of mask.

To accomplish this, the outline of each mask bit must be retracted an average of 1.5 pixels from the part and extended into the main mask at least two pixels. Because of rounding, the main mask and the extra bits will occasionally be one pixel removed from their proper location.

The masks are kept in the subsystem's data base as a series of polygon commands. Polygon commands are added to the data base or deleted from it each time a feature is added or deleted. In the Design editor, the mask is not redrawn automatically each time a feature is drawn, because this would be too time consuming. Two editor commands ("group" and "array") always redraw the mask, but normally the user must use the "rdraw" command to see the current mask. An indexing system is used to keep track of which pieces of mask go with which features.

The masking system is not smart enough to know that the mask should be changed if two or more features combine to remove material all the way across the block on the front or side view.

4. LOCATOR

The Design Editor includes a command named "loc". This command prompts the user to use the mouse to point at the picture and press the right mouse button. When the right button is pressed, a cross-hair is displayed at the position of the mouse cursor, and the location of the point picked is shown in the upper right corner of the picture, given in part coordinates (including the name of the view of the part in which the cross-hair is located). Position information is rounded off to the nearest eightieth of an inch.

Additional information about "loc" is given on page 94 of [K&J2] and pages B-33 and B-34 of [KRA4].

5. FLASHING

The graphics subsystem can flash the picture of a feature or subfeature on and off. Flashing is done automatically in the Design Editor when the user elects to change or delete a feature. Flashing is done automatically after a successful pick, as described in the next section. Flashing is done under user control in the Design Editor by using the "flash" command, as described on page 94 of [K&J2] and page B-24 of [KRA4].

The change in the picture of a part resulting from the execution of a step of a process plan may be flashed by breaking into LISP when a picture which was drawn by the Data Execution module is on the screen and giving the LISP command (flash_step n), where n is the number of the step the user wants to see.

Feature flashing may be done on a picture drawn by the Data Execution module by giving the LISP command (flash_feature n), where n is the number of the feature the user wants to see.

6. PICKING

If, while using the Design Editor, a user wants to know the feature number of a feature drawn on the screen, the "pick" command will do it. After calling the "pick" command, the user points at the feature with the mouse and pushes a button. The number of the feature is printed in the command screen. This is described in more detail on page 95 of [K&J2] and page B-41 of [KRA4].

7. REFRESHING THE SCREEN

The appearance of a picture may be degraded by deleting features (which leaves white patches), by adding features (so that the mask gets out of date), by using the locator (which puts cross-hairs on the picture), by using the Suntools redisplay facility (which puts the features on top of the mask), or other ways. To get the picture clean to the best of the graphics subsystem's ability, the user may call the "rdraw" command of the Design Editor, or break into LISP and give the command (refresh_part_display). More information about this is given on page 95 of [K&J2] and page B-43 of [KRA4].

8. WIPING OUT A PICTURE

The picture created by the Design Editor may be wiped out by turning graphics off. See page 94 of [K&J2] and page B-27 of [KRA4]. When the user quits the Design Editor any existing picture is automatically wiped out.

From vws_cadm a picture may be wiped out by using the "ge" command (short for graphics erase) of the output facility. See page A-28 of [KRA4].

A picture may also be wiped out by breaking into LISP and giving the command (close_part_display).

IV. <u>OTHER GRAPHICS CAPABILITIES</u>

1. INTRODUCTION

Some capabilities of the graphics subsystem not mentioned in Chapter III are available from only one of: the Design Editor, the Data Execution module, and the vws_cadm user interface. These follow.

2. DESIGN EDITOR

The Design Editor includes a "draw" command which may be used to regenerate the picture of a feature even if the feature has not been changed. It is described on page 94 of [K&J2] and page B-20 of [KRA4].

It also includes a "block" command, which will wipe out any existing picture and draw a block with no features. See page 94 of [K&J2] and page B-10 of [KRA4].
output

In helping the user specify a contour outline, the graphics subsystem will automatically draw a "frame" for the outline. The frame is wiped out when the user finishes specifying the outline. Some frames are shown on page 65 of [K&J2].

3. DATA EXECUTION MODULE

In the Data Execution module, the picture is drawn by showing what each machining operation does. This differs from design drawing in that producing a feature may require more than one operation. For example, a countersunk, threaded hole requires at least three operations: a hole-making operation (which may be either "drill_hole" or "mill_pocket"), a "machine_countersink" operation, and a "tap_thread" operation. In the Design Editor, the thread and the countersink appear on the picture as soon as the hole is drawn. In the Data Execution module, typically, there may be several other things drawn between the making of a hole and its countersinking or tapping. If a workpiece is being partially machined (leaving out the thread), only the hole and countersink would be drawn.

4. VWS_CADM

Four graphics capabilities are available from the vws_cadm user interface. These are described in detail on pages 8 and A-23 through A-28 of [KRA4]. One of these, wiping out the picture, was described in section 8 of the last chapter.

A second capability, drawing the path of the tool, is available from vws_cadm only when a picture drawn by the Data Execution module is still on the screen after the Data Execution module wrote an NC-code file. In addition to the description referenced above, Chapter 12 of [K&S2] discusses tool path drawing.

The third graphics capability available from vws_cadm is drawing a workpiece, and the fourth is drawing a design. The design drawing capability is separate from the Design Editor and gives no opportunity for changing a design. It is usually preferable to fire up the editor for looking a design.

V. SOFTWARE TECHNIQUES AND ISSUES

1. DATABASE

The graphics subsystem uses the property list of the LISP atom "drawp" to store information it needs on a continuing basis. Sixteen properties are kept. A description of LISP hierarchical property lists is given in Chapter II, section 2.5 of [KRA3]. A description of the details of the property list of "drawp" is given in Chapter IV, section 3 of the same paper. Three of the items in the database are described in section 7 below.

2. MASKING VS. CLIPPING

As discussed in section 3 of Chapter III, masking is used to create the appearance that the part is in front of a grey background. One of the benefits of masking is that if a feature extends off the side of the block in any of the views, so that part of the feature appears to be hanging in midair, the portions of the feature that go off the block are covered up by the mask. Another way of dealing with such features would be to calculate where the feature runs off the block and not draw the portions of any lines that lie outside the block. This is called "clipping", since the process is like taking a scissors and clipping off any lines that stick out.

Several clipping algorithms were written and implemented during the development of the graphics subsystem, but the routines only clipped lines that ran off a set of rectangles. In order to draw correctly, the clipping routines would have to be able to clip any line extending outside of an arbitrary outline. This involves a great deal of calculation and was not undertaken.

3. SCALING AND TRANSLATION WITH FUNCTION SWITCHES

The graphics subsystem is constructed so that drawing commands use x, y, and z values expressed in part coordinates, not in SunCore's world coordinates for the drawing window. To do this, the graphics subsystem must be able to do scaling and translation automatically. Moreover, the same drawing commands may be used on each of the three views of the part. These capabilities are implemented as follows.

When the subsystem initializes a picture, it defines a set of drawing functions for each of the three views of the part (top, front, and side). Each set has five primitive drawing functions in it, one for drawing a straight line to a specific point, one for drawing a straight line by moving incrementally, one for moving to a specific point without drawing, one for moving incrementally, and one for drawing an arc. The correct translation and scaling numbers for the view are hard coded into these primitive functions. Actually, since the scale is the same for all three views, the same incremental draw and move functions work for all three views.

When drawing is to be done on a particular view, a command is given which redefines three functions - view_line_abs, view_move_abs, and view_arc - by assigning the definition already generated for the corresponding primitive in the appropriate view. For example, to draw on the top view, the LISP command (draw_top_view) is given, and:

A. the definition of view_line_abs is automatically set to the definition of view_line_top.
B. the definition of view_move_abs is automatically set to the definition of view_move_top.
C. the definition of view_arc is automatically set to the definition of arc_top.

The image best associated with this process is that of a large switch with three bars and three positions. By moving the handle to one of the three positions, the juice for each of three functions is drawn from one of three sources. This is shown schematically in Figure 4.

Using these function switches has two benefits: fewer parameters have to be passed to do a drawing and the functions run faster than if parameters were used, since the values are hard-coded.

Two other functions might have been included in this function switch setup but have remained in the old form that requires parameter passing. These are for drawing polygons in the shape of crescents and bars and are called view_crescent and view_bar.

4. POLYGON VS. LINE DRAWING

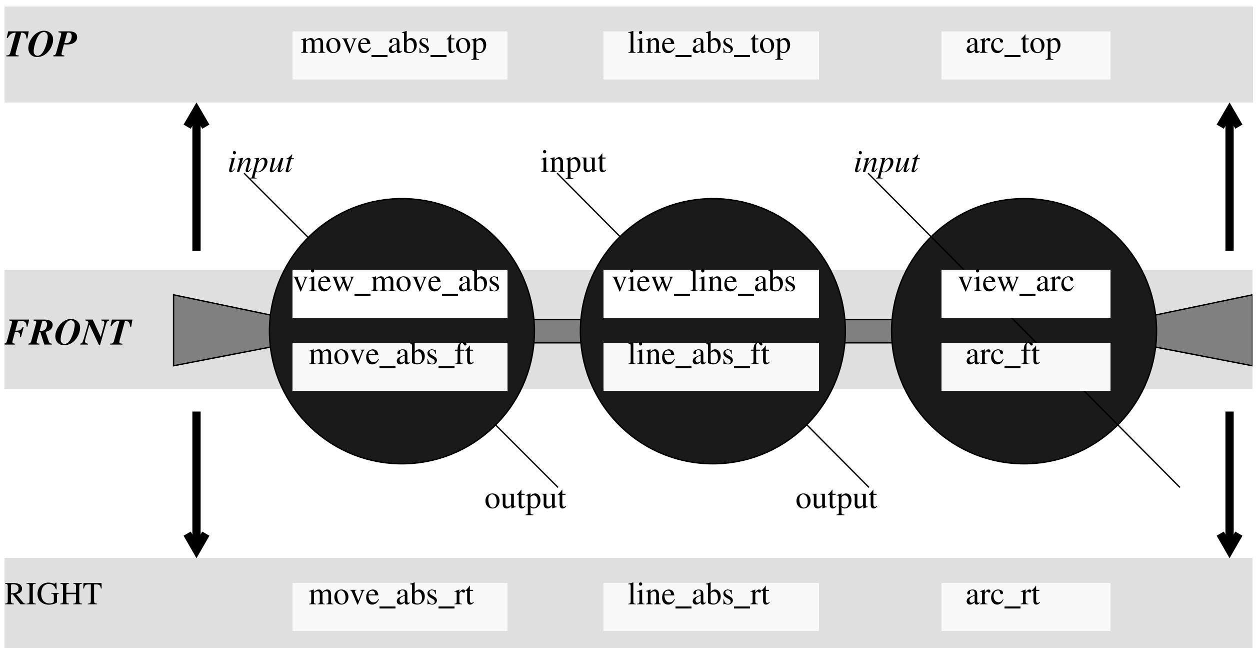
SunCore draws with lines that are an odd number of pixels wide. Most of the lines made by the graphics subsystem are three pixels wide when the window is normal size, but some use is made of 1 and 2 pixel wide lines. Lines 2 pixels wide are made in the subsystem by whiting out one pixel worth of a 3-pixel wide line - an awkward method, at best.

SunCore lines are rounded with semicircles at the ends, so that they potentially mimic the pattern left by a cutting tool in a milling machine quite well. Unfortunately, they do not live up to the potential.

Earlier versions of the graphics subsystem used lines to represent text and contour_grooves. In the current version of the subsystem, text and contour_grooves are made by using polygons. The change was made for three reasons. First, SunCore lines are all an odd number of pixels wide, so that line widths increase by jumps of two pixels, making a less accurate picture than with polygons, which can be made wider in increments of one pixel. Second, although line widths are expressed as percentages of screen width, it is difficult to scale them correctly; the scaling does not turn out quite as expected. Third, arcs made with a series of lines have whiskers one to three pixels long that stick out normal to the arc, if the line is five or more pixels wide. This is apparently a bug in SunCore. Polygons have no whiskers.

In addition, polygon drawing seems to be slightly faster than line drawing. This is surprising since more than twice as many calculations must be done in LISP to describe the outline of a polygon as to describe the center line of the polygon.

Figure 4. Function Switches



This figure shows a schematic view of function switches. Imagine that the three functions, view_move_abs, view_line_abs and view_arc, (shown as circles above) are connected together by a bar with handles on the ends (shown with vertical stripes above). The bar slides up and down vertically.

The definitions of view_move_abs, view_line_abs, and view_arc are determined by the position of the bar. In the front position, the definition of view_move_abs is the definition of move_abs_ft, the definition of view_line_abs is the definition of line_abs_ft, and the definition of view_arc is the definition of arc_ft.

The command "draw_top_view" moves the bar to the top position, "draw_right_view" moves the bar to the right position, and "draw_front_view" moves it to the front position (where it is shown above).

5. STORING AND RESTORING IMAGES

SunCore includes the capability of storing graphics segments in disk files and restoring them when desired. The graphics subsystem uses this capability for only one purpose: displaying fonts. The picture of five fonts shown at the upper right of Figure 1 is stored in a single graphics segment on disk. Whenever a window is created by the subsystem, this segment is restored, bringing it into on-board memory. From there, its visibility is turned on and off as necessary.

6. SUNCORE

6.1. Using SunCore

The SunCore software used in the graphics subsystem is incorporated into Franz Lisp through an interface written by Franz, Inc. The interface is good, but has not been updated in several years. One SunCore function, "set_pick", that is required by the subsystem for picking features is not included in the Franz interface. It is brought into the LISP environment when the environment is built by calling "getaddress" after SunCore is loaded.

SunCore functions are called from LISP by using the name of the SunCore function, as given in the users manual, with the prefix "sc:".

6.2. Advantages of SunCore

SunCore is a very powerful graphics package. It supports two or three-dimensional graphics. The VWS2 graphics subsystem makes use of only the two-dimensional capabilities. SunCore requires the user to draw in segments. Each segment has a name and may have many drawing primitives (lines, polygons, etc.) in it. Segments may be turned on and off, stacked one on top of another, saved and restored, transformed several ways, clipped several ways, and picked with the mouse.

SunCore supports graphical input routines (picking, locating, and button sensing) so that it may be used as the basis for user interactive graphics.

In summary, nearly all the tools a programmer might want to build a graphics application package for the VWS2 system are available in SunCore.

6.3. Disadvantages of SunCore

SunCore's has three distinct disadvantages: it is ornery, comparatively slow, and a memory hog.

Although SunCore is powerful, even after several years of programming with it, getting it to do what is wanted always seems like wading through molasses. It is sensitive to the slightest error in input data or usage in a program, and it usually gives no clue as to what is bothering it. For example, if given a fixed point number for an x or y coordinate when told to draw something (it always wants a floating point number for a coordinate), it is apt to do nothing but draw a dot at the origin. It gives no error message and the manual gives no warning. Only after making this mistake several times and wasting a lot of time does the programmer learn to recognize it quickly.

Using most of the capabilities of SunCore requires the programmer to go through several initiation steps. An example is using the locator; three initiation steps are required: initialize_device, set_echo_surface, and set_echo. If an initiation step is skipped, the system usually sends a helpful error message when a function call is made to the desired capability, but it would have been much nicer if the system would either always initiate all its capabilities itself, or would initiate whatever it needed the first time the capability was used. Barring that, just putting all the initiation in one function call would have been a straightforward matter.

Slowness is relative, of course, but a crude absolute measure is: does the user get irritated waiting for a drawing to be done. By this measure, the VWS2 graphics subsystem is slow only for complicated contour features. The slowness may be in SunCore, it may be in the LISP-SunCore interface, or it may be in memory management for SunCore.

In any event SunCore is much slower than lower level graphics packages, and it has often been tempting to try another package in order to get more speed. Fortunately, the speed of the Sun computer itself has increased so much over the past few years as new models have come out, that the speed of the VWS2 graphics subsystem has increased substantially even while the amount of calculation required of it has also increased.

SunCore uses memory in the LISP environment. It takes more memory when it wants it, and (unlike LISP, which reclaims used memory that does not need to be saved) it never gives it back. If a design is made in the Design Editor which includes two or three complicated contour grooves (so that the picture of each groove requires 50 to 100 polygons), SunCore is apt to commandeer two megabytes of memory, thus expanding the size of the LISP environment beyond its upper limit of 6Mb. This results in either a core dump, an error message, or a "goodbye" message from LISP, which then wipes itself out. It is not clear what SunCore is doing with all that memory, since it seems to be more than necessary by a factor of at least 10.

If the VWS2 system is run with graphics on for a few hours, even if relatively simple pictures are drawn, SunCore eventually uses up all the available space in the LISP environment. If the VWS2 system is run with graphics off, it does not grow more than a few tenths of a megabyte beyond its original size (about 3.5 Mb).

The line-drawing bug and limitations mentioned in section 4 are minor disadvantages.

7. MAINTAINING SEGMENT INDEXES

In order to manipulate the picture of a part correctly for operations like refreshing a drawing, flashing a feature, flashing a step, changing a feature, or deleting a feature, it is necessary to keep information about what graphics segments currently exist, and how the graphics segments correspond to steps or features. This is done in the graphics subsystem by keeping three data structures in the graphics database: a segment list, a feature index, and a step index.

The segment list property name is "segment_list" in the property list of "drawp". It is a simple list of all graphics segments currently in existence. Except for the font picture, which is named "drawp_fonts", the name of each segment is "drawp_n", where n is an integer. A segment counter named "last_seg_no" is kept and incremented by one each time a new segment is drawn. The value of the counter is used for n to generate the name of the new segment. When new segments are drawn, they are added to the list. When existing segments are wiped out, they are deleted from the list. Six segments have reserved names, as follows:

drawp_0 is used (and re-used) for position information.
drawp_1 is the grid.
drawp_2 is the labels, excluding the verification level.
drawp_3 is the block.
drawp_4 is the label giving the verification level.
drawp_5 is the mask.

The step index property name is "step_index". The value of the property is a LISP disembodied property list in which the property names are integers representing step numbers from a process plan, and the value of each property is the name of a segment (namely the one that depicts that step). Each step is drawn in at most one segment, so that this structure is feasible. Some steps, such as initialization, closing, and probing, are not drawn at all.

The feature index property name is "feature_index". The value of the property is a LISP disembodied property list in which the property names are integers representing feature numbers from a design. The value of each property is a list of the names of the segments that depict that step. There will be one to three names in each list. A countersunk, threaded hole, for example, is drawn in three segments even though it is a single feature.

In the Design Editor, the features of the design may be renumbered from time to time. A LISP function, "reseq_feat_index", is used to update the feature index whenever a renumbering of features is performed. The index is also updated whenever a feature is added or deleted.

8. GRAPHICS SUBSYSTEM CAPABILITIES NOT USED IN VWS2

8.1. Picking from Menu with Mouse

Routines based on SunCore for picking items from menu with the mouse have been written and tested. They work, but they are slow compared with Suntools menus, for example. The graphics subsystem does not use these routines.

It would be preferable to build an interface between LISP and the Suntools menu capabilities than to use menu facilities built on SunCore. This has not been done in the VWS2 system.

8.2. Automatic Stuffing of Position Data

The location finding capability called "loc" in the Design Editor and based on the LISP graphics function "show_position" prints information about the position of the mouse on the screen, rather than automatically recording the position information in the design. Since the show_position function returns the position information, it would be feasible to stuff the information into a data structure automatically. This is not done in the version of the graphics subsystem which is documented here. Extensive add-ons to the VWS2 system have been written, tested, and used, which do make use of automatic data stuffing. They have not been documented yet.

8.3. Use of Icons

A typical use of graphics input in many systems is to have the user give commands to the system by pointing at a picture (called an icon) that represents the command, and pushing a button. The VWS1 graphics subsystem, predecessor of the VWS2 graphics subsystem, was used by the VWS control system in this icon picking mode for a few months. The graphics subsystem displayed the pictures of several parts. The user would point at one with the mouse and press a button, and the VWS would make that part. That application also included a method of changing the menu of icons.

The VWS1 application of icons was effective but slow, and the capability was not frequently used, since after a part was picked, it normally took the system twenty minutes to an hour to make the part before another part could be picked. This capability has not been incorporated in the VWS2 system or its current enhancements. It could be restored easily if there is a need for it.

9. THE "FIX_GRAPHICS" FILE

After the graphics subsystem had been largely written using the normal definitions of SunCore functions, it was decided to improve the behavior of three pairs of functions:

A. initialize_device and terminate_device
B. initialize_core and terminate_core
C. create_retained_segment and close_retained_segment

The standard SunCore version of one or both members of each of these pairs of functions will send an error message if it is called at the wrong time. For instance, calling close_retained_segment when no segment is open results in an error message.

It was desired to be able to call these functions without receiving error messages. To do this, the "fix_graphics.l" file was written. This file is loaded when the LISP environment is built. When the instructions in the file are executed, the standard definitions of the six functions are saved under new names, and the old function names get new definitions, which call the old definitions using the new names. The new function definitions check whether a call to the old function definition is actually required before making it. For instance, the new definition of close_retained_segment checks whether there is an open segment. If no segment is open, close_retained_segment does nothing. If there is an open segment, the old definition is used to close it.

In order to make the appropriate checks, the information being checked had to be saved. This was done by creating a place to put data inside the definition of the first member of each pair of functions, and updating the information whenever either member of the pair is called. In other words, calling either member of the pair redefines the first member slightly. For instance, calling create_retained_segment (when there is no open segment) redefines create_retained_segment to include the name of the newly created segment. If close_retained_segment is called later, it examines the definition of create_retained_segment. If the name of a segment is found at the correct place in the definition, close_retained_segment closes the segment and redefines create_retained_segment by removing the name of the previously open segment.

Data is inserted in a function by placing a disembodied property list in the function definition immediately after the list of arguments to the function. Since the list of data is part of a function definition, when the function is called, LISP interprets the list as a function and evaluates it. Protecting the data from evaluation could be done with the "quote" function, but has been implemented by placing an nlambda function named "data_in_def", which always evaluates to nil, at the head of the list. When LISP evaluates an nlambda function it does not evaluate its arguments, and nlambdas take any number of arguments.

Using a function definition to hold global data that changes may seem odd, but it works quite well in LISP. Using the function definition itself to hold the data isolates the data from anything that may befall the rest of the system.

If the graphics subsystem had not already been largely built using the old function names, it would have been better to use new function names for the new functions, rather than redefining the old ones.

VI. SOFTWARE

1. INTRODUCTION

The functions that make up the graphics software are listed in Table 1, where they are divided in eight categories. A description of each category follows.

The functions of Table 1 are all from the subdirectory "draw2" in the directory ~kramer/vws2. Each of them is kept in a file with the same name as the functions, plus the suffix ".l", except for view_arc, view_line_abs, view_line_rel, view_move_abs, and view_move_rel. Those five functions are redefined dynamically as described in section 3 of Chapter V.

The functions shown in Table 1 are called as required by other components of the VWS2 system: the Design Editor, the Data Execution module, and the vws_cadm user interface. Of course, any of the functions may be used directly from LISP, but only the expert user should try such use.

2. HIGH LEVEL AND MISCELLANEOUS FUNCTIONS

The focal point for drawing in all but the Data Execution module is the "draw_feature" function. It draws a feature and any subfeatures the feature may have. It is called by "draw_object" (which, in turn is subordinate to "draw_design" and "draw_part") and by the Design Editor. In the Data Execution module, features and subfeatures are drawn separately by function calls to the graphics subsystem made by the "execute_step" function, as described in section 3.2 in Chapter II of [KR&W].

3. FEATURE AND SUBFEATURE DRAWERS

There are twelve feature and subfeature drawers. Each of the nine features types (contour_groove, chamfer, contour_pocket, side_contour, groove, hole, pocket, straight_groove, and text) has its own drawing function. Three of the four subfeatures (chamfer_in, countersink, and thread) have their own drawing functions. The chamfer_out subfeature uses the drawing routine for the chamfer feature.

4. OTHER CONTOUR FEATURE AND TOOL PATH DRAWING FUNCTIONS

Three low-level functions are required for drawing contour features. The tool path drawing system also requires three functions.

5. FEATURE PROFILE AND OUTLINE DRAWERS

The top view of a feature in the graphics subsystem is called its outline. The front and side views are called profile views. Except in simple cases, the feature and subfeature drawers call on outline and profile drawing routines. There are five outline drawers and seven profile drawers included in the software.

6. LOW LEVEL LINE, POLYGON, AND MASK DRAWERS

There are nine functions for constructing and drawing masking polygons (the seven that have "mask" as part of their name in Table 1, plus "polygon" and "sector").

Nine low level functions do line drawing. As shown in Figure 4, nine more line drawing functions are hidden behind the scenes to save the definitions of view_arc, view_line_abs, and view_move_abs needed for drawing on the three views. No function calls are ever made to the nine hidden functions, however. In fact, since the definitions are LISP lists, saving the definitions could be accomplished by making the definitions be the values of global variables or the values of properties in a property list.

Three low level functions (polygon, view_bar, and view_crescent) are used to draw the outline of text and contour_groove features.

7. FUNCTIONS THAT DEFINE FUNCTIONS

Four of the six functions that define functions (define_draw_funcs, draw_ft_view, draw_rt_view, and draw_top_view) were discussed in Chapter V, section 3.

To be sure the graphics subsystem makes a good simulation of the machining process when drawing for the Data Execution module, some drawing parameters (the diameter of a hole, for example) are taken from the description of the tool used in the process being drawn. The description of the tool is extracted from the tooling database by the "get_desc_from_slot" function. In order to draw for other purposes, the graphics subsystem requires a partial description of an imaginary tool. The "redefine_get_slot" function redefines "get_desc_from_slot" each time "draw_feature" is called so that "get_desc_from_slot" returns an appropriate imaginary description when it is called by other drawing functions. When "draw_feature" is finished, it restores the normal definition of "get_desc_from_slot".

8. INITIALIZATION, TERMINATION, AND LABELLING FUNCTIONS

Picture initialization is accomplished by "init_part_display", which calls eight subordinates. The picture is terminated by "close_part_display".

To do the initialization, "set_window" (which calls "makewindow") starts up the window and initializes all the devices needed. Then "find_scale" figures out how to fit the three views of the part into the window. The block and grid are drawn by "draw_block" and "draw_grid". The labels are drawn by "draw_labels" and "draw_verify" (which is separate so that verification level information can be changed without redrawing the whole picture).

9. DISPLAY MANIPULATION FUNCTIONS

These are the functions required for flashing, picking, deleting, displaying fonts, displaying position information, refreshing the picture, and refreshing the mask, as described earlier in this paper.

Table 1. Graphics Subsystem Software

High Level and Miscellaneous Functions arc_center draw_design draw_feature draw_mask draw_object draw_part inc_seg_no reseq_feat_index set_fill_shading	***Feature Profile and Outline Drawers*** cg_outline chamf_profile char_outline contour_trace groove_profile hole_profile pocket_profile stg_outline text_ft_profile text_outline text_rt_profile thread_profile	***Functions that Define Functions*** define_draw_funcs draw_ft_view draw_rt_view draw_top_view redefine_get_slot
Feature and Subfeature Drawers draw_cg draw_chamf_in draw_chamf_out draw_cp draw_cs draw_csink draw_groove draw_hole draw_pocket draw_straight_groove draw_text draw_thread	***Low Level Line, Polygon, and Mask Drawers*** arc arc2 arc_side_view lozenge main_mask mask_contour mask_lozenge mask_rect mask_sector mask_triangle polygon put_mask sector view_arc view_bar view_crescent view_line_abs view_line_rel view_move_abs view_move_rel	***Picture Initialization, Termination, and Labelling functions*** close_part_display draw_block draw_grid draw_labels draw_verify find_scale init_part_display makewindow set_window
Other Contour Feature and Tool Path Drawing Functions draw_cg_frame draw_cg_lines draw_corner draw_tool_depth_loop draw_tool_path draw_tool_path_seg		***Display Manipulation Functions*** erase_feature flash_feature flash_step pick_feature_num refresh_part_display remask show_fonts show_position

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