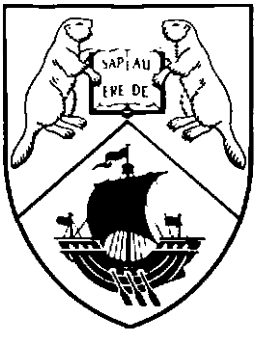
A COMPUTER AIDED DESIGN TUTORIAL SYSTEM (CADETS)

BY

LEONARD SLIPP
UDAY G. GUJAR

TR86-034, MAY 1986

SCHOOL OF COMPUTER SCIENCE



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ABSTRACT

Computer aided design (CAD) systems have proved to be a very valuable tool widely used in industry. These systems are often expensive both from the hardware and software point of view. As such first hand training becomes an expensive proposition especially in an environment where training is the main goal and production a secondary or a minor goal. Such is the case in the educational institutions.

This paper describes a two-dimensional Computer Aided DEsign Tutorial System (CADETS) modelled after Unigraphics I. Written in APL, the system does not demand any knowledge of APL for the user. An IBM 3279 colour graphics terminal is used as a graphics input as well as output device. The screen is divided into five windows. The main, and the largest, window is used for graphics; the others are used for user communication. Menus are used extensively to generate, modify and manipulate the display.

Within CADETS, there are currently eleven ways to create a point, thirteen ways to create a line segment, ten ways to specify a circular arc and several functions to generate common geometric objects such as triangles, rectangles, polygons, etc.

Once created, the user may edit the graphics model by deleting geometric entities either individually or in a group. Line segments may be extended or trimmed to specified boundaries, constrained to intersect at a corner, etc. Arcs may be extended or truncated so that they would be bound by specified angles or points or lines which intersect them. The visual attributes of any entity may be changed. The user can also control the view area and scale of model thus providing a pan and zoom capability to concentrate on selected areas of the display. An interface has been provided to produce a hardcopy on a variety of devices.

The system has been used by several users including high school students who were unaware of even the existence of APL. The system requires minimal investment on hardware as well as software compared to sophisticated expensive systems, yet provides tools for teaching several fundamental CAD techniques. Plans are underway to enhance 2-D capabilities, incorporate other inexpensive graphics devices and include 3-D graphics.

INTRODUCTION

Computer Aided Design has become an important tool in Canadian industry. To effectively use this technology, however, a considerable amount of time is required for novice users to become familiar with a particular system. Dedicated workstations are an expensive resource which generally makes them impractical to train large groups of users. A more economical solution is to move inexperienced users to relatively inexpensive terminals during the initial learning period. Once they have mastered the basic skills, they can use workstations in a more productive manner.

This is the motive behind the development of CADETS (Computer Aided DEsign Tutorial System), a two-dimensional wireframe modelling system designed for use in the university environment. To enhance the utility of CADETS, it is modelled after UNIGRAPHICS I, a two and three dimensional wireframe and surface modelling system developed by McAuto[1].

CADETS is written in APL[2], a powerful language which the authors have found to be very convenient in developing prototype systems. A subset of GRAPHPAK[3], a device independent graphic system, is chosen as the graphics support system. Currently CADETS supports an IBM 3279 colour graphics terminal as an I/O device.

Internally, CADETS is organized in a modular, hierarchical manner (Figure 1). This modularity allows easy modification and extension of the system.

USER INTERFACE

The major requirement of any interactive system is that it provide a logical and consistant interface for the user. This is a primary concern for CADETS since the typical user is assumed to have no experience with a CAD system (at the same time, CADETS does not require the user to have knowledge of APL; in fact, several high school students, who were not even aware of the existence of APL, have used CADETS successfully). With this in mind, CADETS partitions the screen into five distinct windows (Figure 2).

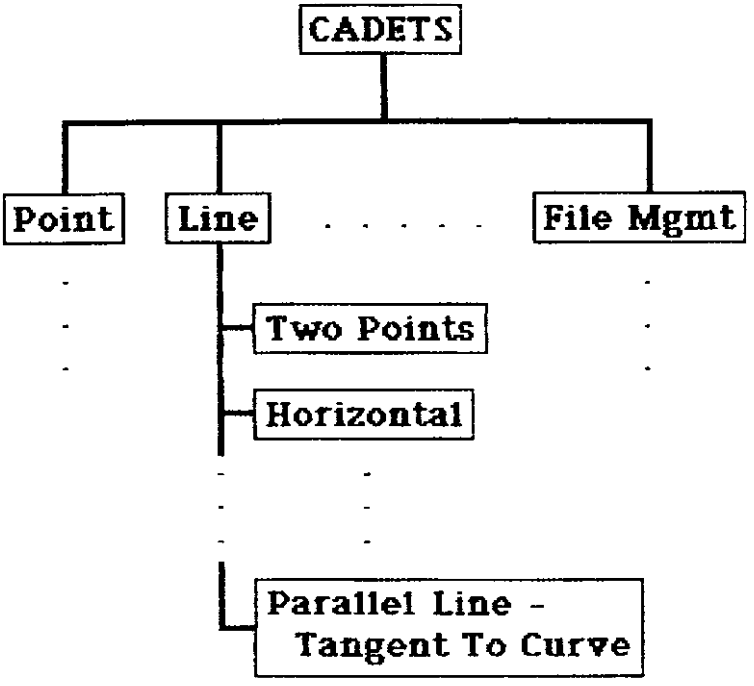


Figure 1: Organizational Structure Of CADETS

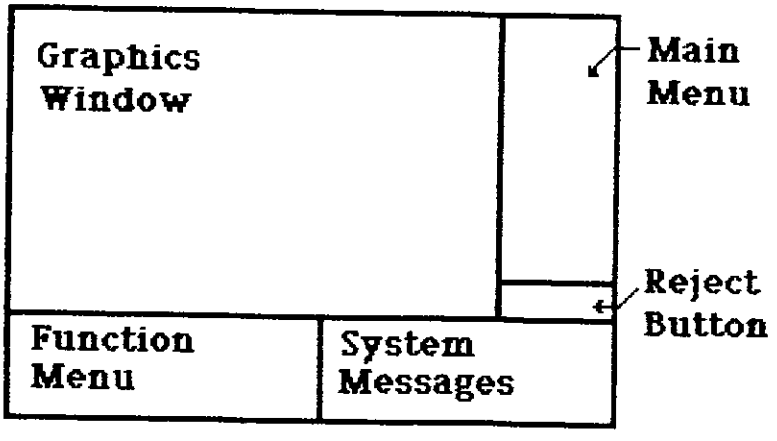


Figure 2: Window Organization

The largest area is the Graphics Window which contains the current view of the geometric model. As the model is created and modified by the user, this window is constantly updated.

Along the right edge of the screen is the Main Menu which contains the primary commands for creation and manipulation of the geometric model, viewing parameters and file management control, etc. (Figure 3). This menu remains on the screen during

the entire session, and the options within it may be selected at any time. Currently, only subset of the planned capabilites of CADETS have been implemented. The options which are implemented are displayed in white, while those which are currently unimplemented are displayed in blue and preceeded by an asterisk. When the user selects an option within the menu, CADETS highlights it in yellow and draws a right pointing arrow in front of it.

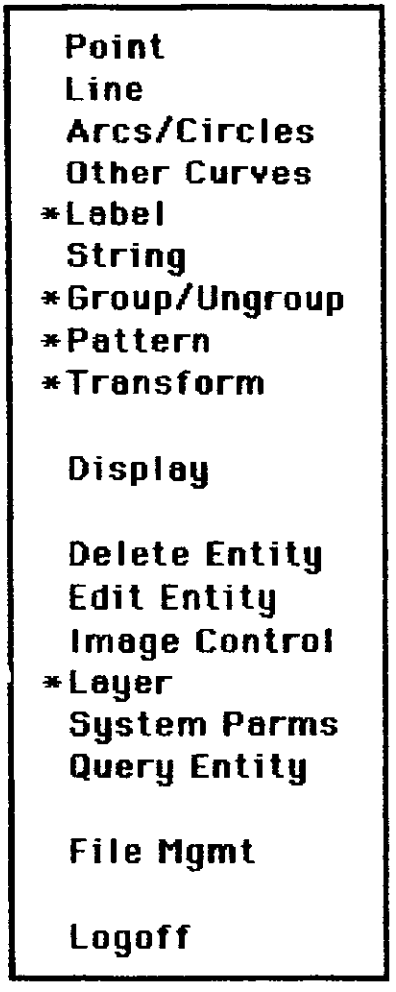


Figure 3: CADETS Main Menu

As the user selects items from the main menu, additional menus are generated within the Function Menu Window. The user selects further options from these menus for model creation and modification. For example, upon selection of the *Line* option from the Main Menu, a subsequent menu appears in the function menu area with a list of options for creating a line segment.

All system status messages, user prompts and error messages appear within the System Messages Window.

Lastly, the Reject Button Window, when selected by the user, removes the effect of the last action performed.

MODEL CREATION FACILITIES

There are currently five options within the main menu which are used to create geometric entities. They are *Point*, *Line*, *Arcs/Circles*, *Other Curves* and *String*. To select an option, the user simply positions the cursor underneath the desired option using the cursor positioning keys and presses the 'Enter' key. At that point, CADETS displays a series of options in the Function Menu Window. This subsequent menu provides the user with a great deal of flexibility in creating the model.

POINT

When the user selects the *Point* option, the menu in Figure 4 is displayed in the Function Menu Window. The user then selects a method of point specification and begins creating points. The options are described below:

Screen Position: Enables the user to create a point in the Graphics Window via cursor manipulation.

Absolute Coordinates: Creates a point at the explicit coordinates specified through the terminal keyboard.

Work Coordinates: Similiar to Absolute Coordinates, except that the user enters the coordinates of the point relative to the user-defined coordinate system.

Existing Point: One would not use this option to create points; however, this is used to select existing points in the Generic Point Menu mode (see below) to create and manipulate other entities such as lines, arcs, etc.

Corner/Midpoint: Enables the user to create a point at the corners or midpoints of the edges or center of the Graphics Window.

Screen Position	Intersection Point
Absolute Coordinates	Arc Center
Work Coordinates	Position On Arc
Existing Point	Modify Offset Mode
Corner/Midpoint	
End Point	
Corner Point	

Figure 4: Generic Point Menu

End Point: Creates a point at the end of an entity closest to the position of the cursor. Endpoints are defined as existing points, the endpoints of line segments and the endpoints of arcs or circles.

Control Points: Include all points defined as endpoints as well as the midpoints of line segments.

Intersection Points: This option creates a point at the intersection point of two entities specified by the user.

Arc Center: Creates a point at the centerpoint of an arc selected by the user.

Position On Arc: Creates a point, at specified angle, on the circumference of an arc.

Modify Offset Mode: Creates a point at a position relative to another point.

The menu described above is referred to as the Generic Point Menu[1] since it is used to specify points for line segments and arcs/circles. Each time a point is created, the *Reject* button is activated. If the user selects it, the most recently created point is deleted.

LINE

The *Line* menu (Figure 5) currently supports thirteen methods of creating a line segment. The names of the individual options largely describe the method in which the line is created. For example, *Two Points* creates a line segment between two points which are specified by the user through the generic point menu; *Pt-Tan To Curve* creates a line beginning at a user-defined point and ending at a tangent point of an existing arc which is selected by the user.

Two Points	Parallel At Distance
Horizontal	Pt - Tan To Curve
Vertical	Pt - Perpend Curve
*Normal	Angle - Tan To Curve
Pt - Absolute Angle	Tangent To 2 Curves
Pt - Angle From Line	Perpt Ln - Tan Curve
Pt - Parallel Line	Paral Ln - Tan Curve

Figure 5: Line Menu

The algorithms used to create the lines are developed largely from constructions in analytic geometry[4]. The algorithm used to create a line segment tangent to two curves is

developed by Bowyer et al[5]. At each stage in the specification of a line segment, the user may undo his last action by selecting the *Reject* button. For example, the option *Perpt Ln-Tan Curve* creates a line segment perpendicular to an existing line segment and tangent to an arc/circle. To create the line, the user initially specifies the base line followed by the desired arc. If, after selecting the base line, the user decides to use another line as the base, he simply selects the *Reject* button. CADETS restores the base line to its original color, and prompts the user to select another base line. Once any line segment has been created, the user may delete it from the model, if desired, by selecting the *Reject* button before creating another line segment.

ARCS/CIRCLES

The *Arcs/Circles* menu (Figure 6) currently supports ten methods of creating a circular arc. The first six options create an arc or circle by initially defining a center point (through the generic point menu), a radius (which may be entered explicitly as in *Key In Radius* or "*Radius, End Points*" or defined implicitly as in *Point On Arc*, *Tangent To Line*, "*Tan To Circle, Small*" or "*Tan to Circle, Large*") and bounding points ("*Radius, End Points*") or angles (the remaining five options). *Arc Thru 3 Points* creates an arc through three specified points. *Simple Fillet* creates a circular arc between two line segments and trims the line segments to the tangent points of the fillet. *Fillet Two Entities* creates a fillet between two line segments, a line and an arc or two arcs.

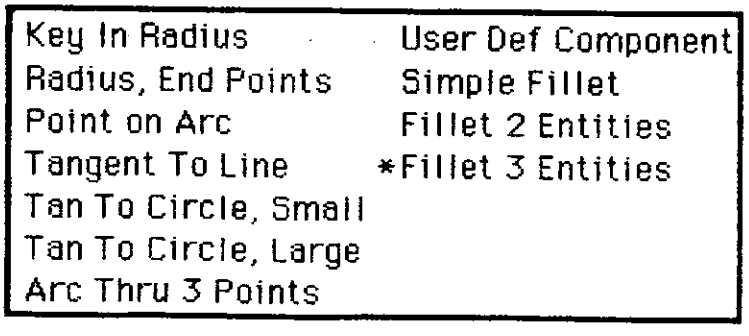


Figure 6: Arcs/Circles Menu

Once an arc has been created, the user may delete it by selecting the *Reject* button. The majority of algorithms used to create the arcs are derived from constructions in analytic geometry[4]. The algorithm used to create an arc through three points on its circumference is adapted from Chasen[6].

OTHER CURVES

The *Other Curves* option (Figure 7) contains facilites to generate polygons, conic and freeform curves. Currently, two options have been implemented: *Triangle*, which creates a triangle from three user-specified verticies, and *Rectangle*, which creates a rectangle through the specification of two diagonal points. Each option creates a set of line segments which may be filleted, edited or deleted as the user requires. Once a curve has been created, the *Reject* button may be used to delete the object if desired.

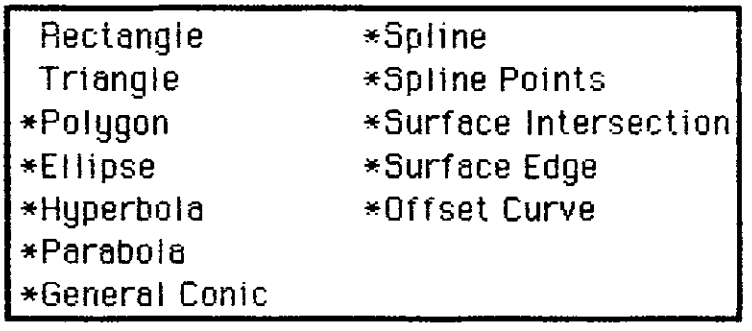


Figure 7: Other Curves Menu

STRING

String is an option which allows the user to create open and/or closed polygons. Upon selection, the user is prompted to specify the initial pivot point of the polygon through the generic point menu. Once specified, the menu in Figure 8 is displayed. *Free Line* creates a line segment from the previous pivot point directly to a point defined by the user. The next three options (*Horiz Or Vert*, *Horizontal Line* and *Vertical Line*) constrain the edge to be either horizontal or vertical. *Horiz Then Vert* creates two line segments from the pivot point to the new point; first a horizontal line followed by a vertical one to the new point. *Vert Then Horiz* creates two lines in an analogous manner. The *Beam Off* option is used to specify a new pivot point. This is commonly used when the operator has completed one polygon and is about to create a second. *Delete Last* removes the last edge from the polygon. The *Reject* button is also activated each time an edge is created; by selecting it, the last edge created is deleted from the geometric model.

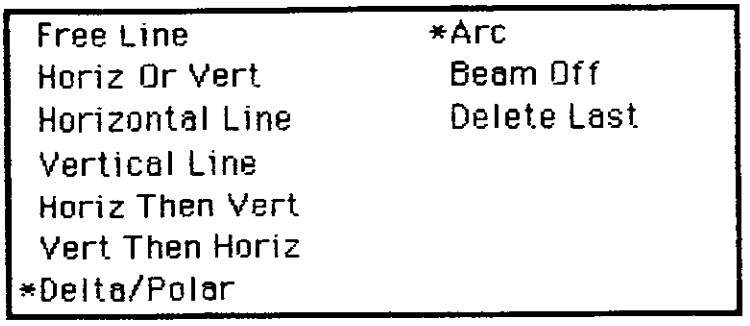


Figure 8: String Menu

As with the *Triangle* and *Rectangle* options of *Other Curve*, each edge in the polygon is created as an individual line which can be modified or deleted by the user as required.

MODEL EDITING FACILITIES

The user may selectively modify or delete any point, line segment or arc/circle once it has been created on the screen. These capabilities within CADETS are summarized below.

DELETION

The user may remove any entity from the model by selecting the *Delete Entity* option. Upon selection, the menu in Figure 9 is displayed which lists the various deletion modes. *Select by Type* allows the user to select points, lines and arcs individually by positioning the cursor in the vicinity of entity to be deleted. *All Of Type* removes all the entities whose type is specified by the user through the menu in Figure 10 (eg. delete all line entities). *All But Type* removes all entities except those of the type specified by the user. (eg. delete all entities which are not line segments). Lastly, *All Active Display* erase the entire geometric model from the screen; since this is a drastic action, the user is prompted for a reconfirmation.

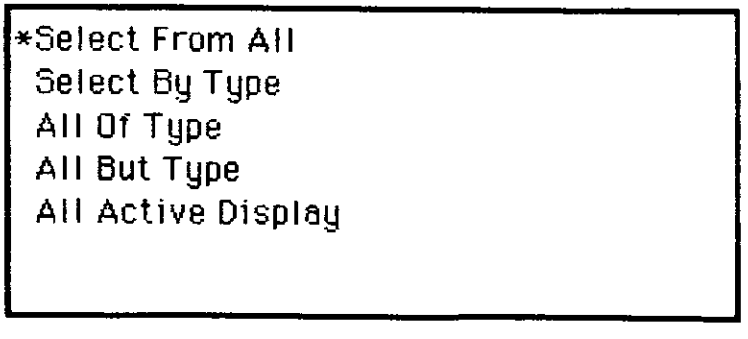


Figure 9: Delete Entity Menu

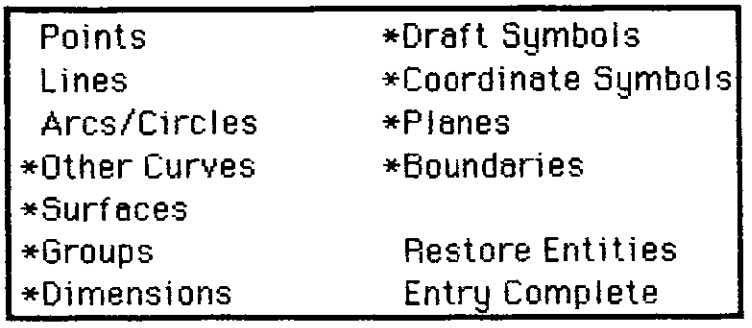


Figure 10: Entity Type Menu

Internally, the deletion operation is a two-stage process. When the user specifies that a line is to be deleted, it is initially erased from the graphics display, and placed on a list of entities about to be removed from the geometric model. If the user selects the *Reject* button before choosing another option to delete further entities or selecting an option from the main menu, then those entities are restored on the screen. Otherwise, they are removed from the model entirely.

EDIT ENTITY

The Edit Entity option allows the user to modify any point, line segment or arc on the screen. Upon selection, the menu in Figure 11 is displayed and the user prompted to select an editing mode. The *Line Trim* option is used to modify the length of an existing line segment. This facility creates a further menu which lists the options which modify the length (Figure 12). *Edit Line Endpoint* modifies an existing line segment by repositioning one or both of its endpoints through the generic point menu. *Line Equal Segments* divides a line into a specified number of segments.

Color/Style/Density is used to change the visual attributes of an existing point, line or arc by specifying a new color, line style or density. Lastly, *Modify Arc Angle* allows the user to respecify the boundary angles of an existing arc or circle. Upon selection, the menu in Figure 13 is displayed.

At each stage of any edit facility, the user may select the *Reject* button to undo his last action in case the modification does not have the desired effect. Internally, the functions within Edit Entity calculate intersection points between lines and lines and arcs, and update the relative fields within the geometric model.

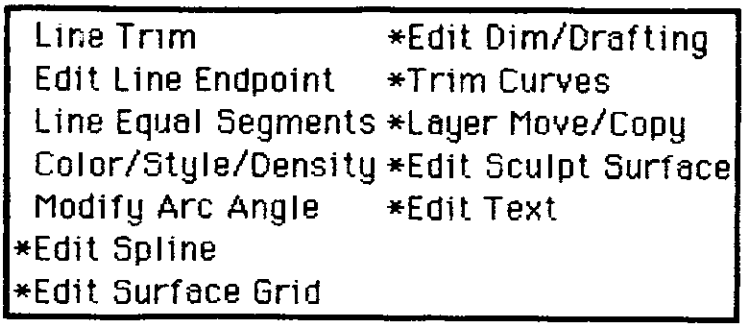


Figure 11: Edit Entity Menu

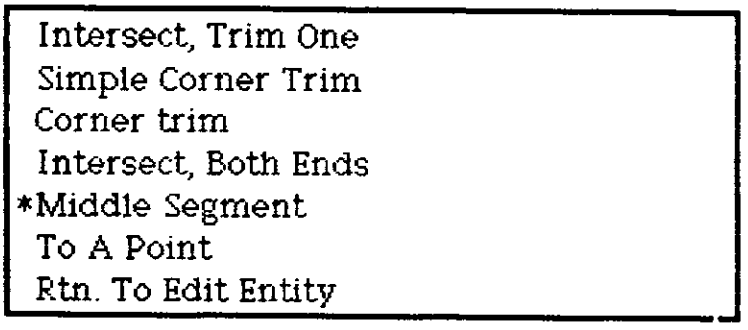


Figure 12: Line Trim Menu

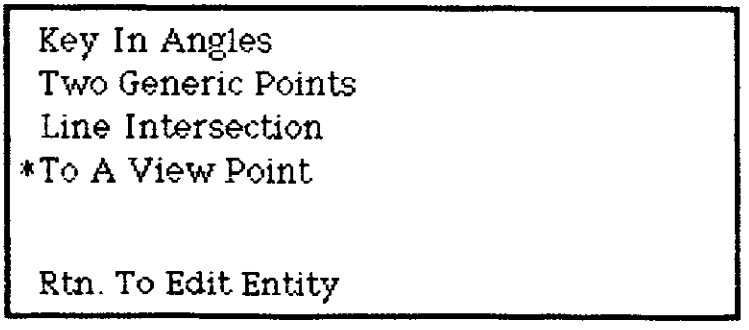


Figure 13: Modify Arc Angles Menu

IMAGE CONTROL

The *Image Control* facility is used to change the portion of the model viewed in the Graphics Window. Upon selection, the menu in Figure 14 is displayed. "*Enter Center, Scale*" is used to change the position and scale of the object. *Half Scale* automatically halves the scale of the image, effectively doubling its size, while *Double Scale* performs the opposite action. The *New Center* option shifts the position of the model while retaining the current scale. *Auto Min Max* is a useful feature which automatically rescales the image so the entire model fits within the Graphics Window. *Diagonal Pt Image* is a related utility where the user specifies a rectangular area of interest which is enlarged to fit the entire Graphics Window.

After creation of a new view, the *Reject* button is enabled. By selecting it, the user may restore the previous view. Internally, *Image Control* updates the extents of the world boundaries and redisplays the model.

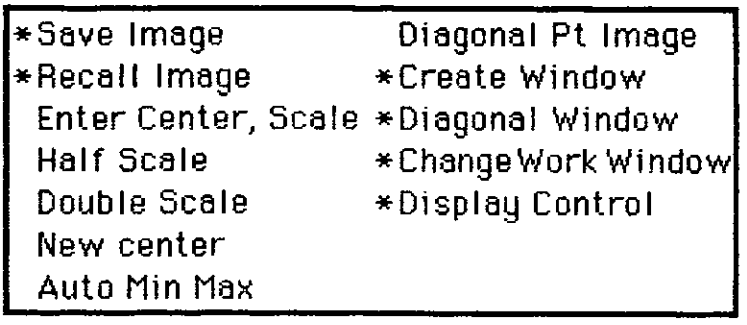


Figure 14: Image Control Menu

SYSTEM PARMS

The *System Parms* option is a facility for the user to modify system defaults and attributes. Upon selection, the menu in Figure 15 is displayed. The *Entity Display Parms* is used to set the default color, style, width and point symbol for all subsequent entities to be created. *Delete Last* deletes the last entity created from the geometric model.

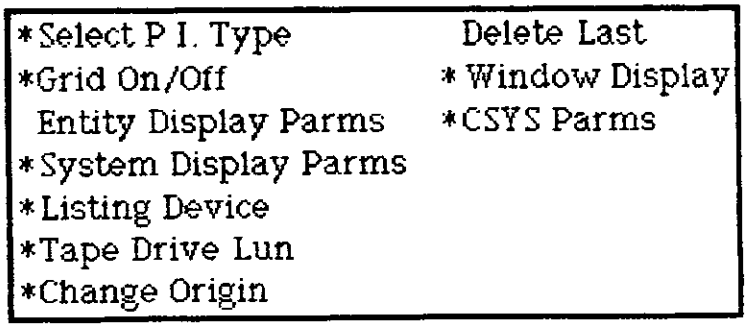


Figure 15: System Parms Menu

QUERY ENTITY

The *Query Entity* option is used to display geometric information of entities specified by the user. Upon selection, CADETS generates a list of entity types which may be queried by the user. After the user selects the type, he specifies the entity of interest by positioning the cursor near it. CADETS then highlights the entity and displays the appropriate information in the Function Menu Window. An example of the information displayed for an arc is shown in Figure 16.

Cen: X =	-11.1502	Str: X =	-9.1502
Y =	4.0187	Y =	4.0187
Z =	0.0000	Z =	0.0000
Radius =	2.0000	End: X =	-9.1502
Arc len =	12.5664	Y =	4.0187
Str Ang =	0.0000	Z =	0.0000
End Ang =	360.0000	Rtn. To Query Menu	

Figure 16: Arc/Circle Query Panel

FILE MGMT

The *File Mgmt* option allows the user to create and restore object files within the host computer. Currently, only the Hardcopy option is implemented. When selected by the user, CADETS displays a list of plotters currently supported at UNB. To generate a hardcopy of the current model, the user simply selects the desired device. CADETS automatically looks after using the correct device drivers and creates the plot without user intervention.

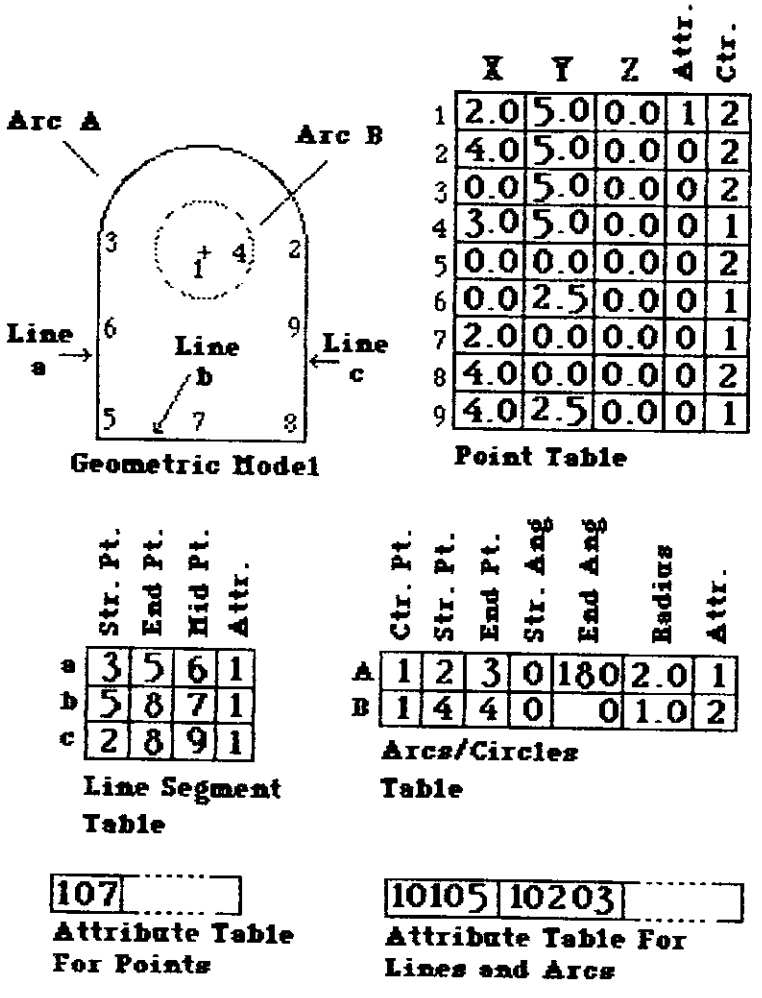
GEOMETRIC MODEL

The design of an object involves more than simply drawing a series of line and arc segments on a terminal screen. In order to edit the model and use it in subsequent analysis functions, an underlying representation of the part, called the geometric model, must be stored.

CADETS currently supports three geometric entities: points, line segments and arcs/circles. Each point is represented by its position in space (x,y,z), an index into an attribute table where the color and identifying symbol codes are stored, and a field which maintains a count of the number of line segments and arcs which use that point in their definition (Figure 17). Although CADETS is currently a two-dimensional modelling system, the z coordinate is included for future 3D extensions.

Each line segment is represented by its endpoints, the midpoint of the segment, and a pointer into an attribute table which defines the color, style and width of the line. The actual coordinates of the mid and endpoints are stored within the point array with pointers to their positions stored within the line segment record.

Each arc/circle requires a center point, starting point and ending point. As in the line segment described above, the coordinates of these points are stored within the point data structure, and pointers to their positions are stored within the arc data structure. In addition to the points, each arc also requires the radius, starting and ending angles and a pointer into the line segment attribute table.



	X	Y	Z	Attr.	Ctr.
1	2.0	5.0	0.0	1	2
2	4.0	5.0	0.0	0	2
3	0.0	5.0	0.0	0	2
4	3.0	5.0	0.0	0	1
5	0.0	0.0	0.0	0	2
6	0.0	2.5	0.0	0	1
7	2.0	0.0	0.0	0	1
8	4.0	0.0	0.0	0	2
9	4.0	2.5	0.0	0	1

	Str. Pt.	End Pt.	Mid Pt.	Attr.
a	3	5	6	1
b	5	8	7	1
c	2	8	9	1

	Ctr. Pt.	Str. Pt.	End Pt.	Str. Ang	End Ang	Radius	Attr.
A	1	2	3	0	180	2.0	1
B	1	4	4	0	0	1.0	2

107	.....

10105	10203	.....

Figure 17: Internal Representation Of The Geometric Model

EXAMPLES

Some examples generated using the various facilities in CADETS appear in Figures 18, 19 and 20. Figure 18 is a gasket which illustrates the use of lines, arcs, fillets, etc. A chair is shown in Figure 19; note that it appears to be a three dimensional figure even though CADETS does not support 3D models at this stage. Figure 20 is a bicycle.

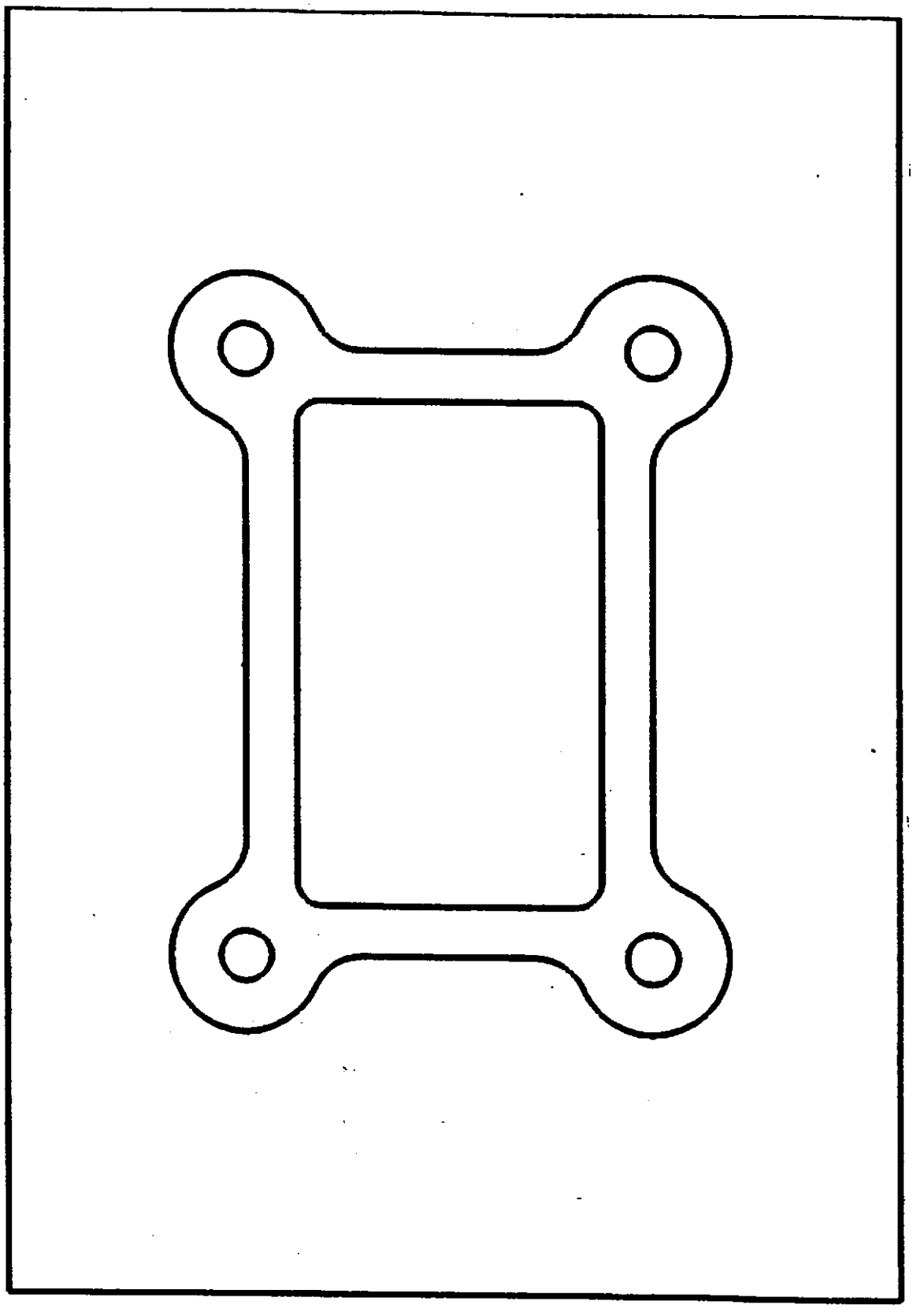


Figure 18: Gasket

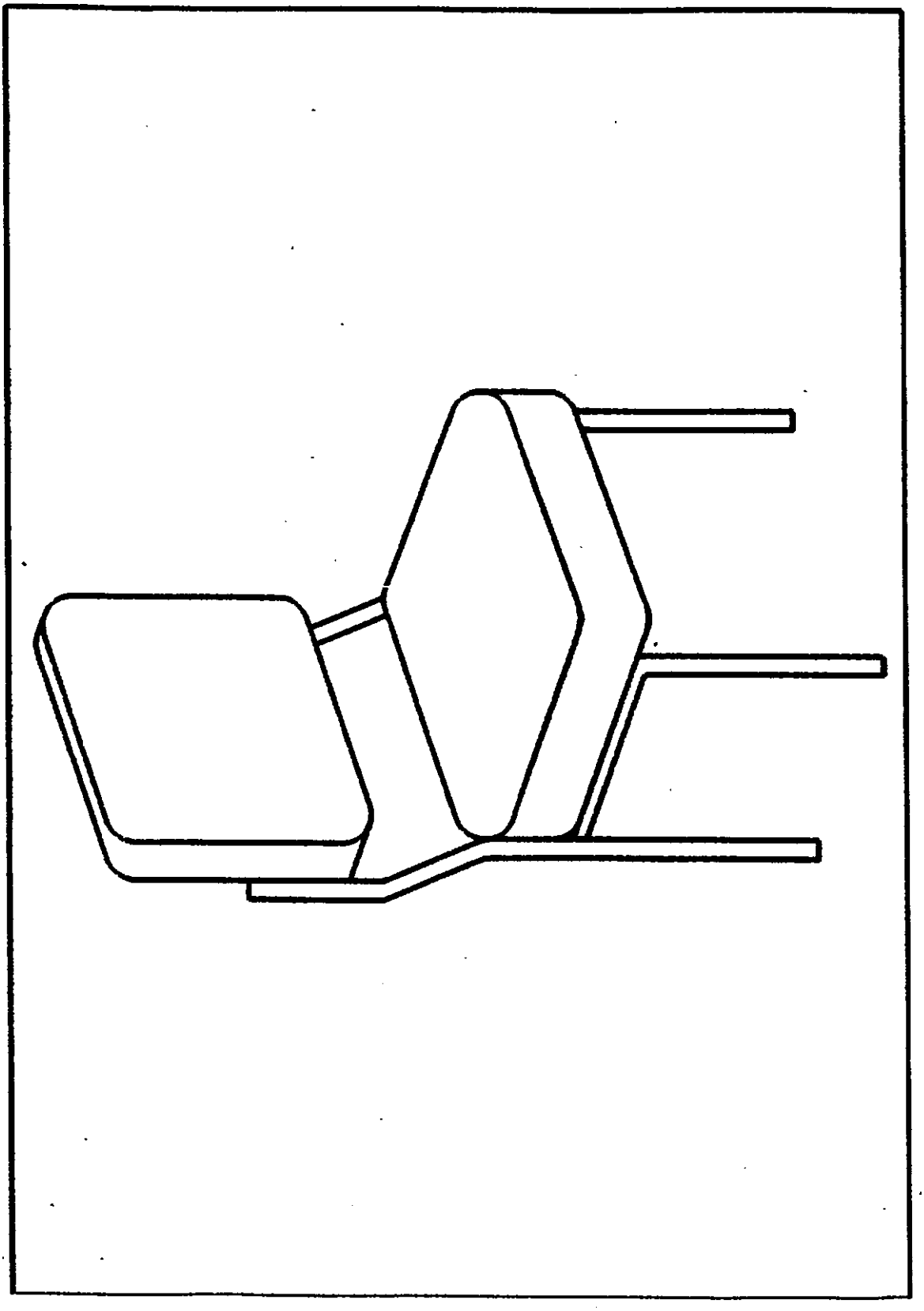


Figure 19: Chair

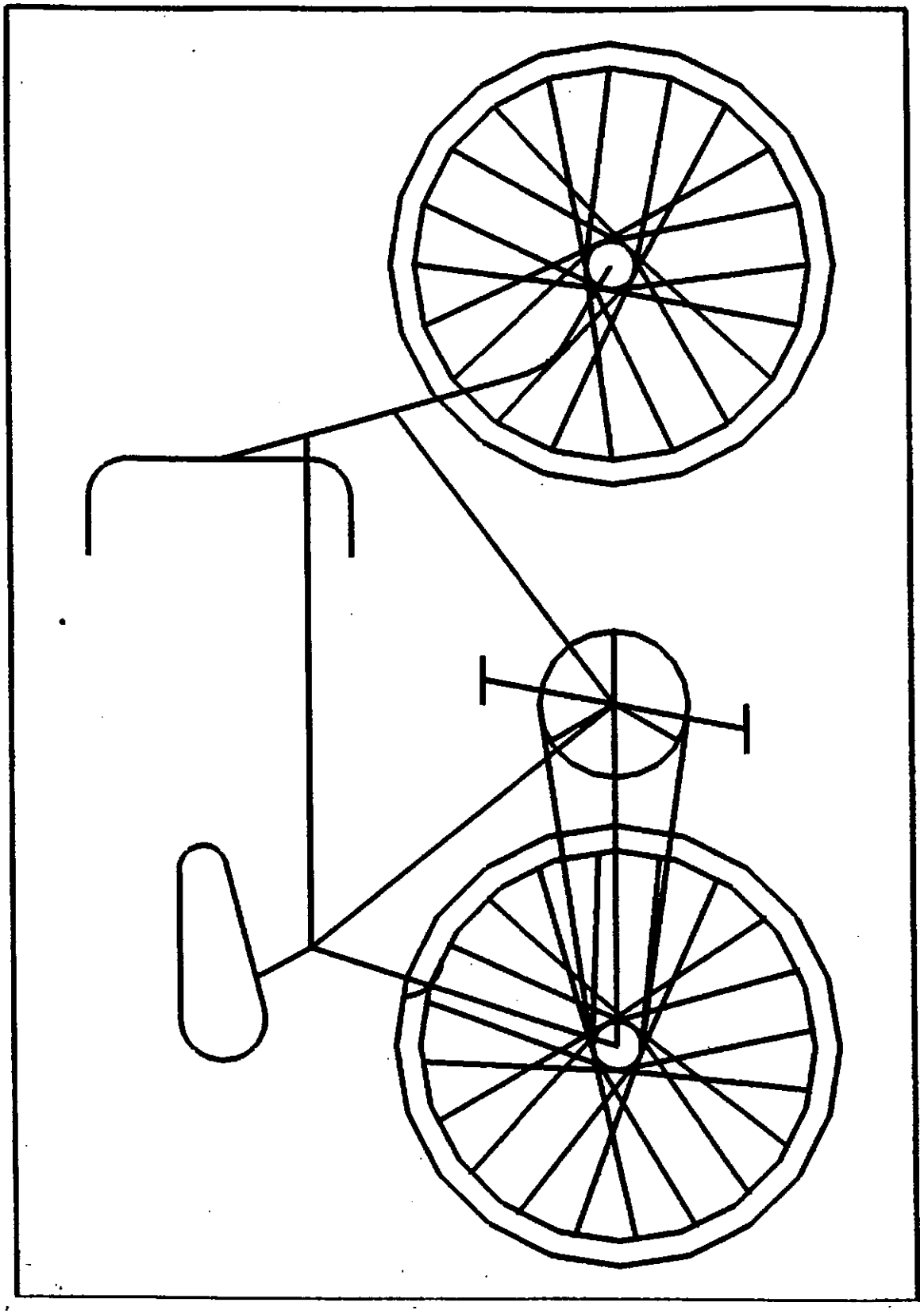


Figure 20: Bicycle

CONCLUSIONS

A two-dimensional Computer Aided DEsign Tutorial System (CADETS) modelled after UNIGRAPHICS I has been designed and implemented. Written in APL, the system does not demand any knowledge of APL from the user. An IBM 3279 colour graphics terminal is used as a graphics input as well as output device. Within CADETS, there are currently eleven ways to create a point, thirteen ways to create a line segment, ten ways to specify a circular arc and several functions to generate common geometric objects such as triangles, rectangles, polygons, etc.

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[4] Slipp, Leonard B., 'CADETS: A Computer Aided Design Tutorial System', M.Sc. (C.S.) thesis, School of Computer Science, University of New Brunswick, Fredericton, N.B., Canada, September, 1985.

[5] Bowyer, Adrian and John Woodward, A Programmer's Geometry, Butterworths, 1983.

[6] Chasen, Sylvan H., Geometric Principles and Procedures for Computer Graphics Applications, Prentice-Hall, 1978.

TECHNICAL REPORTS

SCHOOL OF COMPUTER SCIENCE

Number	Date	Author	Title	No.of Pages	Price
TR74-001	Feb 1974	L.F. Johnson	A Search Algorithm for the Simple Cycles of a Directed Graph	33	$1.65
TR74-002	Oct 1974	W.D. Wasson R. McIssaac	A New Spanning Tree Algorithm	15	$0.75
TR74-003	Oct 1974	U.G. Gujar	Remote Job Entry and Output Through APL	13	$0.65
TR75-004	Apr 1975	U.G. Gujar	Subroutines with Variable Numbers of Arguments	17	$0.85
TR75-005	Jul 1975	L.E. Garey	Block Methods for Nonlinear Volterra Integral Equations	16	$0.80
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