READING A SKETCH BY HUNCH

by

James Richard Taggart

Submitted in Partial Fulfillment of the Requirements

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ABSTRACT

This thesis describes the development of a computer system, HUNCH, intended to provide a simple means for a person to communicate with a computer his ideas through the medium of sketching. The emphasis is not on developing a computer system which produces finished quality drawings from sketched input, but rather on having the computer understand what is meant by the sketch. An overview of the intended goals of such a system is described, along with a comparison to other systems of sketch recognition. A history of the development of HUNCH is given to show the reader the evolution of the ideas invoked by HUNCH as it currently stands. A description of how HUNCH performs a data reduction pass to simplify and structure the sketch is given. Finally, a proposal for a graphical compiler is made to permit development of a system which would be able to understand sketches of a predefined class.

Thesis Supervisor: Nicholas P. Negroponte
Title: Associate Professor of Architecture

ACKNOWLEDGEMENTS

It is traditional to thank everybody in the world in this section. Special reference must be made to Nick Negroponte for providing the inspiration, and to the NSF and Project MAC for providing the means for keeping body and soul together while the project was carried out. There are also nameless millions who have contributed over the years to the development of HUNCH, especially Doris Ju and Cindy O'Connell who had to work under my direction, and Mike Miller and Chris Herot, who have been bricks throughout. Leon Groisser should be thanked for providing a needed boot at a crucial moment. Finally, a nod to Archie the Architect, for whom this system has been developed.

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ORGANIZATION

The body of this paper is divided into four parts: overview, past, present, and future. The first part of the paper is a look at the goals for developing an interactive sketching system. Other implimentations of computer systems are described, and how they matched up to the defined goals is discussed. The second part is a history of events from its inception to HUNCH in its present state. Such a description seems important for two reasons. First, while the way HUNCH works can be understood without the history attached, why HUNCH exists as it is, and the motivation for the fourth part of the paper needs as part of its explanation how the ideas were derived and which ideas were discarded. HUNCH in its present form appears to be a regression from earlier successes. The motivation for this change of state is best explained by describing the sequence of events which led to the current state. Second, some of what has been learned about sketch recognition through the development of HUNCH is represented only by certain elements which are NOT included, perhaps despite earlier versions with these features. The knowledge gained by failures and changes of attitude over time is almost as great as that which currently is known. This history of HUNCH, then, is an attempt to apprise the reader of this knowledge.

The third part of the paper is a description of how the system as it currently exists is run. An extensive description of how straight line data is extracted from the raw sketched input is included. This description not only shows how the more complicated portions of HUNCH work, but also indicates the philosophy of how operations are performed in a HUNCH-like way. From this outlook, one can see how other functions, which might be added to the HUNCH system later, would be implemented.

The last section of the paper may be looked on as conclusions and indications for future work. As it exists now, HUNCH falls short of its stated goals by quite a distance. Its biggest shortcoming is in its inability to derive a higher level description from a sketch. The last section provides the frame of mind which one might need in order to begin solving this inability. The solution proposed is neither complete nor rigorous, and in that sense, it seems strangely inconclusive. The only explanation I can offer is that the solution proposed seems to solve all the challenges I can think of, although sometimes the thinking required seems unnecessarily baroque. There must be simpler solutions, but finding them can only come with further experience.

I. OVERVIEW

Why am I here?

GOALS

There have been many computer systems developed which purport to let the user sketch using a computer. The user is placed before a console display of some sort, handed something which looks like a pen, perhaps is given some instruction in how to use the system, and is told to draw. It is reasonable to wonder in abstract, if one had such a system, what would he want it to do. There seem to be two answers: first, the system should help in the construction and storage of graphical images. Second, the system should act as an aide in the development of the information the sketch is meant to convey.

Under the first goal, when pictures can be constructed out of elements, saved, modified, and recalled at a later time, the designer has a useful time-saving tool for handling pictorial data. Repetitive elements need only be described once to the system. Representations of the complete structure can then be evoked with only a single stroke of the pen. Thus, instead of laboring hours over a drawing, the designer can describe the whole drawing to the computer using many previously defined elements, and the computer can construct the complete, finished work. Similarly, if two drawings are the same, with only minor variations, the designer can construct one of them and store it away. He can then modify a copy of the saved image to match it to the second intended drawing, saving himself the trouble of constructing the drawing essentially twice.

More complicated than the first goal of a sketching system, one might ask a system to perform some more abstract operations on the sketch. A person uses sketches for two purposes: to convey information to other people which is difficult to transmit verbally, and to act as a sort of physical memory, in a sense, conveying information to himself. Once the sketch has been commited to paper, the user can modify it to change the information it contains. This act can be prompted either by the ebb and flow of the dialogue with the observer, or by a change in the sketcher's own idea brought about by the feed-back loop running between brain, hand, paper, and eye. In either case, the sketch is important because of the intended meanings it contains. In a similar way, it is useful for a computer system being used as a sketching tool to be able to attach some meaning to the objects being sketched.

The result of such a dialogue is that the information contained in the interaction is greater than the amount of information which could be contained in the sketch alone, or which the user could carry around in his head. Thus, one would like a computer system for sketching to be alert enough to be able to affect a dialogue with the user. It would need to be knowledgeable enough about the subject matter being sketched to be able to ask reasonable (intelligent?) questions, and perhaps offer some information of its own. In short, the computer should be able to enter into a dialogue with the user, in much the same way as a person observing the sketch being created might interact. Such a provocative system would tend to maximize the amount of information generated in a sketching session.

OTHER SYSTEMS

Computer systems which have been developed to date tend to be divided into two classes, reflecting to a certain extent the two goals for a computer sketching system. The first class, historically, is that which uses some specialized set of functins, keys, or symbols in the process of sketching. Input was accomplished by invoking a function (key, e.g.), which told the computer what the user was intending to do, with the ultimate goal of permitting the computer to store, retrieve, and assist in modifying a drawing. In response to the user's request, the system performed some output which accomplished the action specified. The second sort of computer system seen uses a limited set of known symbols, and attempts to map the user's sketched ikons, usually drawn on a data tablet, into these symbols. In this case, the computer does not know in advance exactly what the user is going to do. What the user intended must be inferred from the match of the sketched item to the known symbols, and the computer is usually expected to take some action as a result of the recognition of the symbol. Because of this level of guessing, such systems are not infallible, but this objection is matched by a comparable improvement in the ease of input (In the first class of sketch handling programs, it should be noted, the computer is incapable of making a mistake; only the user).

The most notable example of the first sort of program is Ivan Sutherland's SKETCHPAD (Sutherland, 1963), particularly since it was the first attempt at communicating a visual image between user and computer in an interactive manner. In its stated goals, however, SKETCHPAD was to be a system unlike drawing with pencil and paper, because interacting with a computer was seen to be a totally different kind of experience. Using primitives common to all line drawings (line segments, points, and arcs of circles), the user creates symbols, structures, and composites of these images. To increase the power of the interaction, certain functions could be applied to previously defined images. Thus, when the user laid down two lines, he could indicate to the system that he wanted them to be parallel or perpendicular, and the system performed the requisite steps to make them exactly that way. Thus, the user could be inaccurate in his original layout and yet get a highly specific output of his final image. Furthermore, since the user was not drawing symbols for the system to recognize, the kinds of graphic images the system could accept was unrestricted.

For such freedom, the user pays a penalty, however. The system of light pen on display and function keys utilized by SKETCHPAD bears no relation to the normal means of communicating an idea graphically. The fairly demanding system of input required by such a system would tend to interfere with the creative thinking process. The user is concentrating so hard on getting the drawing into the machine that is difficult to think about what he is drawing. IBM is marketing a new system similar to SKETCHPAD which uses a tablet instead of a light pen (Saderholm, 1973). While this hardware is an improvement over the old setpoint-rubber-band-line, it still relys on a set of function buttons on the tablet to relay commands to the system. The degree of explicitness required in such systems quickly generates tedium sufficient to offset any preference over the less complicated job of digitizing the data. Any sense of natural graphical communication is lost. Furthermore, since the computer is operating continuously in "slave" mode, it can add no information to the dialogue. Thus, an important potential is lost.

In the second class of computer systems, the computer does add information of its own to the dialoge in its interpretation of the sketched symbols of the user. Although this approach is primarily found in character recognition programs , perhaps the most notable example is the GRAIL system developed by the Rand Corporation (Ellis, et. al., 1969). Besides recognizing the alphabet and decimal digits, it could also handle a set of flow charting symbols (rectangles, triangles, and so forth), and lines connecting these symbols. Using the Rand data tablet, the user drew his flow chart and labeled it. As each symbol was drawn, the system identified it, and the rough display of the user's line was replaced by the machine's representation of the symbol, appropriately scaled and positioned. Because of the level of inference making, the program was capable of making mistakes. In order to allow for errors and to permit the user to change his mind, one of the symbols recognized by the system was the scribbling out motion normally used by people to cross out an error or a misplaced line. The symbol was called a "squiggle," and caused any line or symbol which appeared beneath it to disappear. Once the flow chart was completed, the user could ascribe specific functions to the symbols of the flow chart and see what happened when the flow chart was "run." It provided a neat way of seeing information which might otherwise have been too difficult to visualize.

Systems in the GRAIL class are quite attractive, since they provide a sort of interaction which is very natural and familiar to the experience of the probable user. Drawing with a pen on paper is an experience common to most people, and GRAIL's replication of this experience is not bad. On the other hand, these pattern recognition systems can only handle a limited class of inputs. Given an unrecognizable symbol, the system is lost. This problem is partially overcome in many character recognition systems by having a "learning" mode, where the system samples the individual user's representation of the symbols it knows, thereby adapting its models for the symbols to the habits of the individual user. There are two limitations usually imposed, however. First, the user's representation usually can not deviate beyond some accepted boundary conditions. For example, a character recognition program normally accepts either script or printed characters, but not both. Thus, a user who mixes his characters would inevitbly be mis-understood. Second, it is usually impossible for the user to define symbols of his own. Thus, if a mathematician wished to user a character recognition system for the alphabet, he might be hampered by the inability of the program to accept Greek symbols; similarly, a Russian translator would have to start all over. Furthermore, as the number of symbols recognized by the system is increased, typically, the frequency of error increases at a much faster rate. This phenomenon occurs because the system can not use clues about the interaction between elements in a sketch. If a character recognition system had difficulty distinguishing between U's and O's, for example, it would be useful to look to see if the preceeding character was a Q (in English, anyway).

LETDOWN

It would be nice to be able to claim to have developed the alert, provocative, interactive system mentioned in the earlier section. The system which has been developed, HUNCH, falls short of this goal, however. Provocative it is, although not in the manner described above. It is also moderately interactive. It does not, however, carry on anything which can be called a dialogue. . .yet. Dialogue implies purpose and a developing context, and although HUNCH does know a few tricks, once it has performed, all it can do is walk off stage.

The name HUNCH is derived from the methods it uses to achieve its ultimate goal. It uses guesses about implied intensions to determine what the sketcher PROBABLY meant. In that sense, it is similar to the character recognition systems discussed. It does not have a set of patterns it is trying to match, however. Rather, it attempts to extract from the stream of input data the primitives which make it up: line segments, arcs of curves, end points of lines. Once the data has been so compressed and structured, these components can be combined to form objects of a higher order. This second step is not as well understood, since it requires extensive knowledge about the subject matter being sketched to accomplish this goal.

Because its knowledge is somewhat more limited than a human's, it would appear that HUNCH is at a disadvantage when it comes to reading a sketch. If it was limited to those cues available to human, that claim would probably be true. However, because of the way the data is collected, HUNCH can use some information unavailable to the human onlooker. Inherent in the way the data is sampled is the sequence in which the sketch was drawn, the pressure on the pen at a particular time, and the rate at which the user was drawing.

These cues provide additional information which the program can use to make decisions. In general, for example, the faster the user draws, the less accurate he is. Furthermore, if he is drawing rapidly, it can usually be inferred that he is not interested in the fine detail of his line, but rather in the grosser features of what he is drawing. When it encounters a rapidly drawn line, then, HUNCH is prepared to make bigger assumptions and to permit greater inaccuracies before declaring one line segment ended and a second one begun. Similarly, if the user is drawing slowly with great deliberation, then nearly every bend or tweak in the line is preserved.

Pressure can also be sensed to provide cues to the intentions of the user. Here, the role variations of pressure in a sketch is not so clear. It appears, however that pressure variations occur in quanta; a user typically draws in no more than three or four pressure ranges. An initial inference is that pressure behaves something like inverse rate--that is, the harder a person pushes, the greater the detail implied. The cue to look for, however, is the quantum pressure change, not the small variations across a line.

WHAT HUNCH DOES AND DOES NOT

Sketching can be considered to be a kind of graphical language. A person can read a sketch if he knows the rules for making a sketch, and if he knows the symbols used in the sketch--syntax and semantics. In order to carry on a useful dialogue, you have to have both. The HUNCH system does a reasonable job at providing a large portion of the syntax. It is one of the goals of this paper to outline a means of supplying some of the semantics.

The sketch, as received by HUNCH, is one long serial stream of data. The system tries to apply some structure to this data, to make the search for meaning more manageable. In a sense, the solution developed so far still leaves the computer doing what it does well--number crunching. In the process of discovering the structure of the sketch, massive amounts of data are reduced to a collection of points and relations between points. It performs these operations with uncanny accuracy, using only local information about the dynamics of the line.

The relations formed are only those based on information explicit in the data, such as the aforementioned rate and pressure, continuity of line, and sequence. Attempts to apply further relations to the data failed for various reasons described later, and in fact, appear inevitably doomed without the application of some semantic guides. Some of those relations attempted include latching of two known points, and horizontalizing and verticalizing lines in a sketch which appear nearly so. These functions failed largely because HUNCH was unable to judge those situations in which those relations might or might not apply. Thus, it applied them indiscriminately to any set of lines which fell within its guide-lines. The result inevitably was a severe distortion of the original sketch. Parenthetically, it should be noted that if input was limited to those sketches where the rule was always appropriate, HUNCH solved the problems with distinction. Thus, the problem was not in the rule, but in when to apply the rule. Given any rule, there is always a condition where, applied indiscriminately, the rule will fail (including this one). Thus, some means is needed to guide the system about when a particular relation might be appropriate.

The final output of the system is not intended to be a "working drawing" with all extraneous lines eliminated, all corners squared, and all lines straight and parallel. Rather it is intended that the output be the description of the sketch which might correspond in some way to the verbal description a human might make of the sketch having observed it. The structure of this description would be hierarchical, having at its top the major features of the sketch, at its interim levels the elements which combine to make up these features, and at the bottom the individual line segments of which the sketch is made. The interaction of the various elements in the description provides contextural information. This information can be used to augment the rules about relations between lines which got us into trouble before to provide the guide-lines about when a particular rule might be applied. Furthermore, it helps to avoid the difficulties systems of the GRAIL class get into when called upon to recognize a large number of different elements. The context limits the number of plausible elements which may be used, preventing the system from drifting too far afield.

Unfortunatiely, this desirable description has not been implemented in any form. In order to derive such a description, the system needs to know what the elements are for which it should be searching (wired in to most systems). While in most types of sketches the number of these elemetns is not large, it has never been clear how one would specify these elements for the system. The description offered in the last section of this paper is a first attempt at making such a specification possible.

HARDWARE USED BY HUNCH

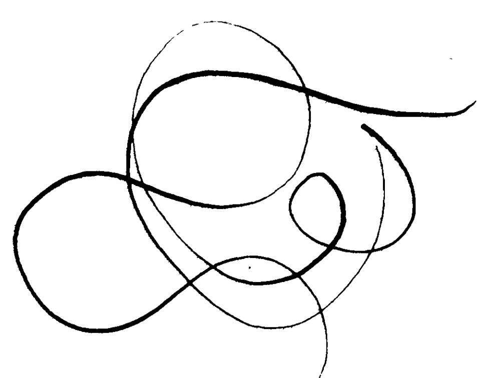
HUNCH runs on the Architecture Machine, a family of Interdata mini-computers, running under a disk resident operating system. The original sketch is read from a Sylvania data tablet, and can be stored on a variety of mass storage devices. The Sylvania tablet is (was) the Cadillac of data tablets, offering resolution to three thousandths of an inch, constant rate data sampling, and a clear tablet. This clear tablet means that it can either be drawn on as with other tablets, or it can be placed in front of the display and used in a manner similar to a light pen. Both of these modes are used by various parts of HUNCH. The tablet samples data at a constant rate (two hundred times per second), sending off to the computer twelve bits of x- and twelve of y-coordinate data at each sample. The tablet can also sense a limited capability for a z-dimension (three bits), such that it can tell if the pen is touching, is in the near field (about one half inch), is in the far field (up to four inches), or is away from the tablet. This feature suggested a logical extension, and the pen was modified to be able to sense pressure--how hard the penman is pressing on the paper. A load cell (a sort of transverse strain gauge) has been built into the shaft of the pen, taking the thrust from the top of the ball point pen cartridge. It can measure pressure from a fraction of an ounce up to a pound. This load is converted into a digital signal which is sent as a six-bit number to the computer. Each pressure sample is associated with the point read when the sample was taken.

The display is not crucial to HUNCH, although it is useful for demonstration and debugging purposes. Because of the amount of data developed by the data tablet and the complicated pictures possible, it would be impossible to maintain a flicker free image on a refreshing display. After ten seconds of drawing, the screen would have two thousand vectors on it. HUNCH uses an ARDS storage tube, which effectively avoids this difficulty. Although it is difficult to dynamically modify the image on a storage tube, there is very little need to do so in a sketching environment. The difficulty of erasing is not unlike that the user experiences when drawing with pen on paper, anyway. Rather than erasing, the user just gets a clean sheet of paper. The ARDS has a limited dynamic mode, called write-through, which permits the dynamic alteration of a limited number of lines. This feature is adequate for those rare occasions when a picture must be modified.

While the sketch is being initially stored, it can be displayed in an exact mimic of the original. The ARDS is a relatively slow display, however, and the time taken to display the image reduces the sample rate which can be obtained from the tablet. Thus, the resulting stored sketch is less detailed. To overcome this difficulty, display while drawing can be suppressed. The stored sketch can, of course, be replayed to the display. During times when the pen is not touching the tablet, a real time clock is sampled, so that the length of pauses in drawing can also be stored. The replayed sketch, then, can be an exact replica of the dynamic development of the original.

The addition of pressure sensitivity demanded an additional feature for the data display--some method for showing variations in pressure. The ARDS was altered such that its focus could be modified under computer control. Thus, while the tube normally displayed a thin, sharp line, by defocusing the beam slightly, the width of that line could be increased up to an eighth of an inch. This feature is integrated with the load cell in the pressure pen such that the width of the line varies as a function of the (original or redisplayed) pressure (Figure 1). This line variation greatly enhances the visual effect of the display, since it provides a better feel for pressure than the line output of a ball point pen can provide.

Figure 1.



II. PAST

How Did I Get Here?

READING AND REDISPLAYING--DRAW/SHOW

In the spring of 1970, the Architecture Machine Group obtained its Sylvania tablet, and embarked on an experiment to discover about reading a sketch by computer. The tablet was an ideal device for this experiment, having the natural feel of pen on paper, while at the same time providing a fast, accurate, time-dependent sampling of the sketch as it was created. The first programs written, naturally enough, were programs to read and save the data from a sketch, DRAW, and to redisplay the stored data, SHOW. DRAW senses the z-position of the pen, only recording data when the pen touches the tablet. The maximum distance the pen is away from the tablet (near or far field) is recorded as a flag in the stream of data whenever the pen leaves the tablet. The distinction of the z-fields is not used by any part of the program to date. It is thought, however, that the degree of pen lift may be useful for providing some clues into logical separation of the sketch into sub-sections, divided by higher lifts of the pen.

Where the pen went while it was not in contact with the tablet could be read from the data, and there was some discussion at the time about whether or not this information should be saved. Since at the time, we did not know what information was going to become important, we were leery of discarding any obtainable information. The use to which pen-up information could have been put was unclear at the time (it is still so), however, and space limitations for storage of data were relatively severe at the time. It was decided, therefore, to discard this data.

DRAW begins by sensing the position of the pen in the z-field. When the pen touches down, DRAW records a far-field pen-lift flag and the x- and y-coordinates of the first point. With the recent addition of pressure sensitivity, the value of pressure is also saved. It then continues to read successive points and pressures, storing them away and (optionally) displaying them on the storage tube. When the pen is lifted from the tablet, DRAW waits for the pen to be replaced and saves the pen-up flag recording the farthest field reached by the pen and the time the pen was lifted. DRAW continues to read and save data in this manner until the pen is lifted away from the tablet field and then signals that the drawing is complete.

Once the data has been saved, it can be redisplayed by a call to the program SHOW. When this program was run for the first time, it caused the sort of serendipidous discovery which occasionally provides direction for research. Although it seems obvious in hind-sight, the effect the time based sampling of data would have on the data itself had not occurred to anyone. Since the tablet samples data at a constant frequency (200 times per second), the distance the pen covers between samples is a direct function of how fast the pen is moving. Obviously--now--the faster the pen is going, the greater the distance it will cover in a two hundredth of a second--the farther apart the recorded points will be. The effect of this fact, of course, is that SHOW not only redisplays the original sketch, but also it replays the sketch at exactly the same rate it was originally drawn. Inherent in the way the data is stored is the data is stored is the RATE at which the line was drawn.

This fact provided the ground on which HUNCH is built. It may be assumed that the speed at which a person draws reflects in some way his degree of purposefulness, his detailed interest in exactly what he is sketching. More specifically, it is usually true that if a person is drawing quickly, he is not as interested in detail as he is when drawing slowly. In a quick sketch, the person is usually interested in the general impression his lines make, rather than in the exact reproduction of those lines. Conversely, a slowly drawn sketch may often be painstakingly detailed. In this case, the position of each line becomes important, and the sketcher wants his drawing to be seen exactly as drawn.

SQUIGGLES

One special purpose kind of line is detected "on the fly." As mentioned in the description of the GRAIL system, the scribbling out motion has a special meaning. If drawn over previously drawn lines, it means that the earlier lines are to be crossed out. If filling an open area, the scribble implies that the area is to be shaded. In either case, the exact configuration of the line is not as important as the area it covers. Thus, it is not critical to submit the line to exact analysis. In order to extract these scribbles from the raw data, a "squiggle" recognizer was devised as a part of DRAW. Coincidentally, Rand's use of a squiggle, even the to the name itself, was not discovered until after the one in HUNCH had been developed.

A squiggle is characterized by several things. First of all, it has many changes of direction. It is usually drawn at a fairly high rate of speed, however, so it is not confused with the curving line of a driveway, for example. Finally these changes of direction form a sawtooth pattern (they are neither too spread out nor too sharp), so that a squiggle is not confused with a wobbly fast straight line nor with a line which has been heavily overtraced (Figure 2).

When the pen is placed on the paper, the squiggle recognizer begins searching the data as it is read for sharp changes of

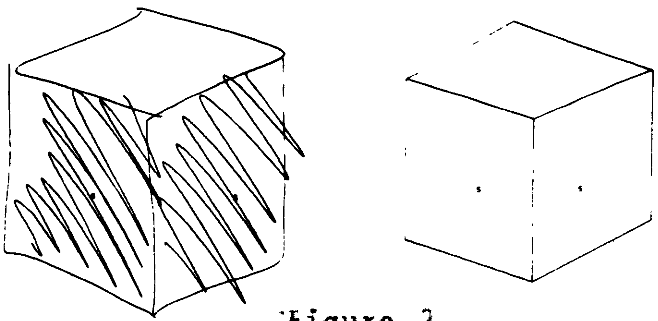


Figure 2.

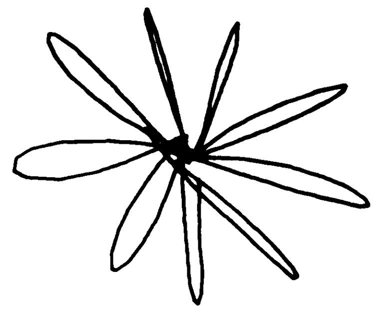


Figure 3.

direction, called extremes. Since a squiggle must be drawn quickly, the program expects to find many of these extremes before many points have been read. In fact, if the required number of extremes have not been found before a maximum number of points have been read, the program decides that the line is not a squiggle, and it quits looking. If the requisite minimum extremes do fall within the limit, then the position of these extremes is examined for the sawtooth pattern. If the extremes are too spread out or too close together (separated by angles greater than 9 degrees or less than 10 degrees), then the squiggle is rejected. Finally, the total rotation of lines connecting the extremes is compared to some maximum allowable value. If it falls above this maximum, the squiggle is rejected (this check is added because the person who implemented the algorithm objected to the fact that flowers were recognized as squiggles (Figure 3)). Having passed all these tests, the line is recognized as a squiggle. The beginning point of the line is tagged, so that subsequent programs can recognize the line as a squiggle to be treated as a special case.

EXTRACTING LINE SEGMENTS--STRAIT/STRAIN

After the discovery of the rate dependence of the data, it was decided that the next step FUNCH should undertake would be to try to extract from the original data the straight line segments of which it consists. It would make its decisions by searching the sequential, raw data for "significant" changes of direction, tempering these decisions by taking into account the rate (and later the pressure) at which the line was produced. A more detailed account of how this program works follows in Section III. This section covers how the program arrived at the state it is in now.

The original attempt at a solution was a set of programs which eventually became known as STRAIT. This original version calculated the tangents of segments defined by connecting pairs of points in the raw data. It then looked for differences in these tangents, comparing the change in tangent to some value. If the change was greater than this threshold value, it was determined that one segment ended and another began. This solution quickly turned out to be a mistake. Because the tangent is so non-linear (going to infinity for a vertical line), the threshold level had to vary as a function of the direction of the segment. Furthermore, when dealing with infinity on a finite state machine, one quickly becomes embroiled in roundoff and overflow difficulties. As a result, this original approach was abandoned, and a calculation of the arctangent of the segment was substituted. Except for a discontinuity in the arctangent function around zero radians, it has the attractive feature of being linear everywhere else. Thus, the threshold problem became direction independent. Furthermore, since the arctangent is limited to values between zero and two pi, the difficulties with infinity were eliminated.

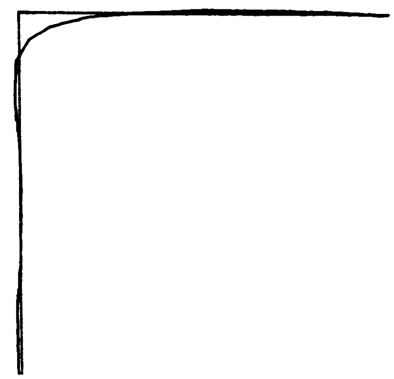


Figure 4.

It is the nature of a sketch that although a sharp corner is intended, it is rarely achieved. Instead, the two segments meeting at the corner are connected by some circular arc. Furthermore, since the drawer has to slow down in order to negotiate the corner and still be drawing where he intends afterwards, points tend to collect at corners. As a result of these facts, the first point fallin above the threshold for a corner could not be assumed to be the actual intended position of the corner. In fact, because the (sharp) corner might actually be represented by an arc, there is no guarantee that the intended corner exists in the data at all (Figure 4). The only reliable way of determining the intended position of a corner is to determine the two segments lying on either side of the corner, and then to calculate algebraically the intersection of these two lines. This was the approach taken in STRAIT. Once a segment has been discovered by an instance of a change of arctangent greater than the threshold, its endpoints are saved. When a second segment is found, then, the intersection of the two segments is calculated and used as the common endpoint of the two segments.

The result of such calculations is the creation of points and links between points which represent lines. When a pen-lift flag is found, the points on either side of it are saved as the end and the beginning of a segment. When the position of a corner is calculated, that point too is saved. To represent a line between two points, a link is created which contains information about which two points are connected, the rate at which the particular line was drawn, and the greatest pressure reached across the line. This structure is the output of the program STRAIT.

In order to cut down even further on the amount of data to be saved, and to maximize the inferred information in the final structure, STRAIT had a program which looked for implied "latches." When two points fall near each other, people will often mentally connect them as if they were a single point. STRAIT tried to do the same thing. In Figure 5, the first and last point of the line fall near each other. STRAIT decided that they were intended to be the same point, and latched them (The raw sketch appears at the beginning of Section IV).

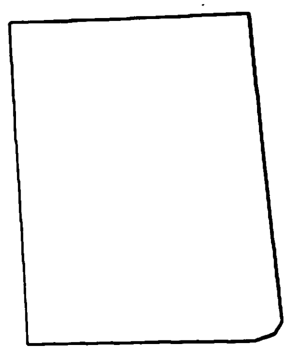


Figure 5.

The method for performing this operation is similar to that for finding corners. Each time a new point is determined, the list of existing points is searched for points nearby. In order to be considered near, the distance between the new point and each point on the list is compared to some threshold limit. If the distance is less than that threshold, the point is considered near. If no point falls below the threshold, then the new point is added to the structure with the appropriate link to any points which may be related by lines. If at least one point is found below the threshold distance away, the nearest point to the new point is considered to be the intended match. Links are created between this point and any related points, and the new point is not saved. Initially it was thought that the tendency would be for people to draw lines to known points, so the initial position of a known point was unmodified, and the direction of the new line was modified to take it to the known point. Subsequent experience seems to indicate that people tend to correct earlier errors in positioning points by drawing subsequent lines to where the point should preferably have been. A somewhat better treatment, therefore, would have been to move the old point to the position of the new point, or at least to average the two points somehow. Difficulties with the whole latching scheme later tended to render the whole approach suspect, however, so this minor modification was never implemented.

The output structure of STRAIT, then, represented the minimum number of line segments and points which could describe the sketch, subject to some threshold values. For certain classes of sketches, this assumption proves to be entirely adequate; using these simple principles, STRAIT's handling of such a sketch is remarkable (Figure 6). STRAIT had several severe short-comings, however, which tended to point away from its existing mode of operation to some more complex handling of the data.

One difficulty came in the problem of handling overtracing. The tendency to retrace a line already drawn is a normal behavior on the part of a human user of the system. The method for finding corners was inadequate for handling the small angles commonly resulting from retracing a line. The precision of the computer was inadequate for sharp angles, due to roundoff errors and a tendency to wind up dividing by zero. Calculating the algebraic position of a corner between two lines which are nearly colinear resulted in frequent, severe misplacing of the common point. To combat this difficulty when calculating a corner, an additional

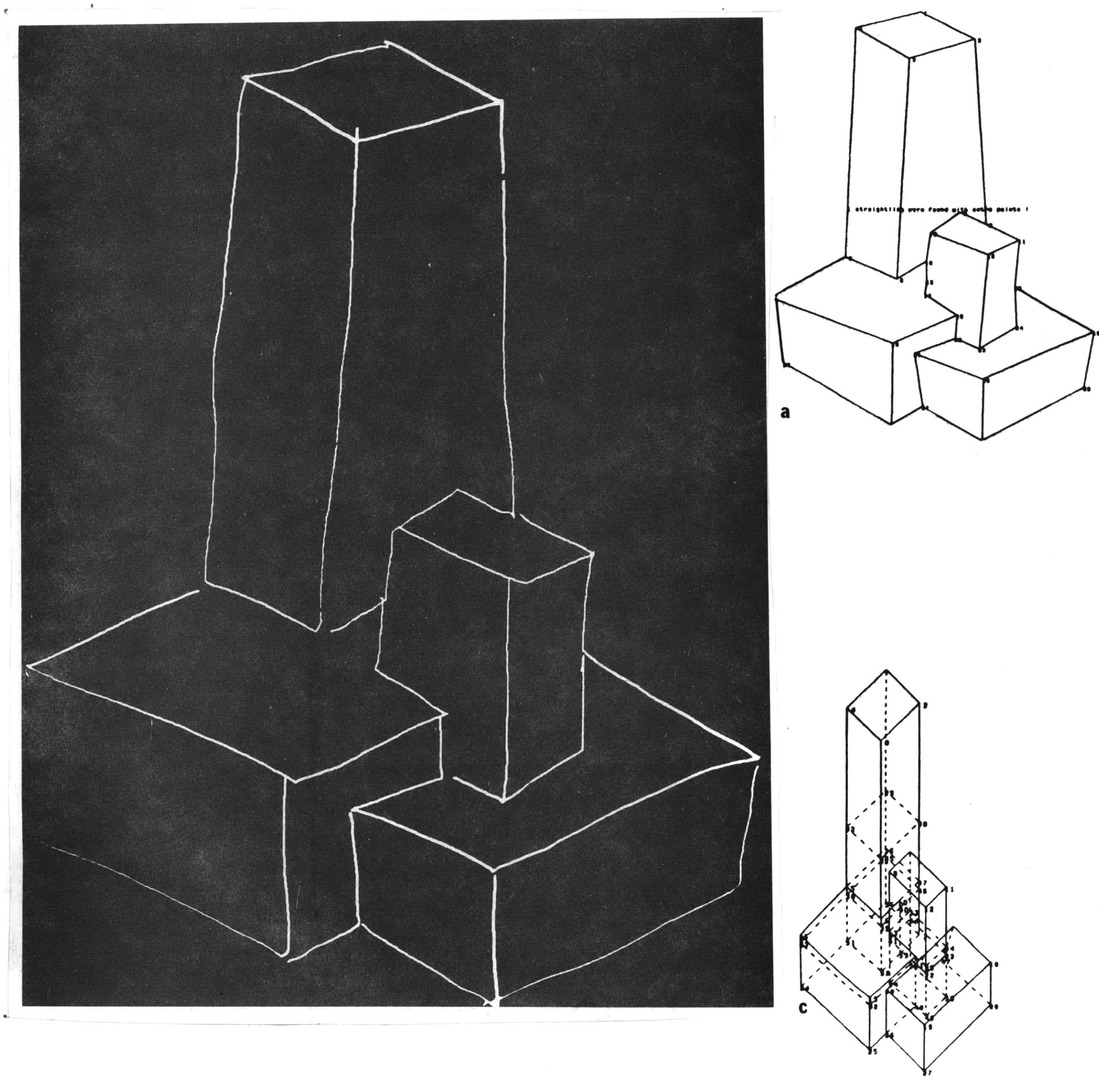


Figure 6.

routine was added to check specifically if the angle between the two lines was very small. For a small angle, using the calculated intersection is dangerous. Instead, an effort is made to find the point at which the line changed direction--the locally extreme point on the line. In such an instance, this extreme is used as the common point between the two segments. In the case of a sharp angle, the corner can not be very rounded, so the error induced by using a real data point on a corner is small. Unlike the case of a wider angle, furthermore, such an error causes little change in the direction of the line (this fact, after all, is what makes calculating the intersection so difficult).

The introduction of overtracing causes a vast proliferation of segment endpoints in a sketch. One of the restrictions on the class of sketches STRAIT could handle well is that the sketch must have a fairly diffuse distribution of corners and endpoints. When the density of points increases locally, then segments begin to become wrongly latched (see Figure 7, the proverbial sketch of Aunt Fifi's house). The addition of overtracing only

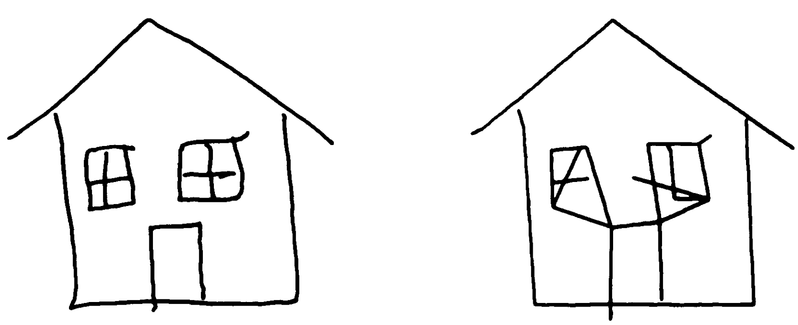


Figure 7:

aggravates the problem. The decision to latch or not to latch is not a purely local decision. Who should have authority to make such a decision is a point which is still under debate. The last part of this paper is one proposal at a solution. At any rate, it seemed futile to try to continue with the solution used by STRAIT, so a variation was developed which eliminated the latching step (STRAIN, STRAIghten with No latching). This seemingly backward step is justified as a basis for the groundwork for future development. We already know one method which will not work.

RATE/PRESSURE

Mildly glossed over in the above discussion of finding straight line data was the role that rate and pressure played. The original version of STRAIT had no measurement of rate or pressure; the various threshold values applied were constant throughout the program. After the basic routines were functioning more or less correctly, a method for figuring rate was determined (see description in Section III). Once the rate that a line had been drawn was calculated, that value could be applied to a function for figuring the various thresholds. Nominally, for a faster line, the thresholds were higher. The effect of this additional function on STRAIT was striking. There was an immediate, marked improvement in the decisions STRAIT was making about the data. In order for earlier versions of STRAIT to work, the thresholds had to be set quite low to allow for the comparatively small changes of direction which occur when a line is being drawn slowly. Similar difficulties arose for latching. The effect of this limitation was to cause STRAIT to permit many more corners than were actually intended. If the thresholds were increased, STRAIT began to miss intended corners on slow lines. The addition of a rate measurement permitted application of a more liberal threshold for fast lines, a more conservative one for slowly drawn ones.

One side effect of this treatment was that STRAIT (and also STRAIN) became fairly sensitive to the "hand" of the user. Different individuals have different styles of sketching. Some people can sketch quite accurately at a very high rate of speed; others are not so accurate. Thus, the value of the thresholds for one person at a particular rate might not be appropriate for another person at that rate. In a pathalogical case, one can imagine a person who drew quite smoothly when moving his hand rapidly, but who suffered from palsey when moving his hand slowly. In order to work properly for an individual, then, STRAIT has to be tuned to each user's hand. Several methods for discovering the proper tuning for a particular person have been tried. The only one which works at all successfully is intuitive manual adjustment of parameters.

One program was written which tried to to the tuning job implicitly. The way the value of a threshold is determined is by applying the rate to a polynomial function:

TH=A*(Rate)**3+B*(Rate)**2+C*(Rate)+D

Rate varies between a value of zero and a value of fifteen. The various parameters (A,B,C,D) are a function of the hand of the indivual user. Because of the complexity of tuning the parameters manually, the value of A was normally set to zero, reducing the polynomial to a quadratic. In such a case, the effect of the various parameters can be seen to be as follows:

At low rates, D predominates.

At high rates (assuming the value of B is a small fraction), the C term is dominant.

For the middle ranges, the value of the fraction B determines which way the function curves and the degree of curvature.

It was thought, then, that the various parts these parameters played at various rates could be separated and treated individually. Thus, the tuning program asked for a set figure (a square) drawn at a slow rate. It then juggled its D parameters until it got a four-lined, four-cornered figure. The program then asked for a quickly drawn square, and modified its C parameter until it got a value that made the figure fit. Finally, it took a square drawn at a moderate speed and set the B parameters. While the program frequently could come up with a solution, almost equally often it could not find a value for one or more of its parameters which was satisfactory. Part of the problem derived from the limits which had to be placed on the values the parameters could take. In order to provide some starting point for the program and to prevent the arrival at some totally unreasonable parameter values, each of the parameters had an upper and a lower bound for the values it could take. In many cases, however, rather than settling on an intermediate value for a parameter, the program had a tendency to slide to one limit or the other. To compensate, the other parameters would become equally skewed. It is difficult to speculate on why this error tended to occur, but it appears likely that it was caused in part by the inter-relation of the parameters. Experience in manual tuning of the parameters seems to indicate that it may not always be true that the parameters can be separately tuned. Occasionally a better set of parameters was arrived at if, while increasing the value of one parameter, another parameter was comparably reduced. Since the implicit tuning program knew nothing about this technique (which appears to be largely intuitive, anyway), its results were often inadequate. At any rate, that particular experiment has been abandoned.

With the ability to sense pressure, a new variable has been introduced into the system. How this parameter should affect the behavior of HUNCH is not certain yet, as we have not lived with it for very long. It seems reasonable to assume that a heavily drawn line requires more detailed analysis than a light line. This effect can be accomplished by using pressure to offset rate. As the pressure increases, it applies more drag to the line, slowing down the calculated rate. Thus, a quickly drawn line, drawn at great pressure, receives as detailed an examination as a slow and deliberately drawn line at any pressure. The rate is made to vary as a function of pressure according to the equasion:

$$Rate=Rate*\frac{16-Pressure}{16} \qquad (0<Pressure<15)$$

This function has the interesting side effect that its impact varies as the rate it is operating on changes. At high rate, a moderate change in pressure (say from zero to four) cause a comparative change in rate (from fifteen to eleven). At a slow rate, the effect is less (three to two, e.g.). This fact is rather attractive, intuitively, but the overall effect has never been evaluated.

INTERSECTIONS--INSECT

Because of the way the data is generated and stored, there is no reason to believe that if two lines cross each other, their intersection actually exists in the raw data. This problem aside, in the process of searching for straight line segments described above, it is impossible to find intersections at the same time. Nonetheless, it is not unreasonable to want to know about the existence of intersections. In fact, for some applications, the finding of crossings and related T-intersections, is a great aid toward solution of the particular problem (Negroponte 1972). In order to locate these points, then, a program to find them was developed, INSECT (from INterSECTion).

INSECT uses a brute force method for locating intersections of lines in a sketch. The first line discovered is compared to all the other lines found, and the algebraic intersection of the line and each subsequent line is calculated. As these points of intersection are found, they are compared to the endpoints of the two lines being worked on to see if the intersection falls between, or within some delta (varying according to rate, as usual) of the endpoints. Intersections falling outside these limits are discarded. Those falling within the limits are considered to be discovered intersections (Figure 8). If the intersection falls within the threshold of one of the endpoints

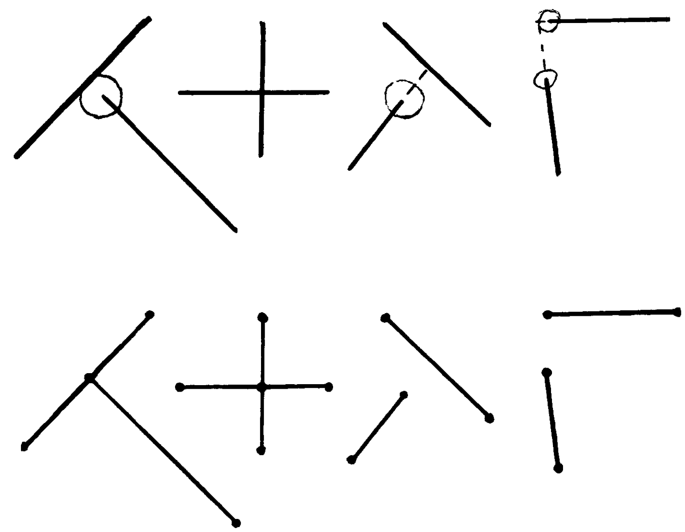


Figure 8.

of the two lines, that point is moved to the coordinates of the intersection, the other line of the pair is broken, and the endpoint is made the common end of the two new segments. If the intersection falls well within the ends of the two segments, a new point is added to the structure, and both lines are broken and attached to it. The second line in the structure is then compared to all subsequent lines; the third; and so on. The resulting structure has all intersections and T-joints inserted in appropriate places in the straightened version of the sketch.

It can be seen that the amount of calculation which must be done by this method goes up as the factorial of the number of lines in the sketch. This load is clearly unacceptable. As a sketch becomes more complicated, with overtracing for example, the amount of calculation goes up astronomically while the number of useful results does not. It seems reasonable to say that we are willing to make N linear passes through the data (where N is a small integer--we are willing to look at each line N times), but we do not wish to pay the cost of even one pass through the data which is worse than linear. It took a long time to come up with a solution better than INSECT for finding intersections, and the better method has not been implemented yet.

We have a method for mapping a sketch, raw or straightened, on to a large array (existing on a fast-access fixed-head disk). For a complete description, see Appendix II. With a bit of cleverness, the straightened data can be mapped into two grids (or one two-bit grid), such that if the mapping program discovers that the bit in the first grid is already on (a bit being a point on a line in the straightened data), it turns on the equivalent bit in the second grid. It can be seen that, if every line in the straightened data is mapped on to the grid once, the only points which could appear on the second grid would be those points where two lines intersected. Thus, in order to include the intersections in the data structure, it would be simply a matter of reading points from the second grid which relate to lines in the straightened data. If a bit is found to be on, then, it is an intersection, and the coordinates of that point could be inserted into the line currently being tested. The extration of all intersections would require only two linear passes through the data for a complete solution: one to map on to the grid, one to read for intersections.

It should be obvious that this solution does not find T-joints which were near misses (Figure 8A). This objection is not entirely bad, however. Since the method for finding T-joints in INSECT used the same kind of "latching" described for STRAIT, it was prone to the same kinds of difficulties. Essentially, this problem comes up whenever there is an attempt to apply a local decision to a situation which requires more global information. This error occurs where there is an attempt either to remove or to add information which can not be directly derived from the available raw data, where the data is extrapolated across empty space. Thus, the loss of this "missed T-joint" capability only parallels the removal of latching which turned STRAIT into STRAIN. If one wished to recover this ability for some particular application, one could take windows off the grid around the points in a sketch and look for lines which cross these windows.

HORIZONTALIZING AND VERTICALIZING--LEVEL

In an architectural context, lines which are horizontal or vertical have special meaning. This effect occurs because we live in a gravitational system which makes building horizontally or vertically a more reasonable way to construct buildings than any other way. Since the applications for HUNCH were considered to be primarily architectural, it was decided that it should be able to place a special meaning to lines which were horizontal or vertical. The program LEVEL was written to search the straightened data for lines which could be implied to be horizontal or vertical. It calculated the restricted arctangent (between zero and pi/2) of each straightened line segment, and compared it to a pair of rate-dependent threshold values. If the line fell above the upper threshold, it was considered to be a vertical line, and the coordinates of its endpoints were adjusted so that the line was forced exactly vertical. Similarly, if it fell below the lower threshold, it was eventually forced exactly horizontal. This program attempted to take into account the implied continuity of lines. If one line was found to fit one of the thresholds, the lines connecting to the points on either end of the segment were examined to see if any of them fit the threshold the same way. If a line was found continuing in the same direction, its second endpoint was also searched for a continuing line. This process was repeated until no further continuing lines were found. Then the positions of all of the points found to be part of the continuous horizontal or vertical were adjusted at once, so that the

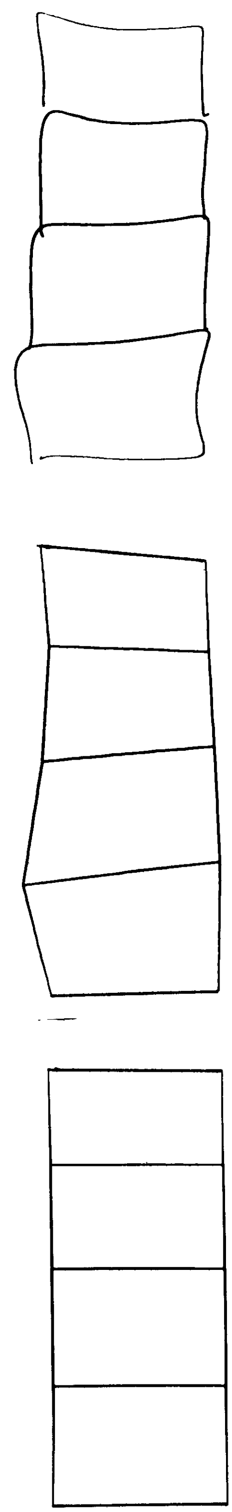


Figure 9

continuity was preserved (Figure 9). This need arises from the desirability of preserving continuity, and from the danger of moving one point without examining the points around it. There could exist a condition where a line which falls outside of the thresholds is moved within them by the leveling of one of its endpoints being acted on at another segment. Thus, if the points were adjusted independently, information from the original data might be lost by the partial treatment of a line segment. This approach made LEVEL perform as well as it could be expected to, but since it used the same extremely local information about line segments that latching and intersection finding do, it suffered from the same kind of indiscriminating errors that those two functions make. Thus, while serving as an educational and jazzy exercise, its usefulness is questionable.

CURVES

One of the first decisions made in the development of HUNCH was on the subject of cureves. Curves are somewhat more difficult to handle than straight lines, since they are more difficult to define. A straight line, after all, can be represented by two points. A curve requires at least three, and it is not at all clear which three are appropriate. Furthermore, in a sketch, it was difficult to come to grips with the problem of differentiating a curve from a wobbly straight line or from a very sloppily drawn corner. In Figure 10, for example, it is not even clear to a human whether that is a sketch of badly drawn rectangle or of a a super-elipse.

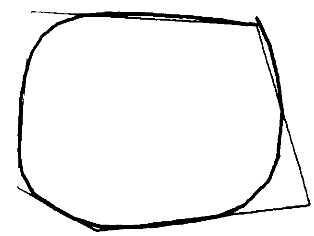


Figure 10.

As a result of these difficulties, it was initially decided to side-step the issue by refusing curves as valid input. This decision can be partially justified on the grounds that, in the assumed architectural context, curves just do not occur that frequently. Avant guarde architects aside, the vast majority of buildings have straight walls and flat ceilings (Negroponte, 1973). Thus, while ignoring the problem of curves imposed a limitation on HUNCH, the resulting simplification of the goals seemed to get us a long way before it became a problem.

The immediate goal of HUNCH, then, was to look for straight lines. The approach used has a rather interesting side effect if the program is presented a curve. Since corners are defined by finding two line segments and calculating their intersection, a curve becomes simply a very long corner. Once a curve starts, no further action is taken by the straightening program until the curve ends. This fact makes the operation of HUNCH on curves rather unpredictable. In fact, it may be said that the way HUNCH operates is the worst possible way to handle curves there is: HUNCH will make worse decisions about curves than any other method of data reduction from sketches. The most extreme case of failure is shown in Figure 11. In 11A, HUNCH found a straight line segment at the beginning at at the end of the stroke. They have been emphasized in 11B. It decided that everything in between the two segments was a corner, and calculated the intersection of the two segments, to define the position of the corner between the two segments. The results are shown is 11C.

While the initial assumption about the importance of curves still appears valid, over the years it has become a bit of a thorn in the side. The first thing anyone does in a demonstration of HUNCH is to throw a curve at it. As a result, it was decided to try to find a method for at least recognizing curves. If HUNCH knew a curve existed, that would be sufficient to keep it from being confused. Furthermore, in a sketch, the actual shpe of a curve is not as important as is the recognition of its existence. The user is not likely to care whether the curve is a parabola, circular arc, sine curve, or part of a complex polynomial. He will care if it gets straightened, however.

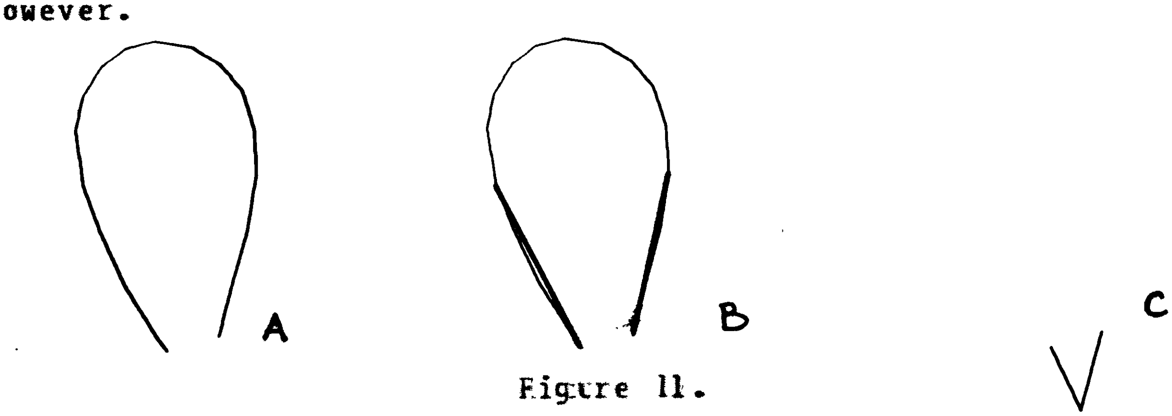


Figure 11.

The initial approach taken to try to recognize curves was to use the mathematics of the line to cause the curves to stand out. The slope of a sketched line (its first derivative) changes along its length. In the case of a straight line, the variations are small around some constant value. At a corner, the first derivative undergoes a discontinuity. For a curve, the first derivative is constantly changing, smoothly. If one looks at the second derivative of a line, then, that of a straight line will be zero, or nearly so. A corner would have a spike around the discontinuity, and a curve would be identified by some fairly uniform, non-zero value. Unfortunately, due to the method of sampling data, the theory does not work when put into practice. Local variations in the data tend to over-ride the actual data from the second derivative. Figure 12 shows some samples of sketches and the first and second derivatives associated. Any positive value in the second derivative is lost in noise from the data.

Another approach which shows more promise is to capitalize on the poor curve handling ability of the straightening pass of HUNCH. One way to make HUNCH handle a curve better has always been to draw it more slowly, since that would cause the curve to be segmented into smaller lines. In fact, small variations in the parameters used to determine the minimum bend which defines a corner result in radically different behavior of HUNCH on curves while having only minor effects on the analysis of straight

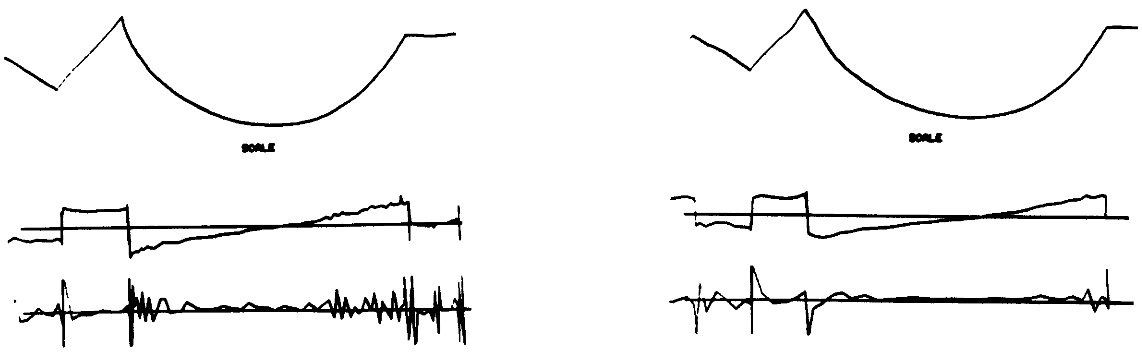


Figure 12

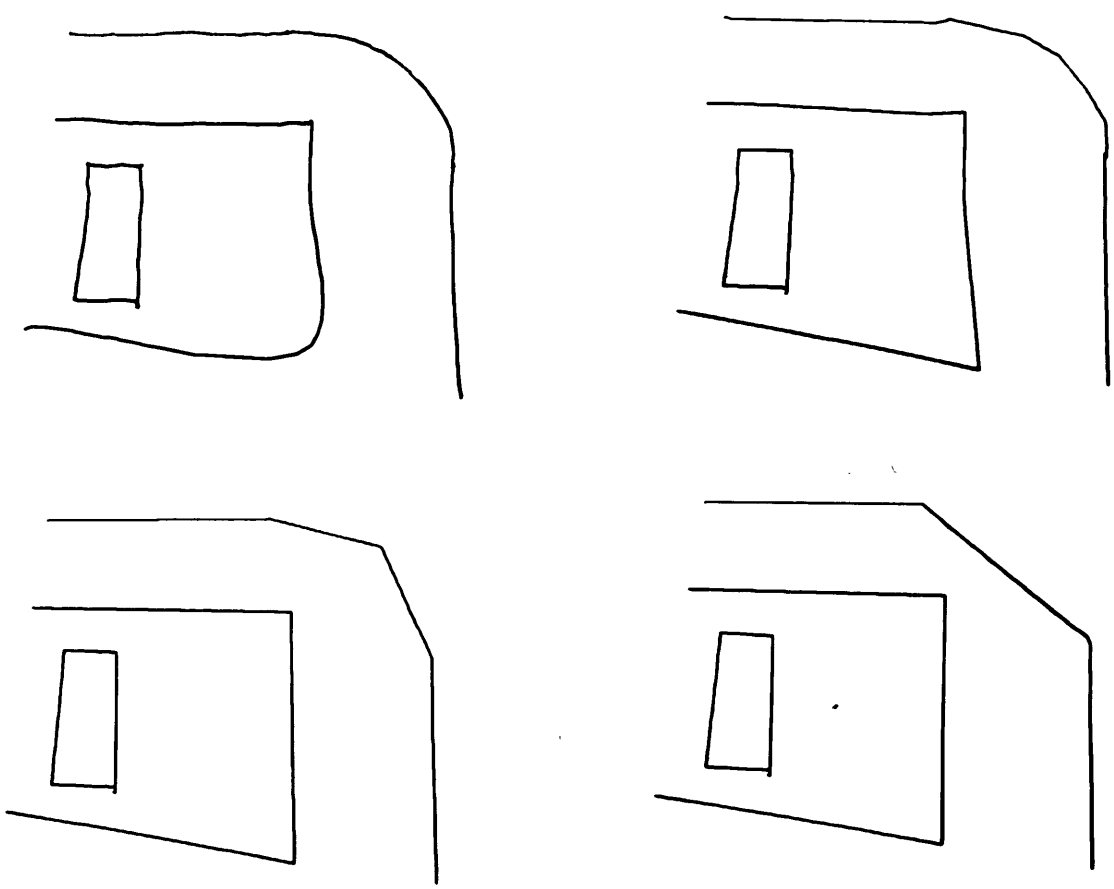


Figure 13

lines. Figure 13 shows a sketch consisting of both lines and curves, and three analyses by HUNCH of the sketch, using different rate parameters. It can be seen that while the variation of the analysis of the straight lines is slight, there are vast differences in the handling of the curves. Note that the handling of the rounded courner (at (a)) is done correctly in all cases. The implications of this discovery are not fully investigated yet. Although this approach was first proposed over a year ago, it was not tried until recently, after the first approach had been thoroughly discredited.

EDITING

Since HUNCH frequently makes mistakes (largely due to objections previously discussed), it seemed desirable to implement a means of editing the resulting structure. Since this editing was ultimately accomplished by explicit commands, their implementation has no direct bearing on the philosophy behind HUNCH. Their description is included for completeness, however.

To edit a sketch one needs the ability to perform four functions: the ability to add a point; the ability to remove a point; the ability to link a line to a point; and the ability to break such a link. The workhorse of the editing package is a program called MOVE. By pointing with the stylus of the tablet, the user can grab a point in the displayed structure and move it to some other position in the display. If the new position falls close to another point, all the lines attached to that point are latched to the newly positioned point, and the other point is deleted. A point can be slid down a line that it is on until it becomes latched with the other end of the line and the extra point deleted. Points may also be deleted by a program called CLEAN, which eliminates slight bends in otherwise straight lines. Since this process over-rides a decision made in the straightening pass, however, this program is extremely timid

To add a point, there is a program called BEND. If the stylus is pointed at the line to which the point is to be added, the line is broken, and a new point is added to the line at the location indicated. This point may then be moved or latched, as in MOVE

Finally, there is a program called DETACH which breaks links between points. The user draws a line across those lines in the display which he wants detached from a given point. A new point is created, offset slightly from the point in question, and the crossed lines are detached from the old point and latched to the new one. The program decides which point is to be detached from by finding the common endpoint of the lines drawn across. If there is only one line crossed, it decides which end of the line segment the intersection is closer to, and detaches from there.

III. PRESENT

Where Am I Now

Let us step through HUNCH's resolution of a sketch. The user invokes the command DRAW, and draws Figure 14, a rectangle. The drawing was done in one stroke in a counter-clockwise direction from the upper right. He signifies that the drawing is complete, and the file containing the data is closed. The actual data points stored by the program are shown in Figure 15. The distance between the points gives some indication of the rate at which the line was drawn. It can be observed that the first half of the square was drawn at a fairly rapid rate, while the last half was drawn more slowly. Since the pressure sensitive pen was not available when this sample was taken, the pressures associated with the data in this sketch are all zero.

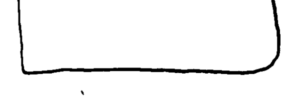


Figure 14.

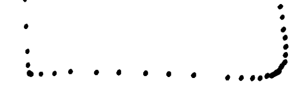


Figure 15.

The sketch is now ready to be examined for straight line segments. This pass at the data is described as separate from the DRAW routine, but there is no inherent reason for the two operations to be separated. With minor modifications, the command STRAIN could be integrated with the draw phase. In that case, the search for line segments could be done "on the fly." Under the present scheme, the straight line finding pass at the data is invoked by the command STRAIN.

The body of the work in finding line segments is bound up in three routines: NOEND, TANGNT, and TRNTST. These routines provide the main interface between the program and the raw data, and they are usually called in sequence, in the order they were named above. NOEND performs lookahead, data management, and parameter setting. TANGNT, a slight misnomer from historical reasons, calculates the arctangent of a line over a segment. TRNTST determines the difference between two successive arctangents.

NOEND is perhaps the most subtly complicated program in the system, since it apparently does so little and is responsible for so much. The first thing NOEND does is to call the routines which calculate the current applicable rate and pressure. RATER does not calculate the rate at every point, since the rate does not fluctuate greatly over a very small area and since the method of calculating rate works over a range of points around the current one. In order to minimize the effect one anomalous point could have on calculateion of rate, a method of calculation was chosen which examines points near the current point. Rate is considered to be an inverse function of the number of points sampled before the line has traveled some set distance, approximately three eithths of an inch. The current point pointer is temporarily backed up a few points, so that the sample will likely fall across the current point, rather than one side or the other of it. Then a points traversed counter is bumped, and the distance between the new current point and its following point is calculated. This length is compared to the fixed distance, and if greater, the calculation is complete. Otherwise, the current point counter is incremented, the counter bumped, and the next distance is calculated. The length of this segment is summed with the length from previous calculations, and the sum is compared to the fixed length. This process is repeated until either the fixed length is exceeded or until the points traversed counter exceeds sixteen. The difference between the points traversed couner and sixteen equals the rate (0-15, a reputable computer-based numbering system). The pressure at the original current point is then normalized to fall in the 0 to 15 range as well, and this value is applied inversely to the rate (see Section II, Rate/Pressure).

This calculated rate is then applied to the user's parameter polynomial, TANDIF=A*Rate**3+B*Rate**2+C*Rate+D

where A, B, C, and D are parameters unique to the user for this application of the function. TANDIF is the maximum allowable change in arctangent before STRAIN decides that a corner was intended. Thus, the degree of turn which determines a corner is a function of the individual user and the local rate he is drawing at any given time.

The next task NOEND has is to check to see if it is going to run out of data. STRAIN is going to calculate the arctangent of a segment connecting the current point to a point some interval down the data (usually two points away). The reason for using this interval, rather than simply calculating for the segment between the current point and its successor is that such an approach would make the program to susceptible to local jigs in the line. By skipping a point or two in between, extremely local variations in the line tend to be smoothed out, while major changes in direction are unaffected. However, there are two events which must be watched for across this interval. First, since the data exists in a fixed buffer, NOEND must check to make sure that the end of the buffer has not been reached. If this is the case, the ramaining data in the buffer is flushed, and more data is fetched. Second, and more important, the data across the interval must be checked for "pen-up" flags. Such a flag indicates that the line being looked at has ended. If a pen-up flag is encountered, a special exit is required to a subroutine called ENDSEG. At the end of a segment, no more calculation can be done on the current line, so loose ends must be tied up, and the program must be reinitialized to begin a new segment. ENDSEG will be discussed later.

NOEND has one more function to perform; it checks for extremes on a line. As it examines the points on the line, it sends each point to a subroutine called EXTRMR. This routine checks to find out if the line has changed direction more than ninety degrees over the last few points. Such an occurrence is called an extreme. If searching for extremes seems redundant to the main-line search for corners, it is. The information developed by EXTRMR is used later by subroutine CFSA (Check For Small Angles), however, and therefore must be found. Note, this EXTRMR is the same as the routine called in the search for extremes defining squiggles.

Finding no ends of lines across the next interval, NOEND loads the x- and y-coordinates of the current pointer value it was handed (or the first point in the new buffer, if the end of the buffer was reached), and returns. The next step is a call to subroutine TANGNT. This routine increments the current point counter by the interval (two points), and gets the x-length and the y-length for the segment between the previous and the new current points. Using these values, TANGNT calculates the arctangent of that segment, resulting in a value between zero and two-pi. This number is added to the top of a circular list of arctangents for later access, and TANGNT returns.

The third member of the trilogy, TRNTST, obviously can not be called until TANGNT has been called at least twice. After the second call to TANGNT, the list of arctangents is handed to TRNTST, which calculates the difference between the top two arctangents on the list. Because of the discontinuity of the arctangent function around two-pi, TRNTST has to worry about lines in this vicinity (a pair of nearly colinear, horizontal lines could return an arctangent difference of nearly two-pi). The exact difference of the arctangents is not as important as the magnitude of the difference, so TRNTST gets around the discontinuity by returning the lesser value of the following functions:

$$\text{Difference} = |\text{Arctangent}(1) - \text{Arctangent}(2)|$$
$$= 2*\text{Pi} - |\text{Arctangent}(1) - \text{Arctangent}(2)|$$

It can be seen that in the horizontal line case, the routine would return the correct value.

The power of these three routines can be shown by seeing how STRAIN uses them in its search for line segments. The first buffer of data is fetched and the currnet point pointer is set to the first point in the buffer (194,x;540,y in the sample sketch). STRAIN is going to try to deal with two line segments at a time.

1) Since the first point obviously begins a segment, its x- and y-coordinates are saved in an array called THOLD; a pointer to this location is stored as the first element in a second array called CORNER; and a pointer to the point's sequential position in the original data is stored as the first element in an array called DATP. Furthermore, a flag is set in RATE to signal that a new TANDIF parameter should be calculated, and a call is made to NOEND. Since the interval is currently set to two points, no endpoints or end of buffer is encountered. The rate is found to be 14, the x-coordinate 194, and the y-coordinate 540. When stored, the maximum rate reached while drawing the line segment is associated with the line for furture reference. Since this is the first data examined, the associated rate must be the greatest found, so it is set aside for later comparison. A call is made to TANGNT, and the arctangent of the first segment, between the first and third points is calculated (6.27) and stored on the circular list TAN. This arctangent is the only one on the list, so a call to TRNTST would be futile at this point.

2) The current point counter is incremented to the second point in the buffer and NOEND is called again. RATER does not need to recalculate yet; there is no endpoint across the next interval, which lies entirely in the buffer. Therefore, NOEND returns with x equal to 98, y at 547, and rate the same as before. The rate is not greater than that previously determined, so the saved

value is unchanged. TANGNT is called and adds the arctangent of the second segment (6.22) toTAN. TRNTST is now called; it returns the magnitude of the difference between the two arctangents, DIFFERENCE=.05. This difference is compared to TANDIF, which for this user drawing at rate 14 has a value of .19. The change in direction falls well below this value, so no start of corner is determined. STRAIN returns to 2), increments the current point counter, and continues.

3) This loop continues until point 7 is reached. The x- and y-coordinates of point 7 are -667 and 531, respectively. The arctangent of the segment between points 7 and 9 is .25. At point 8, however, the arctangent has changed to .62. Meanwhile, the rate has changed to 15, so the value of TANDIF is .20. Thus, when TRNTST returns a change of arctangent of .37, something happens.

4) The significant bend in the line indicates that the line is entering a corner. The current point counter is backed up one point, so that it points to the end of the first straight segment. The x- and y-coordinates of this point are stored in THOLD, and a pointer to this data is stored in the second element of CORNER. The current point counter then goes into DATP.

5) A call is made to subroutine LINE, which calculates the slope of the line segment defined by the points indicated by the first two elements in CORNER. This information will be of use later, so the slope is stored in the third element of CORNER.

The maximum rate reached across the segment (15) is stored in a location called RMAX1.

Because of a tendency to make rounded, rather than sharp, corners when sketching, it can not e assumed that a corner occurs at a single point in the original sketch. To cope with this problem, STRAIN searches for the straight line segments on either side fo the corner. Using these segments, then, the algebraic intersection of these lines is calculated, and this intersection is edfinde to be the corner connecting the two segments.

6) This method for calculating corners renders the data between line segments valueless. The collection of points which make up the corner in the raw data are useful only where they help to define where the second segment begins. Just as the corner was defined to begin where the change in arctangent was greater than TANDIF, the corner is defined to end and a new segment to begin where the delta arctangent falls below this limit. Thus, once the start of the corner is found, a new cycle of calling NOEND, TANGNT, and TRNTST is begun. Because the current point counter was backed up one point, the first results of the first cycle are the same as those described in 3) above. Since .37 is greater than TANDIF, the corner is continued. The next cycle, on point 9 results in an arctangent of 1.06. The difference between this value and the arctangent of the previous segment is .44, which is still greater than TANDIF.

7) This cycle is repeated until between points 10 and 11 the difference in arctangents has fallen to .13. This small change in direction indicates that a new segment has started.

8) The current point counter is backed up one point to get it to the first point in the segment (since the difference in arctangents was small, the segment must have started with the previous point). This point is preserved in THOLD and CORNER. CORNER is examined to see if it contains information about two segments, so the corner between the segments can be calculated. In fact, only one segment has been found and the starting point of a second one. Since no calculation can be made until the second segment is found, STRAIN returns to 2) to search for it, saving the data in the appropriate locations in CORNER and THOLD.

TABLE A

DATP	CORNER	THOLD x	THOLD y
1	->	194	540
7	->	-687	531
-	1	-	-
11	->	-743	431
20	->	-727	-751
-	-4668	-	-
23	->	-719	-745

By the time the routine gets back to 8), the current point counter has made its way up to 23, and a second corner has been delimited. DATP, CORNER, and THOLD have the values shown in Table A.

There are now two segments, so their intersection can be calculated. An examination of Table A shows that one would expect the corner to fall between -687 and -743 in the x-direction, and between 531 and 431 in the y-direction--approximately. Once this intersection has been determined, the exact endpoints of the first line segment in the sketch are known, and may be saved. Therefore, let us digress from the original sketch and see how this step is performed.
9) First, the angle between the two segments defined in CORNER is checked to see if it is very small, in subroutine CFSA (Check For Small Angles). For very tight angles, such as occur in overtracing, the precision of the arithmetic permitted by the computer was found to be inadequate. The calculated intersections of lines at small angles were frequently found to be highly inaccurate. As a result of this difficuly, the actual raw data was deemed preferable to calculated data for determining corners at small angles. Calls to EXTRMR from NOEND have previously determined if any extremes exist along the line so far. CFSA first determines the arctangents of the two segments defined in CORNER, then checks the difference between these arctangents to see if the two segments qualify. It then looks to

see if there are any extremes. If so, the point of interest must have an associated point number which falls somewhere between the indices of the midpoints of the two segments in CORNER. The "average" point numbers of the two segments are calculated, therefore, and the list of extremes is searched for one with an index which falls between these values. If one is found, and if the angle between the segments is small enough, then CFSA returns the x- and y-coordinates of these extremes as the location of the corner between the two segments. Parenthetically, if no such extreme is found, but the angle is still small, then the value returned is the second end of the first segment. If the angle is not small, then CFSA just does a little house-cleaning, discarding extremes already passed, and returns.

In the case of the sample sketch, while an extreme was found, the angle between the segments is nearly ninety degrees. This angle is too large to be considered, so CFSA returns no value. 10) The corner must be calculated, a task performed by CFIX. Since two points on each of two line segments in CORNER are known, the formulas for each of the lines (Y=A*X+B) can be calculated. "A" for each line is the slope, calculated by LINE, contained in slot 3 and slot 6 of CORNER for the first and second lines respectively. "B" can be determined by: B=Y-A*X1. This equasion can be calculated by taking either of the known points in CORNER, getting its x- and y-coordinates, and substituting. Once the formulas for the two segments are known, another fact can be applied--at the intersection, X1=X2 and Y1=Y2. Therefore:

A1*X+B1=A2*X+B2

and:

```
                  B2-B1
X(intersection)= -------
                  A1-A2
```

Once X(intersection) is known, it can be substituted into the formulas for either of the lines to determine Y(intersection). In the interest of accuracy, in fact, X(intersection) is substituted into both formulas, and the resulting Y which causes the least change in arctangent from those of the two segments in CORNER (there is bound to be some slight adjustment) is used as Y(intersection).

The above description is true in most cases. However, there is a special case which arises when one of the lines is nearly vertical, as is the case in the second line segment of the sample sketch. When a line becomes vertical, its slope becomes infinite. Dealing with infinite, or large, numbers in a computer becomes difficult, since one begins to encounter round-off and overflow difficulties. There is one saving grace, however. A line is vertical because there is only a small variation in its x-coordinate across its length. In this case, there can be little error in assuming that the x-coordinate of the intersection is the same as the x-coordinate of the point of the vertical line segment nearer the proposed corner (in the case of the sample sketch, the x-coordinate of point 11, x=-743). This value can then be substituted into the formula for the other line in CORNER, to determine the y-coordinate of the intersection. This approach is the one which CFIX takes, returning the values X(intersection)=-743, Y(intersection)=530. If both lines are nearly vertical, then the discovery of an implied corner was a mistake. The two segments are merged into one, and the program returns to look for a second segment.

11) Since both ends of the first segment have been determined, the first segment can be saved by a call to LINER. The data about straight line segments is stored in a variably sized structure; a more complete description of the data structure can be found in Appendix I. Generally, the data which is stored about the endpoints is as follows: the x- and y-coordinates of the two endpoints of the line segment; the index of the position in the raw data where the point was first discovered (the first point in the stroke, or the beginning point of a corner); and a flag indicating whether the point was immediately preceeded or followed by a pen-lift flag. The line is stored as a relation between the two endpoint, holding information about the maximum rate and pressure attained while the line was drawn. Absence of such a relation means that no line was discovered between two points. A point can have as many line relations associated with it as necessary to represent the picture, but in the current

approach, a point can have either one or two lines related to it after the initial pass at finding straight lines. On the segment just discovered, the first point will have a single associated relation, one with the second point. The second point, being a corner, is related to the first point (the same relation, in fact), and eventually to a third point which will define the second corner discovered. Since no latching is done at this pass, there can be no more than two lines associated with a point.

12) Once the segment has been saved, it can be discarded from CORNER, THOLD, and DATP. The beginning point of the second segment is shifted to the first position in CORNER, and the remaining data is shifted down accordingly in the various arrays. Then the pointer in CORNER to the first point in THOLD is changed to point to the second point just saved by LINE. This second point will be used instead of the numbers in THOLD as one end of the next segment defined, the next time LINE is called. The common endpoint will thus be defined.

The state of the program has now returned to where it was after the first corner was discovered. The only difference is in the data in the various arrays (see Table B).

TABLE B

DATP	CORNER	THOLD x	THOLD y
11	->POINT(2)		
20	->	-727	-75[illegible]
-	-4568	-	-
23	->	-719	-745

As it did before, therefore, STRAIN loops back to 2) and continues. The second corner is determined, and because the rate slowed toward the end of the line, the third turn in the line is broken into several corners. STRAIN has now gotten to point 84 looking for a corner to end, so it can go to determine the seventh segment. When it picks up point 84 in a call to NOEND, however, it is discovered that the data element is a pen up flag; the line has ended. Since there are no more corners to be found on this line, the program branches to ENDSEG, which deals with end conditions of lines.

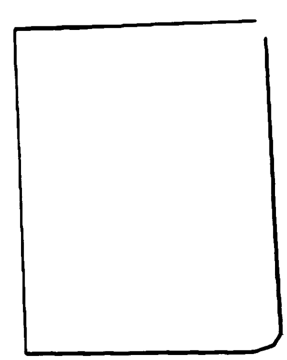
13) ENDSEG basicallly deals with the end of a line the same way the beginning of the line was handled in 1). Since the last point in the line obviously ends a line segment, the current point counter is backed up one before the pen-up flag. A pointer to this point is placed in CORNER, and its index is saved in

DATP, along with the pen lift flag (Note that since this point will be disposed of immediately, there is no need to save its coordinates in THOLD. There is no danger of the data being overlaid by a refill of the buffer). LINE is called to figure the slope. Two segments have been determined thus, so the corner between them can be calculated by a call to CFSA or CFIX. Then the first segment can be saved by LINER.

14) Finally, since the end point of the stroke is known exactly, from the data, no calculation needs to be done to determine the last point of the last segment. It can be saved directily by LINER. Once this operation has been done, all the information which can be determined directly from the stroke has been dealt with. CORNER is cleared, and STRAIN returns to 1) to look for more data.

There are two other possible cases which might have to be dealt with by ENDSEG, however. One is that the beginning of a corner has been found, but the curve of the corner has not terminated at the point where the pen lift flag is encountered, as is the case in the sample sketch. In this instance, there is little choice but to ignore the data occuring after the corner began. There is no way to calculate a position for this final corner, so it is simply dropped. This rarely results in any major distortion of the sketch, but occasionally, an entire final line is dropped if the line is sufficiently curved to fool the program (See the discussion on curves, in Section II). The calculation for this case is essentially the same as in 13). The second case, which occurs more frequently, is that of a single straight line segment. If the pen is lifted before any corner is drawn, ENDSEG has no interim corner to find. In this case (i.e. CORNER only has two or three cells filled in), CFSA and CFIX are not needed, and the two points (first and last on the stroke) can be saved directly by LINER. In either case, all the information which can be found on the stroke is done with and CORNER is cleared.

When STRAIN returns to 1) to pick up another line, it discovers that there is no more data; it is done. The completely STRAINed sketch appears in Figure 16. The data is stored in a structure of points and lines described in Appendix I, and is accessible to other programs for further analysis. The above description covers essentially all the steps required to create this structure, covering all the special cases. The only likely extension is that which will enable the system to recognize and describe curves.



IV. FUTURE

Where Do We Go from Here?

DESCRIPTION OF A SKETCH

Having examined all that has occurred since HUNCH was begun, let us go back a bit to look at the original goals, particularly, the development of a hierarchical description of the sketch. The output of the straightening pass at the data is a two level structure of lines and points. While this structure makes the data much more manageable, it is not much of a step toward a description of the sketch in any normal human sense.

To elucidate what is meant by "a normal human description," let us try to generate one from a particular sketch. Figure 17 is a sketch of a house plan, much simplified. A verbal description which one might expect from a human is as follows:

1. It has 5 rooms
2. Rooms 1 and 6 have access to the outside; room 6 through one door, room 1 through two.
3. All the rooms are rectanglular, having four walls, except rooms 3 and 6 which have six walls each.
4. Room 1 is connected to the outside through (doors in) its left and right walls, and to room 2 through its bottom wall.

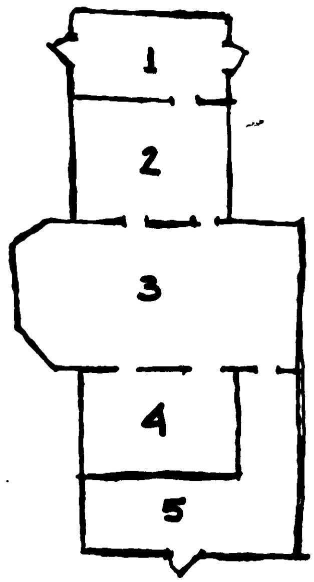


Figure 17a.

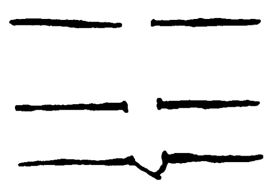


Figure 17b.

5. Room 2 has access to room 1 through its top wall, and to rooms 3 and 4 through its bottom wall.

6. Room 3 is connected to room 2 through its top wall, and to rooms 4 and 5 through two doors and one door, respectively, in its bottom wall.

And so forth.

This verbal description is not complete. One might wish to describe the exact configuration of rooms 3 and 5, to enumerate which walls were on the perimeter of the building and which walls were shared by the various rooms. The verbal description does not even specify a unique house plan. However, it does supply sufficient information such that some specific questions could be asked about the relationships between the rooms ("What rooms would I cross going from room 1 to room 5?"), about the overall accounting for the building ("How many rooms? doors?"), and about specific parts of the sketch ("How big is room 3?"). (Note that while the last question is not specifically answerable from the description, the area which has to be examined to determine the answer is considerably restricted.

In order to generate such a description, a person (or program) needs to know what kinds of elements might be found in a sketch, what kinds of questions are going to be asked about these elements, and how to recognize the various elements represented in the sketch. In the sample sketch, there are basically three elements: walls, doors, and rooms. The kinds of questions one might be asked are about position, relative size, and relationships between elements. If the information is stored in some reasonably structured way, these questions ought to be easy to answer, once the various elements have been found.

The recognition of elements is perhaps the most difficult requirement. In the sample sketch, three different representations were used for doors (Figure 17b). In this simple case, then, what are some of the cues people use to identify the three elements which comprise the sample sketch?

To find the rooms in a plan, one would look for areas enclosed by sets of lines which define walls and which do not enclose other rooms.

Walls are characterized by sets of fairly long colinear, continuous lines which appear at the edges of areas which are rooms. They may have doors in them. They comprise most of the lines in a plan sketch.

Doors may be characterized by the fact that they appear in walls. They may be represented by a break in an otherwise colinear wall or a set of (probably) short lines bracketing a break in the perimeter of a room. These short lines will probably be perpendicular to the lines which make up the wall in which the break occurs. Finally, there may be a line about the same length as the break in the wall which lies at a small angle to the wall in which the break occurs, and which shares a common end point with those points making up one end of the break.

The seeming circularity of some of the definitions (a wall is an edge of a room, and a room is limited by its walls) is an asset of such a description. One can apply one rule tentatively (take a guess at a room, for example), and then use the consequence of this guess to draw other conclusions. Eventually, one will either come to a solution, or because of the circularity of definition, one will arrive at a contradiction. If the description were completely directed and acyclic, one could drift farther and farther from the facts after an erroneous guess without ever noticing that anything was wrong.

In order to have a computer program which can construct a descriptive structure for a particular class of sketches, then, one must be able to specify to the program what features to look for and how the program is to go about recognizing these features. The process of recognizing features seems to require the application of those functions already discredited in earlier discussion: latching, horizontalizing, verticalizing, parallelizing, perpendicularizing, conlinearizing, normalizing, and continuing. While this is true, in this case the functions are applied in some context. Earlier attempts were simply exercises in investigating how the HUNCH approach could be applied to solving these various functions. The result was a program which knew a rule and which applied that rule under all conditions. The effect of this method was that the rule was appllied under conditions where it was possible but not appropriate. In the proposed solution, the program would have some idea about when the rule could reasonably be applied while searching for a specific item.

Using this system, the user would name a set of features which would be searched for in a particular class of sketches. The names of these features will provide the means of describing the sketch, and relationships between the features will provide clues to the hierarchy for the description (a kind of precedence relation). Once the features have been named, the user would describe the attributes of each feature which would be searched for in a given sketch. In general, a feature consists of a set of points, or lines, or perhaps other features, or a combination of these elements. Identifying whether a part of a sketch is a particular feature involves matching elements of the sketch to attributes of the set describing that feature. For example, an attribute of a one element set consisting of a straight line segment is the direction in which the segment lies; another attribute is the length of the segment. The process of telling the program how to recognize a particular class of sketch involves naming a set of features and then describing attributes of the sets which determine a feature. This description will provide a structure against which sets of lines and features will be matched by the program providing the description of the sketch.

EXISTING KNOWN SETS

After a sketch has been processed by STRAIN, the output of the operation can be considered to be two sets: a set of lines and a set of points. These two sets are the primitive sets from which the rest of the description will be derived. Furthermore, the elements of these sets each have their own set of primitive attributes.

The most basic element of a sketch is a point. It has two primitive attributes: position and sequence. The initial value of position is the obvious one--simply, where in the coordinates of the tablet the point lies. Later analysis might require changing this value (a three-dimensional mapping, for example). Sequence can be taken to be the temporal position of the point. In the process of straightening the sketch, the index of a point, in the original steam of data, which is the start of a corner or an end of a stroke is saved and associated with that point in the straightened data structure. These two basic attributes, then, provide a one-to-one mapping from a point number into a three-dimensional space/time volume.

There is another attribute of a point which should be considered; that is, it can define one end of a line segment. In the straightened data structure, the role this attribute can play is fixed, since there are at most two line segments which can have a given point as an endpoint. This attribute was not included in the discussion of primitive attributes, however, because in defining features, one might wish to construct lines not appearing in the original sketch. Thus the manifestation of this attribute might change under varying circumstances. More properly, this attribute of a point will be reserved for the discussion of the relationships between points.

A larger set of attributes is associated with a line segment. As with points, there are two obvious primitive attributes: direction and magnitude. The direction can initially be taken to be the arctangent of the line relative to the positive horizontal direction of the tablet. Its magnitude is its length, using the tablet coordinate system. As with the position of a point, the value of either of these attributes might have to be changed if the line is mapped into three-space. In the process of straightening, the fastest rate and the greatest pressure reached while drawing a particular line are associated in the structure with the line. These attributes suggest others which might be considered at some later date, if the means of input should be modified. One can imagine a line having width, color, texture, even thickness. Finally, as the inverse of the point attribute, two attributes of a line segment are the points which define its ends. Unlike the point example, the two endpoints of a segment are fixed, so these attributes are unchanging.

Given these two sets, some analysis of a sketch is possible, as long as that analysis is related to some absolute scale. One might wish to examine all the lines longer than a certain minimum length, or those lying in a particular direction. The process of looking for horizontal and vertical lines requires just this sort of analysis. Most analysis requires the ability to distinguish relationships between sets of points or lines, however; there is no absolute background against which the measurement takes place. Because of this need, there must be the capability to describe relationships between points and lines which can be assigned as attributes to sets. These primitives are discussed in the next section.

LINE SET ATTRIBUTES

In describing the features of a sketch, one uses words like parallel, perpendicular, angle, corner, near, and so forth. It is proposed in this section to define a set of primitives which can be applied to lines to test them for these descriptors, and to describe how the procedures which establish the existence of these attributes might be implemented. Given these primitives (and some other, more general ones described in a later section), one can describe the attributes of a set of elements which would make up a feature of a sketch.

PARALLELISM: In most sketches, there are preferred directions. In the sketch of the house plan of the average house, the great majority of the lines would fall into two perpendicular directions. In an axonometric sketch, there would be three preferred directions. A histogram of the direction of the lines in a sketch versus either the number of occurrences of a given direction, or the total length of line in a particular direction, or a combination of both, will show peaks at the various preferred directions with a fairly narrow standard deviation (Figure 18). It is a simple matter to divide th sketch into families of lines, using the valleys between the preferred directions as division guide-lines. One could user rate and pressure to influence the decision, as far as allowable deviation is concerned. Some sort of average direction could be used to define the family which was implied, and this identifier for the family could be associated with each line in the straightened data structure. A set of lines could be considered parallel, then, if they all belonged to the same family.

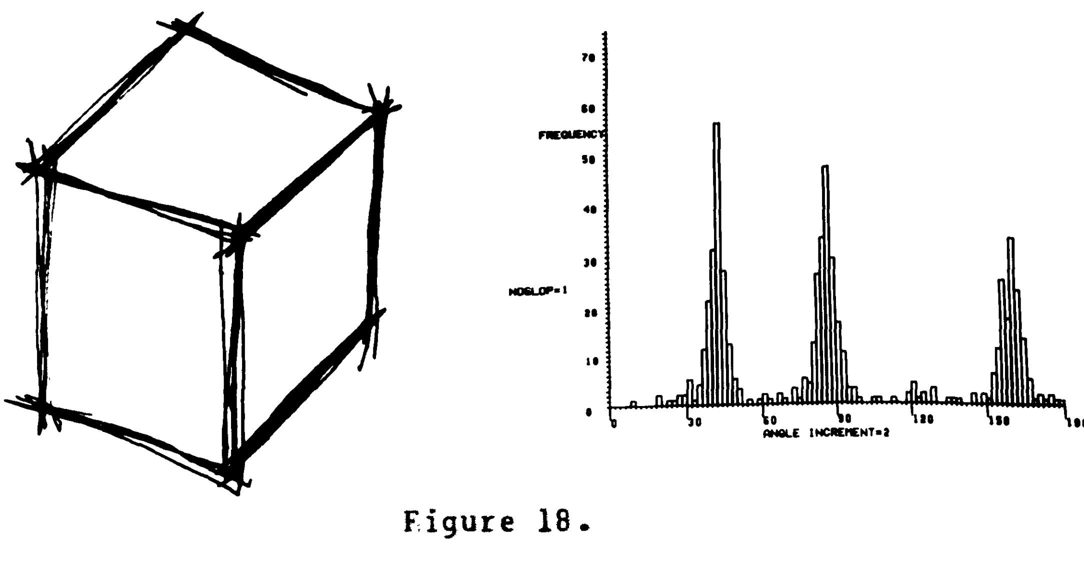


Figure 18.

COLINEARITY: Once the family of a line is determined, the family identifier can be used to calculate the x- or y-intercept of that line. The result of this calculation could also be associated with each line in the structure. It is likely that intercepts would tend to fall in groups as arctangents do. A set of lines could be said to be colinear, then, if the set had the attribute of parallelism, and if each element of the same, or nearly the same, x- or y-intercept. Again, the definition of near could be subject to rate and pressure data influence.

CONTINUITY: In the strictest sense, a set of lines can be defined to be continuous if the set is conlinear, and if there are no "breaks" in the line. More specifically, a line is unbroken if there is never a case where, scanning from left to rght (or from top to bottom), the right-most end of the line segment is encountered before the left-most end of another line segment is found, if there are still line segments to the right. Normally, one would wish to include instances of "near continuity," where the break in the line is small, in this definition of continuity. This modification of the definition is somewhat risky, since it is prone to the same difficulties encountered in earlier latching attempts. A way to get around this objection would be either never to apply the weak continuity rule until other analysis had failed to provide a satisfactory result, or to flag a weakly continuous set, such that later difficulties might be resolved with a minimum of searching for the error. In any case, it should be noted that this form of latching is only applied in a fairly explicit set of circumstances: the distance is small, and the lines to be latched are colinear.

With the above primitives, one could make a generous stab at reducing the complexity of a heavily overtraced sketch. A "Meta-line" could be defined as a feature of the sketch having the attribute that each Meta-line in the sketch would consist of a set of continuous line segments. The endpoints of the Meta-line would be the left- and right-most points which were attributes of the lines making up the set (in some cases, the top- and bottom-most points would be used), and the deviation in the y-intercept of the lines in the set could be used to define a width for the Meta-line. Once this information had been determined, further analysis could proceed exclusively at the Meta-line level. It would not usually be the case, however, that an analysis would proceed in an exclusively bottom-up manner, as described above. The example does show how the attributes of a set might simply be related with fairly powerful results.
SEQUENCE: In the set of points, a point which ends a line segment must be preceeded immediately by the point which began the segment. Similarly, the following sequential point is either the end of a line eminating from the point in question, or it is the beginning of the next line to be started. At any rate, the straightened data structure contains the complete sequence in

which all the lines in the sketch were drawn. Two lines are in sequence, then, if the second point in one line is either the first point in the other one, or it immediately preceeds the first point in the second line--or vice versa. A Dashed-line could be defined as a set of lines which are colinear, non-continuous, and in sequence.

ANGULARITY: The intersection of two lines forms an angle. Angles seem to perform two functions in a sketch: they permit definition of relationships between non-parallel lines ("line A is perpendicular to line B"), and they indicate intended changes of direction (as at corners). An angle provides a relationship between two (sets of) lines, and it consists of two defining elements: a pair of lines or line sets and a magnitude. The position of the angle can be taken to be the point of intersection of the two lines. The magnitude of the angle between line A and line B can be taken to be that solution of the following two equasinons which is non-negative and less than PI:
Magintude=B.direction-A.direction or
Maginiude=PI+B.direction-A.direction
Note that this method of measureing the magnitude makes the value of the result depend on which line is mentioned first;
Angle.Magnitude(lineA,lineB) = PI - Angle.Magnitude(lineB,lineA).
Since an angle has two sides, this distinction is important. To compare the magnitudes of two angles, he must first be certain that he is measuring the angles from the same side.

Where the corner between two lines exists, this definition of an angle is fairly simple to handle. In those cases where two lines do not physically intersect, however, the problem becomes more complex. One would like to create a point for the intersection, and then construct lines from it to the ends of the two lines whose angle is to be measured ("Construct point P, such that line(P,B) is colinear with line(A,B) and line(P,D) is colinear with line(C,D). . ."). This desire leads to the need for the ability to describe a "working point" and a "working line." Two functions are needed to modify the point-line structure: the first, P=Setpoint(X,Y), adds a point to the structure at location (X,Y) on the tablet (or perhaps some modification of the above to allow for three-dimensional positioning). The arguments of the function would serve to establish the position attribute of the element. Since the point did not appear in the original data, it has no sequence attribute. A pointer to this new point would be returned in P. The second function is L=Line(A,B); it constructs a line between points A and B and assigns L a pointer to it. The direction and length attributes can be calculated, while other attributes (rate, pressure, and so forth) are undefined. Once a point or a line has been created, it can be taken as an element in any set defined by the attributes described above. Thus, one might examine a sequence of points to see if they were colinear by constructing lines between them and then examining the lines. Similarly, the distance between two parallel lines segments could be found by constructing a line perpendicular to the lines from one of the endpoints of the lines. By adding to the structure the intersection point of this line with the other of the parallel lines, the length of the constructed segment is determined. The value of this length is the distance between the two lines.

OTHER KNOWN SETS

While experimenting with primitives to describe features, one keeps arriving at a need to define a set with an attribute of area. For example, in the house plan, a room is an area enclosed by walls. Similarly, in an axonometric sketch, a surface of a solid can be described as an area enclosed by edges. It seems necessary, then, to define an extension to the current structure for a set of areas.

The attributes of an area are similar to those of a line. Corresponding to the line's attribute of length is the area's attribute of magnitude--the amount of area encompassed. This attribute can be defined by the number of tablet coordinate squares enclosed by the area. Corresponding to the endpoints associated with a line is the perimeter of the area. Unlike the endpoint attribute, which has a fixed number of elements, the perimeter of an area consists of an indefinite number of elements; it is a variable length list of pointers to features in the sketch which defines the set of elements containing the area.

Note that the set of elements defining the perimeter might change as the analysis of the sketch proceeds. The perimeter of an area might initially consist of a set of line segments. As these segments are absorbed into the description of features of the sketch, these features would be substituted for the lines. Thus, when the lines defining the room in a house plan are included in the description of the walls in the plan, the walls become the defining elements of the room. With the perimeter attribute of an area, however, it seems reasonable to extend the attributes of a line to include the attribute that a line is an element of the perimeter of an area, just as a point was described as one end of a line segment.

Other attributes which might be associated with an area are reflected in those of a line. An area could have an attribute of orientation, which would be defined as the direction perpendicular to the plane in which the area lies. Initially, the orientation of all areas would be the same--perpendicular to the plane of the tablet. In the case of a sketch of a three-dimensional object, however, this orientation might change (as might the magnitude attribute). While an area does not have either the attributes of rate or pressure, it could have color, texture, or thickness.

Having gone this far, it seems reasonable to propose that a further extension to the structure be added to permit the definition of volumes. Just as the description of features in two dimensions led to the necessity of describing areas, it is inevitable that the need for descriptions of volumes will arise. Like areas, a volume would have the attributes of magnitude and perimeter, although the perimeter would consist of a set of areas. Orientation does not seem to be relevant in the description of a volume, but color and texture seem possible, along with density, center of mass, opacity, and just about anything else.

FEATURES AND SET ATTRIBUTES

Features may be defined by enumerating the attributes which must hold for elements of the set comprising the feature. Some of these features may be defined in terms of those attributes already described, as the Meta-line was defined. There are other attributes which will prove useful, however, which operate on sets in general, rather than on the specialized set described above.

BOOLEAN OPERATORS: The three operators AND, OR, and NOT specifically, may be used either as modifiers to attributes or as operators on sets. As an attribute modifier, the operators can specify that a particular condition may NOT occur, that either of two conditions may hold, or that a pair of attributes must hold ("colinear & ¬continuous V ¬colinear. . ."). As a set operator, the booleans would act as the Union, Intersection, and Set-Subtraction operators, permitting the concatenation of sets and the subsetting of sets (Wall::=Wall & Door V Wall & Wall. . .). The effect of such an operation on the description structure would be the addition of an element with links down to those elements being concatenated (or in the case of a subtraction, the creation of two elements linked to the original set from below).

NUMBER: A set may have to have a particular number of elements (or features). There must be a means of specifying that number, then, and of comparing a number of elements against that number. A rectangle, for example, implies an area with four edges in its perimeter set. Once an area has been isolated, the number of its edges must be compared to the number of edges specified for the set, to see if it is less than, equal to or greater than the required number.

Similarly, since some attributes return values other than boolean values, the relative magnitude of these values should be comparable, addable, subtractable, and so forth. This requirement implies that either numbers of elements or value of attributes must be countable and able to be operated on by the normal arithmetic functions.

SIMILARITY/EQUALITY: Two sets are equal if all the attributes of both sets and of all the elements of each set are equal. Two sets are similar if the values of the specified attributes are the same. In the absence of an attribute, a particular feature is similar to a feature name if it is in that feature class. Thus:

rect1==rect2 if everything is the same.
rect1<=>rect2 if rect1.width=rect2.width &
rect1.length=rect2.length
rect1<=>Rectangle if rect1 is in the class of features called Rectangle.

These working definitions permit the comparison of sets by permitting the user to define what he means by two sets being similar. In a case where it is desirable to define features which are similar but which may have minor variations, this ability can greatly simplify the definition process.

MEMBERSHIP: A particular element has the property that it either does or does not belong to a particular set. In the hierarchical description, if an element belongs to a set, there will be a vertical path from that element linking it to the set name (Wall ∈ Area.Perimeter).

RECURSE

In order to demonstrate how the functions defined above might operate, the features mentioned in describing the sketch at the beginning of this section will be defined in terms of these functions. The sketch had basically three features: Rooms, Walls, and Doors. The third paragraph on page 72 gives a verbal description of what a person might look for in recognizing these features. Table C gives a translation of this description into the set of attributes defined in this section. In order to complete this definition, three auxiliary features were defined: Breaks, Clusters, and Metalines. The description of a door mentioned that it was indicated by a break in a wall. This description implies that what is meant by a break is known, so it has to be defined as a feature as well. The other two features are defined merely to help simplify the descriptions. A meta line is defined formally in the same way it was described earlier in the text. A cluster is simply a collection of points no farther distant from one another than some distance, whose magnitude is defined by the rates of the lines which the points define.

The notation used to define the features is a sort of bastardized set notation. A glossary of the notation is given in Table D. While the circularity of the definitions for Door indicates that more work is desirable to make this method of describing features more humane, it does show that such a method is a viable approach to the problem. This statement is reenforced by the fact that I had no idea about how the formal definition was going to be implemented until after I had defined all the sets described in this section. Since I was able to do the formal definition using only those sets, it can be argued that they are at least sufficient to accomplish the job at hand.

TABLE C

```
Room::=R | R<=>Area & ( ^R1 | R1<=>Room & (R &^ R1)^== R)

        *A room is an area which contains no other rooms

Room.Perimeter<=>R.Perimeter


Wall::=W | W<=>Metaline

    V Door

    V W1 & W2 | W1<=>Wall & W2<=>Wall & W1^==W2
          & L1 e W1 & L2 e W2 & {L1,L2}.Continuous

        *A wall is the concatenation of two continuous walls

    V W | R<=>Room & W e Room.Perimeter


Metaline::=S | S=={L | L<=>Line} & S.Continuous

Metaline.Direction<=>L.Direction

Metaline.Endpoint=={P1,P2} | L1 e S & L2 e S
        & P1 e L1.Endpoint & P2 e L2.Endpoint
        & (^L3 | L3 e S & P1 e L3.Endpoint
             & P1.X < P3.X & P2.X > P3.X)

        *The endpoints of a Metaline are those with the Maximum
             and Minimum X-coordinates

Metaline.Length<=>line(P1,P2).length


Cluster::=C | C=={P | P<=>Point} & P1 e C & P2 e C
    & L1 | P1 e L1.Endpoint & L2 | P2 e L2.Endpoint
    & L=Line(P1,P2) & L.Magnitude < F(L1.Rate,L2.Rate)

        *A cluster is a set of points such that the length of a line
             between any two points in the set is less than some
             function of the rates of the lines of which those two
             points are endpoints
```

(Table C, continued)

```
Break::=B | B=={C1,C2 | C1<=>Cluster & C2<=>Cluster & C1^==C2

    & (¬L | L<=>Line & L.Endpoint e C1 & L.Endpoint e C2)

    & (¬C3 | C3<=>Cluster & P1 e C1 & P2 e C2 & P3 e C3
         & L1=Line(P1,P2) & L2=Line(P1,P3) & L3=Line(P2,P3)
         & {L1,L2,L3}.Colinear
         & L1.Magnitude > L2.Magnitude
         & L1.Magnitude > L3.Magnitude)
```

*A break is a set of two clusters with no line having one endpoint in each cluster, and with no cluster lying between the two clusters

```
Break.Direction<=>L1.Direction
```

```
Door::=D | D=={C1,C2 |
     (C1<=>Cluster & (P | P e C1 & P e L1.Endpoint
               | L1 e W & W<=>Wall)
         & C2<=>Cluster & (P | P e C2 & P e L2.Endpoint | L2 e W & W<=>W

         & {C1.C2}<=>Break

         & {L1,L2}.Colinear)
```

*A door is a pair of clusters which have as elements the endpoints of a pair of colinear walls surrounding a break

```
     V ((S1 | S1<=>Metline) & (S2 | S2<=>Metaline)
              & {S1,S2}.Parallel
         & C1<=>Cluster
         & C2<=>Cluster
         & {C1,C2}<=>Break
         & P1 | P1 e S1.Endpoint & P1 e C1
         & P2 | P2 e S2.Endpoint & P2 e C2
         & Line(P1,P2) e R.Perimeter | R<=>Room
         & D.Direction-S1.Direction= +-Pi/2  }
```

*or a pair of clusters forming a break which are endpoints of a pair of parallel metalines such that a line connecting the endpoints is on the perimeter of a room and perpendicular to the direction of the metalines

(Table C, continued)

```
V Dl | Dl=={D,L | D<=>Door & L<=>Metaline
    & Cl e D & C2 e D
    & P | P e L.Endpoint & (P e Cl V P e C2)
    & L.Direction-Door.Direction < Pi/4}

    *for a door with a line projecting from one of its clusters
         at an angle less than 45 degrees

Door.Direction<=>Break.Direction
```

TABLE D

Symbol	Meaning
::=	
::=	is defined to be
{. . .}	is the set
|	such that
V	or
&	and
¬	not
e	is an element of the set
xxx.yyy	the attribute yyy of set xxx is true
==	the set is equal to
<=>	the set is similar to
(. . .)	group delimiters (to aid in reading this stuff)

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Appendix I

EXISTING DATA STRUCTURE

Appendix I is reprinted from MACHINE RECOGNITION AND INFERENCE MAKING IN COMPUTER AIDS TO ARCHITECTURE

EXISTING DATA STRUCTURE

In any complex system, it usually becomes true sooner or later that there is a demand for a data structure with a varying number of elements of varying size. The data structures available from Fortran are inadequate. Consequently, the General Purpose Structure was developed for users of the operating system. The structure is created and modified by a set of function calls which can be made from Fortran to the system. These permit creation and deletion of structures, and they permit the addition, subtraction, modification and accessing of data elements in the structure. The structure is created in free storage made available by supervisor calls to the operating system, and, therefore, is limited in size only by the physical size of the memory of the machine in which it resides.

The structure has three constituent elements: a Structure Pointer Block, a set of points, and a set of links. They are related in a somewhat hierarchial fashion. Since there may be more than one structure in the system being accessed at a given time, they are separately identified by a Structure Pointer Block. Each Block consists of six data elements containing information about the particular structure: a pointer to the first point of the structure; a count of the number of points in the initial point block of the structure; a flag indicating if any points have been dropped; the size of a link, or zero, if link size is not fixed; the virtual point number of the last point created; and a pointer to the next Structure Pointer Block available in the system, if there is one.

Points are currently allocated in blocks of seven at a time, in order to increase the ease with which they are manipulated. Each point consists of four data items, two of which may be accessed by the user as general purpose arguments. (Typically, they are used as the x- and y-coordinates of a point in a display of some sort. Extending the number of arguments from two to some higher number is a simple extension being contemplated.) The other two arguments are a pointer to the first link associated with the point, and the point's number. As points are created, they are assigned a point number, sequentially from one for the first point created. In order to avoid confusion as more points are added and deleted, this number is fixed. Thus, even though a slot in a point allocation block may be reused, the numbers of the points on either side of it do not change, and the numbers of new points as they are created are monotonically increasing. The virtual point number of any newly created point wil be one more than the number of the last point created as indicated by the Structure Pointer Block, and the Block will be modified accordingly.

A link is a means of establishing a relation between two points. A request to add a link between two points appends a copy of the link requested to the link chain pointed to by the third data field in a point. A link consists of at least two fields: a pointer to the point being linked to, and a pointer to the next link on the chain. The size of the links in a structure may be constant or varying. If at creation time, the structure is declared to have uniform links, the size of a link is stored in the Structure Block Pointer, and that size is used throughout. Otherwise, the size of a link is declared at the time the link is created and stored in a field of the link itself. Links may have between four and sixty addressable fields. A field is four bits wide (and thus may contain a number beetween 0 and 15), and fields may be addressed singly or in groups of up to four (generating a sixteen bit wide field). The first four fields in a link are used for the pointer to the point linked to. The next four are for the next link pointer, but they are not addressable. The next field contains the link size if it is non-uniform. The remaining fields are free to be used for storage of any information about the relationship between the two points desired.

In order to create a structure, the

user makes a function call of the form: PTR=CONSTR(size) where size is the size of the links in the structure if uniform, or zero if varying. CONSTR sets up a Structure Pointer Block, allocates space for the first seven points, and returns to PTR the address of the Structure Pointer Block created. All further calls referencing this structure take this pointer as their first argument. Since any call with an improper Structure Pointer Block specified can only lead to disaster, the other calls check to see whether the address handed in future argument list points to a valid Block (hence the pointer as the last element in a Block). An invalid block causes the system to type out an error message and halt. This is the only fatal error. Other errors, if they occur, are returned as results from the function, and a message is printed on an output device available to the user consisting of a two letter code. The first letter specifies in which function the error occurred, and the second letter specifies what the error was. Most errors are caused by faulty argument passing, either by requesting an impossible change or asking for information from non-existant links. In the case where a change is requested, if an error is detected, the change does not occur. In some instances the returned error code can be useful in programming. For instance, since links can be referred to by sequential number, in order to access every link associated with a given point, a counter specifying the number of the link to be accessed could be increased by one until an error returns saying there is no such link. Then the program knows it has finished. Similarly, to establish if a link between two points exists, any reference to that link specified by those two points will return an error code if no such link exists.

Other function calls are as follows:

Function Calls

To add a point to the structure
PN=PADD(PTR,VALUE,VALUE1)
returns the virtual point number of the point added or -1 if there was an error. Since each point can have two arguments associated with it directly, they are set by VALUE & VALUE1. The error code is Pn.

To add a link to the structure
x=LADD(PTR,PN,PN1,SIZE)
PN & PN1 specify the points between which the link is to be added. SIZE specifies the number of fields in the link (required whether or not the SIZE is uniform). The error code is Ln.

To access or modify an argument in a point
x=GPOINT(PTR,PN,ARGN,VALUE)
sets VALUE equal to the contents of ARGN of point PN. The error code is An.

To access or modify a set of fields in a link
x=GPFLDR(PTR,PN,LN,NO,WIDTH,VALUE)
x=PPFLDR(PTR,PN,PN1,NO,WIDTH,VALUE)
returns in VALUE the contents of the specified field(s) in the link specified by PN,LN or the link between points PN,PN1. Note that the difference between the two calls is simply that GPFLDR specifies a link by link number while PPFLDR specifies a link by passing the two points the link connects. The error code is Rn.

x=GPFLDF(PTR,PN,LN,NO,WIDTH,VALUE)
x=PPFLDF(PTR,PN,PN1,NO,WIDTH,VALUE)
puts VALUE truncated to the size specified by WIDTH into the specified field. The difference between the two calls is the same as above. The error code is Fn.

To delete a link from the structure
x=LDROP(PTR,PN,LN)
x=LLDROP(PTR,PN,PN1)
removes the specified link. The error code is En.

To delete a point from the structure
x=PDROP(PTR,PN,[COLLECT])
drops the specified point from the structure ONLY if the point has no remaining links. If COLLECT is requested, points are garbage collected after every 8 drops. The error code is Dn.

Appendix II

THE GRID FACILITIES

Appendix II is reprinted from MACHINE RECOGNITION AND INFERENCE MAKING IN COMPUTER AIDS TO ARCHITECTURE

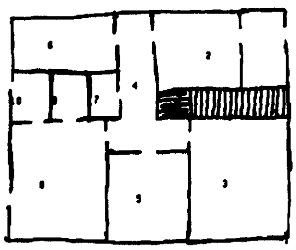
DISK GRID PACKAGE

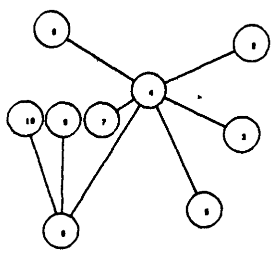
The grid package provides the FORTRAN user with a set of x-y addressable grids (up to 1024 by 1024 bits) which are used to store sketches and more generally, data from a number of graphics input terminals including the Sylvania Data Tablet for drawings made by hand and a television camera for input of predrawn sketches. This type of storage medium allows a sketch to become completely independent of time and provides a computer scratch pad for analysis of complex configurations.

Each grid is stored as a bit map on a fixed head disk storage device, with each 1024 point line represented by a 128 byte record. A grid can consist of between 1 and 1024 such lines, and any number of separate grids may be used, limited only by the capacity of the disk. When a 1024 by 1024 grid is used to represent a sketch drawn with the Sylvania Tablet, which addresses 4096 by 4096 points, a bit is set on the grid if a line drawn on the tablet passed through a square 4 by 4 tablet coordinates in size. When used with the television camera, each line of video data is stored one after another until the entire sketch or drawing is scanned.

The data on the grid is accessed by means of an assembly language program which transfers a "window" of arbitrary width and height from the grid to a FORTRAN user's array in core. Likewise, data may be transfered from a FORTRAN array to the grid. In addition, a scale may be specified so that one element of the array can represent anything from one bit in the grid to the entire grid, with the value returned equal to the number of bits set within that portion of the specified window. At the largest scale, with the array containing the entire grid, most details are too small to affect the mapping into the array, leaving only the outlines of the major forms, as when the human eye views a scene from a distance. Since an image of the original sketch is now in core, the entire sketch can be examined very easily, in much less time than it would take to scan a magnetic tape containing the original positions. Based upon the shapes, voids, bodies, etc. found by scanning the array, a program can select areas of the sketch to be examined in greater detail. As the scale, hence the size of the window, is decreased, more and more details appear. Usually there is some scale, about 3 or 4, at which most of the important features are present but at which noise from minor movements of the pen is absent. Features of the sketch found at smaller scales are usually of no significance as far as position-dependent interpretations are concerned, since they are usually the kind of noise ignored by a human examining a drawing.

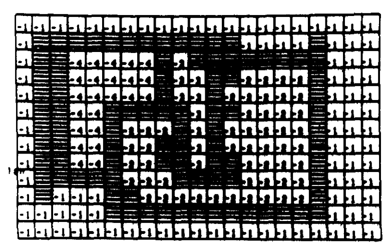
Data can be entered into a grid from a variety of sources, including magnetic tape, a vidicon camera, and directly from a FORTRAN program. The most common method takes its input from a magnetic tape or disk file produced by the DRAW program in HUNCH, consisting of a list of pen coordinates measured at constant intervals. These coordinates are converted to grid coordinates and the appropriate bits set on the disk. If two successive points are more than one grid unit apart, as often happens with lines drawn at high velocity, the intervening points are interpolated, so that the bit image on the disk approximates the appearance of the completed sketch. Thus the programmer need not burden himself with the problem of connecting points, which would be very difficult in the time-independent context of the grid. Since most drawings are smaller than the maximum size of the grid, the conversion program automatically reduces the size of the grid to the size of the sketch, saving both disk space and access time. Another input source is a television camera which enables the grid to replicate a completed paper sketch. Data conversion in this case is very simple, as the vidicon scans line by line, just as the grid is organized on the disk. It is also possible to set bits in the grid directly from a FORTRAN program, by means of an assembly language routine which maps a FORTRAN array onto the disk, in a manner analogous to the

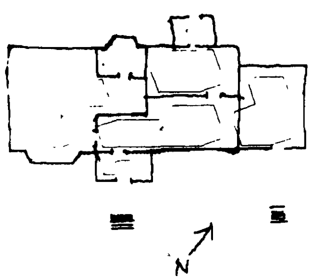


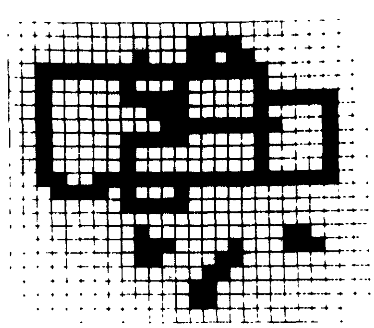


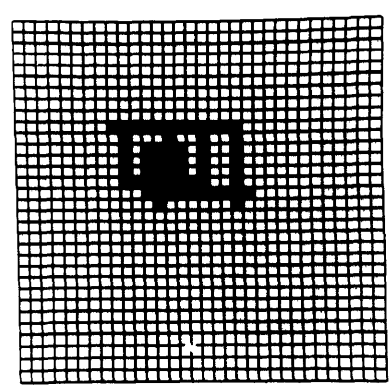
window program described above. Finally, there is a complete set of entry points which enable the assembly language programmer to set and retrieve single bits and to access individual lines in the grid.

Following are examples of 5 of the more important of the 15 FORTRAN callable entry points in the grid package.









Subroutine DISPLW

Purpose

The purpose of the subroutine is to display the contents of an array on the ARDS.

Usage

```
INTEGER*2 ARRAY(XDIM,YDIM), DENSTY, XDIM, YDIM, GRIDF, DISPF

CALL DISPLW(ARRAY, DENSTY, XDIM, YDIM, GRIDF, DISPF)
```

The subroutine draws a grid XDIM by YDIM and fills in those squares whose corresponding array elements are not equal to zero.

ARRAY	is the array.
DENSTY	is the number of fill-in lines to be drawn per square. Optional default is 4.
XDIM YDIM	describe the array. Both are optional. XDIM defaults to 32. YDIM defaults to XDIM.
GRIDF	specifies if the grid is to be drawn. = 0 no grid = 1 grid (the default)
DISPF	allows the grid to be drawn without filling in the squares. = 0 no fill in display = 1 fill in (the default) - 1 fill in with the number of hits

Subroutine GRDSK

Purpose

The purpose of the subroutine GRDSK is to convert a drawing from time-dependent magnetic tape to position-dependent disk.

Usage

```
CALL GRDSK(IDISPL,ICNVRT,IERASE,GCB)
```

All arguments are optional, if omitted, the default is assumed.

If IDISPL = 0 drawing will not be displayed (default).
= 1 drawing will be displayed as it is converted.

If ICNVRT = 0 no conversion will take place.
= 1 conversion will take place (default).

The ICNVRT option allows the displaying to original drawing from tape.

If IERASE = 0 the drawing will be placed on the grid along with any previous drawing.
= 1 any previous drawing will be erased (default is to the value of ICNVRT)

GCB is the Grid Control Block (see INIGRD)

DIMENSION ARRAY (XDIM, YDIM)

CALL WWWDOW(ARRAY, SCALE, XBIAS, YBIAS, IERR, DRAW, XDIM, YDIM, GCB)

All arguments have the same meaning as in subroutine WINDOW.

For any element of ARRAY equal to zero, no action is taken.

For any non-zero elements the corresponding bit in the grid is turned on.

Note

Since no action is taken for ARRAY entries of zero, the original bit value is retained for that entry in the grid.

Subroutine INIGRD

Purpose

The purpose of the subroutine INIGRD is to initialize the disk constants table and to define one or more grids.

Usage

```
INTEGER*2 TAPE(66), GCB1(271), SIZE1, GCB2(79), SIZE2
SIZE1=4
SIZE2=1
CALL INIGRD (TAPE,GCB1,SIZE1,GCB2,SIZE2,...GCB4,SIZE4)
```

Only the first three arguments are required, allowing the definition of one to four grids.

TAPE is an array 132 bytes, long used for magnetic tape.
GCB1 is an array (128*SIZE1) + 30 bytes long.
SIZE1 specifies the length of the buffer in lines.

Note

This program must be called before any other grid system subroutines.

The first 6 elements of a grid control block (GCB) specify information about the corresponding grid. If the user calls INIGRD, these values are filled in automatically, and the first GCB specified is established as the default for other fortran-callable subroutines. Alternatively, the user may fill in these values himself as follows:

```
BIAS      DC x'2000'      Disk address of start of grid
BADTRK    DC x'FFFF'      Can be used to specify bad track
                          on disk
NLIB      DC 4            Number of lines in buffer (SIZE)
BOTLIN    DC 0            Number of first line in grid
TOPLIN    DC 1023         Number of top line in grid
LEFT      DC 0
RIGHT     DC 1023
BFST      DC A(BUFFER)    Address of buffer
          DS 14           Used by the system
BUFFER    DS SIZE*128
```

Subroutine WINDOW

Purpose

The purpose of the subroutine WINDOW is to transfer a portion of the grid to a FORTRAN array.

Usage

INTERGER*2 ARRAY (XDIM,YDIM), SCALE, XBIAS, YBIAS, IERR, DRAW, XDIM, YDIM

CALL WINDOW(ARRAY, SCALE, XBIAS, YBIAS, IERR, DRAW, XDIM, YDIM)

The grid consists of 1024 by 1024 squares numbered as shown:

Thus one square of the grid corresponds to four units on the Sylvania tablet.

SCALE specifies how many grid squares correspond to one element of the array. The value of each element of the array is the number of grid squares "turned on" within the corresponding spot on the grid.

XBIAS
YBIAS specify the location of the lower left hand corner of the window.

IERR
= 0 if all is well
= 1 if the specified parameters would force the window off the tablet. The values of XBIAS and YBIAS will be modified in the FORTRAN program to make the window fall within the range of the tablet.
= 2 if the SCALE*LARGEST_DIMENSION 1024 (the size of the tablet). The valve will be adjusted.

DRAW is an optional variable.
1 = A square will be drawn on the ARDS corresponding to the portion of the original drawing included in the window.
0 = No square will be drawn (the default).

XDIM is an optional variable which specifies the dimension in the X direction. Default is 32.

YDIM is an optional variable which specifies the dimension in the X direction. Default is to the value of XDIM.

GCB is an optional variable which specifies the grid to be used (see INIGRD).

Subroutine WWWDOW

Purpose

The purpose of subroutine WWWDOW is to write out an array on the grid.

Usage

INTEGER*2(ARRAY, SCALE, XBIAS, YBIAS, IERR, DRAW, XDIM, YDIM)

Appendix III

COMPUTER LISTINGS FOR STRAIN

```
0000R                    EXTRN DSKTAP,SKIP,BSTORE
0000R                    EXTRN DISKST,INITAF
0000R                    EXTRN PTMAX,JNAME
0000R                    EXTRN ENDN,GETLAT
0000R                    EXTRN MARK,IODEV
0000R                    EXTRN OFFSET,TANIRV,CONSTR,PTMAX
0000R                    ENTRY PTCALC,PERROR,PRLOOP

0000            STORE    EQU   0
0002            STORE2   EQU   2

0006            INCREM   EQU   6

                * CALL PTCALC(STATUS,SCRATCH.ARR,SC.LENGTH,[N
                *                STATUS=>0 O-CK
                *                      =>-1 STORAGE NOT ALLOCA
                *                      => 1 RAN OUT OF SPACE
                *                SCRATCH.ARR=>33*6 BYTE ARRAY
                *                SC.LENGTH=>SIZE OF ARRAY IN H


                *
                *           IF NO NUMBER, INITIALIZE & STRAIT
                *           IF NUMBER NEGATIVE, CONTINUE
                *           IF NUMBER NON-NEGATIVE,STRAIGHTEN
                *                (0=1)


0000R 4300               B     PTCALC
      0024R
0004R           SAVER    DS    32
0022R           SAV15    EQU   *-2
0024R D000      PTCALC   STM   0,SAVER
      0004R
0028R 48AF               LH    10,0(15)
      0000
002CR C5A0               CLHI  10,4
      0004
0030R 4280               BL    DONE
      0130R
0034R C5A0               CLHI  10,8
      0008
0038R 4380               BNL   OK
      0044R
003CR C8A0               LHI   10,-1
      FFFF
0040R 4300               B     PERROR
      0124R
0044R E110      OK       SVC   1,REW
      0160R
0048R 48AF               LH    10,4(15)
```

```
      0004
004CR 26A6          AIS   10,INCREM
004ER 40A0          STH   DC,OFFSET
      000OF
0052R 48D0          LH    13,DSKTAB
      0000F
0056R 4330          BZ    NOEN
      006ER
005AR 48DF          LH    13,6(15)
      0006
005ER 4AAD          AH    DC,0(13)
      0000
0062R 4AAD          AH    D0,0(13)
      0000
0066R CBA0          SHI   D0,INCREM+INCREM
      000C
006AR 40A0          STH   10,ENDN
      0000F
006ER 41F0    NOEN  BAL   15,CCNSTR
      0000F
0072R 0004          DC    4
0074R 015ER         DC    SIZE
0076R 40E0          STH   14,PTMAX
      0000F
007AR 48AC          LH    DC,MARK          ********MARKED
      0000F
007ER 40A0          STH   D0,DISKST
      0000F
            *READ IN THE FIRST BLOCK OF DATA
0082R 4850          LH    5,DSKTAP
      0054R
0086R 4210          BM    TAPEI
      0092R
008AR 4220          BP    PASS
      00DCR
008ER 4300          B     NODAT
      00EER
0092R C8A0    TAPEI LHI   10,-1
      FFFF
0096R 40A0          STH   10,DISKST
      0080R
009AR 48F0          LH    15,SAVER+30
      0022R
009ER 48AF          LH    10,0(15)
      0000
00A2R C5A0          CLHI  10,10
      000A
00A6R 4380          BNL   COUNT
      00B0R
00AAR 07AA          XHR   10,10
00ACR 4300          B     INIT
      00C4R
```

```
00B0R 48DF      COUNT   LH    13,8(15)
      0008
00B4R 48AD              LH    10,0(13)
      0000
00B8R 4210              BM    PASS
      00DCR
00BCR C8BA              LHI   11,1(10)
      0001
00C0R 40BD              STH   11,0(13)
      0000
00C4R 41F0      INIT    BAL   15,INITAP
      0000F
00C8R C5A0      CHECK   CLHI  10,2
      0002
00CCR 4280              BL    PASS
      00DCR
00D0R 41F0              BAL   15,SKIP
      0000F
00D4R CBA0              SHI   10,1
      0001
00D8R 4300              B     CHECK
      00C8R
00DCR 48D0      PASS    LH    13,OFFSET
      0050R
00E0R 48E0              LH    14,ENDW
      006CR
00E4R 26E5              AIS   14,INCREM-1
00E6R 41F0              BAL   15,GETDAT
      0000F
00EAR 4200              NOP   DONE
      0130R
                *SET R9 FOR FIRST LINE END
00EER 4890      NODAT   LH    9,OFFSET
      00DER
00F2R C8A0              LHI   10,X'F000'
      F000
00F6R 45A9              CLH   10,STORE(9)
      0000
00FAR 4330              BE    GO
      0106R
00FER 48A0              LH    10,DSKTAP
      0084R
0102R 4210              BM    PASS
      00DCR
0106R 2796      GO      SIS   9,INCREM
0108R 40A9              STH   10,STORE(9)
      0000
010CR C8E0              LHI   14,GOTIT
      0114R
0110R E180              SVC   8,UNAME
      0000F
0114R 07AA      GOTIT   XHR   10,10
```

```
  0116R 40A9               STH    10,STORE2(9)
        0002
  011AR 40A0               STH    10,ESTORE
        000F
                *GO STRAIGHTEN
  011ER 4100               BAL    1,TANDRV
        000F
  0122R 07AA               XHR    10,10
  0124R 48B0    PERROR     LH     15,SAV15
        0022R
  0128R 48BF               LH     11,2(15)
        0002
  012CR 40AB               STH    10,0(11)
        0000
  0130R 48B0    DONE       LH     15,DSKTAP
        0100R
  0134R 4310               BNM    EXIT
        013CR
  0138R 41B0               BAL    15,SKIP
        00D2R
  013CR C8B0    EXIT       LHI    15,X'0D'
        000D
  0140R 48D0               LH     14,IODEV
        000F
  0144R 9DED               SSR    14,13
  0146R 4290               BTC    9,*-2
        0144R
  014AR 9AEF               WDR    14,15
  014CR D100               LM     0,SAVER
        0004R
  0150R 4AFF               AH     15,0(15)
        0000
  0154R 030F               BR     15

  0156R C8A0    PRLOOP     LHI    10,1
        0001
  015AR 4300               B      PERROR
        0124R
  015ER 000C    SIZE       DC     12
  0160R C002    REW        DC     X'C002',0
        0000
  0164R                    END
NO ERRORS

* BSTORE   011CR
  CHECK    00C8R
* CONSTR   0070R
  COUNT    00B0R
* DISKST   0098R
  DONE     0130R
* DSKTAP   0132R
* ENDN     00E2R
  EXIT     013CR
```

```
* GETDAT  00E8R
  GO      0106R
  GOTIT   0114R
  INCREM  0006
  INIT    00C4R
* INITAP  00C6R
* IODEV   0142R
* MARK    007CR
  NODAT   00EER
  NOEN    006ER
* OFFSET  00F0R
  OK      0044R
  PASS    00DCR
* PERROR  0124R
* PRLOOP  0156R
* PTCALC  0024R
* PTMAX   0078R
  REW     0160R
  SAV15   0022R
  SAVER   0004R
  SIZE    015ER
* SKIP    013AR
  STORE   0000
  STORE2  0002
* TANDRV  0120R
  TAPEI   0092R
* UNAME   0112R
```

****

****

```
                  *TANDRV,CSTART,ENDSEG,CFIX,AND INTERS USE 'CO
                  *  TO STORE POINTERS TO THE BEGINNING AND END
                  *  SEGMENTS.  WHEN FILLED, THE ARRAY 'CORNER'
                  *      CORNER(0) POINTER TO 1ST POINT ON 1ST L
                  *      CORNER(2) PTR TO LAST PT ON SEGMENT BEF
                  *      CORNER(4) SLOPE OF THE 1ST SEGMENT( DY/
                  *           (WHICH MOVES DECIMAL PLACE 6 BITS
                  *      CORNER(6) POINTER TO 1ST POINT AFTER TH
                  *           1ST POINT OF 2ND SEGMENT
                  *      CORNER(8) POINTER TO LAST POINT ON 2ND
                  *      CORNER(A) SLOPE OF 2ND SEGMENT
                  *      CORNER(C) POINTER TO START OF 3RD SEGME
                  * THIS SERIES CAN EITHER BE CUT OFF AT CORNER
                  * IF THE PEN IS LIFTED

0000R                      EXTRN  SAVEC,EOB,PUSHER,GETSQ
0000R                      EXTRN  CSTART,ENDSEG
0000R                      EXTRN  RATER,EXTRMR,SEX,SEY
0000R                      EXTRN  DISKST,GETDAT
0000R                      EXTRN  INTERV,RTESTC,RMAX2,PMAX2
0000R                      EXTRN  TANGNT,TRNTST,TANDIF
0000R                      ENTRY  TANDRV,RETER ,CNEXT,NOEND
0000R                      ENTRY  TANDRI
0000R                      EXTRN  DATP,CORNCT,EIN
0000R                      EXTRN  OFFSET,DSKTAP

0000               STORE   EQU    0
0002               STORE2  EQU    2

0008               PTSIZE  EQU    8
0006               INCREM  EQU    6

0000R 4000         TANDRV  STH    0,RETERN
      0130R
0004R 0B55                 SHR    5,5                 SET UP POINTER
0006R 4050                 STH    5,CORNCT            FOR 'CORNER' LI
      0000F
000AR 4050                 STH    5,DATP
      0000F
000ER 4D00                 BAL    0,GETSQ
      0000F
0012R 0B77         TANDRI  SHR    7,7                 ENTRY FOR BEGIN
0014R 4070                 STH    7,RMAX2             INIT FASTEST DW
      0000F
0018R 4070                 STH    7,PMAX2             INIT HARDEST PR
```

```
       0000F
001CR  4820             LH    2,CORNCT        GET 'CORNER' PO
       000BR
0020R  4819    CNEXT    LH    1,STORE(9)      AM I AT AN ENDP
       0000
0024R  C910             CHI   1,X'8000'
       F000
0028R  4220             BP    FLAGED
       0030R
002CR  0777             XHR   7,7
002ER  4070             STH   7,SQFLAG
       0088R
0032R  0889             LHR   8,9
0034R  4B80             SH    8,OFFSET
       0000F
0038R  48D0             LH    13,DISKST
       0000F
003CR  CDD0             SLHL  13,7
       0007
0040R  0A8D             AHR   8,13            SET UP BACK POI
0042R  C410             NHI   1,X'C000'       TO BLOCK ON DIS
       0000
0046R  0618             OHR   1,8             INDICATE ENDPOI
0048R  4012             STH   1,DATP(2)       AND SAVE
       000CR
004CR  2696    PBUMP    AIS   9,INCREM
004ER  4590             CLH   9,ENDN
       0000F
0052R  4280             BL    LOW
       007AR
0056R  4330             BE    LOW
       007AR
005AR  48D0             LH    13,DSKTAP
       0000F
005ER  4330             BZ    ENDFL
       015ER
0062R  48D0             LH    13,OFFSET
       0036R
0066R  48E0             LH    14,ENDN
       0050R
006AR  CAE0             AHI   14,INCREM-1
       0005
006ER  41F0             BAL   15,GETDAT
       0000F
0072R  4200             NOP   ENDFL
       015ER
0076R  4890             LH    9,OFFSET
       0064R
007AR  2671    LOW      AIS   7,1             INDICATE A STAR
007CR  4300             B     CNEXT           LOOP AGAIN
       0020R
0080R  0877    FLAGED   LHR   7,7             WHEN NOT AT END
```

```
00082R 4330          BZ     NEND            LOOK FOR START
       00D8R
0086R  C870          LHI    7,0
       0000
0088R        SQFLAG  EQU    *-2
008AR  4220          BP     PBUMP
       004CR
008ER  C870          LHI    7,X'8000'
       8000
0092R  4570          CLH    7,SEX
       0000F
0096R  4330          BE     NOSQ
       00C0R
009AR  4879          LH     7,STORE(9)
       0000
009ER  4570          CLH    7,SEX
       0094R
00A2R  4230          BNE    NOSQ
       00C0R
00A6R  4879          LH     7,STORE2(9)
       0002
00AAR  4570          CLH    7,SEY
       0000F
00AER  4230          BNE    NOSQ
       00C0R
00B2R  4100          BAL    15,GETSQ
       0010R
00B6R  2471          LIS    7,1
00B8R  4070          STH    7,SQFLAG
       0088R
00BCR  4300          B      PBUMP
       004CR
00C0R  4D00   NOSQ   BAL    10,SAVEC
       0000F
00C4R  C8A0   STEND  LHI    10,X'800'
       0800
00C8R  40A0          STH    10,RTESTC       FORCE IMMEDIATE
       0000F
00CCR  0B55          SHR    5,5
00CER  4100          BAL    15,NOEND        GET 1ST PT, CHE
       00F0R
00D2R  4100          BAL    15,TANGNT       GET ARCTAN FOR
       0000F
00D6R  2652          AIS    5,2
00D8R  4D00   NEND   BAL    10,NOEND        GET NEXT PT, CH
       00F0R
00DCR  4D00          BAL    10,TANGNT       GET NEXT ARCTAN
       00D4R
00E0R  4D00          BAL    10,TRATST       CHECK FOR CHANG
       0000F
00E4R  4510          CLH    1,TANDIF        IS IT GREATER T
       0000F
```

```
00E8R 4220              BP     CSTART           YES: CORNER HAS
      0000F
00ECR 4300              B      NEND             ELSE RETURN FOR
      00D8R
                  *

                  *THIS ROUTINE CHECKS FOR END OF SEGMENT FLAG
                  *  DATA WITHIN AN INTERVAL OF CURRENT POINTER
                  * IF IT FINDS ONE, EXIT IS TO ENDSEG

00F0R 4000        NOEND STH    0,EXIT
      015CR
00F4R 41F0              BAL    15,PUSHER        RETURNS WITH PR
      0000F
00F8R 41F0              BAL    15,RATER
      0000F
00FCR 0889              LHR    8,9
00FER 08A9              LHR    10,9
0100R 4AA0              AH     10,INTERV        GET POINTER TO
      0000F
0104R 4818        LOOP  LH     1,STORE(8)       LOOK TO SEE IF
      0000
0108R C910              CHI    1,X'F000'
      F000
010CR 4320              BNP    ENDSEG
      0000F
0110R 4980              CH     8,ENDN           AM I OUT OF DAT
      0068R
0114R 4320              BNP    ENUF             NO , GO ON
      013CR
0118R 08B9              LHR    11,9             YES,
011AR 41D0              BAL    15,ECB           SAVE OLD POINT
      0000F
011ER 48D0              LH     13,OFFSET
      0078R
0122R 48E0              LH     14,ENDN
      0112R
0126R CAE0              AHI    14,INCREM-1
      0005
012AR 41B0              BAL    15,GETDAT
      0070R
012ER 4200              NOP    0
      0000
0130R             RETERN EQU   *-2
0132R C889              LHI    8,-INCREM(9)
      FFFA
0136R 0898              LHR    9,8              RESET REGISTERS
0138R C8A8              LHI    10,INTERV(8)
      0102R
013CR 0598        ENUF  CLHR   9,8
```

```
013ER 4330          BE     NEXT1
      0148R
0142R 0818          LHR    13,8
0144R 41F0          BAL    15,EXTRMR          LOOK FOR SMALL
      0000F
0148R CA80   NEXT1  AHI    8,INCREM           GO FOR NEW POIN
      0006
014CR 05A8          CLHR   10,8               IF PAST END
014ER 4380          BNL    LOOP               OF NEXT INTERVA
      0104R
0152R 4819          LH     1,STORE(9)         YOU'RE OK
      0000
0156R 4839          LH     3,STORE2(9)
      0002
015AR 4300          B      *
      015AR
015CR        EXIT   EQU    *-2


015ER 4800   ENDFL  LH     0,RETERN
      0130R
0162R 0300          BR     0
0164R               END

NO ERRORS

* CNEXT   0020R
* CORNCT  001ER
* CSTART  00EAR
* DATP    004AR
* DISKST  003AR
* DSKTAP  005CR
  ENDFL   015ER
* ENDN    0124R
* ENDSEG  010ER
  ENUF    013CR
* EOB     011CR
  EXIT    015CR
* EXTRMR  0146R
  FLAGED  0080R
* GETDAT  012CR
* GETSQ   00B4R
  INCREM  0006
* INTERV  013AR
  LOOP    0104R
  LOW     007AR
  NEND    00D8R
  NEXT1   0148R
* NOEND   00F0R
  NOSQ    00C0R
* OFFSET  0120R
  PBUMP   004CR
```

```
* PMAX2   001AR
  PTSIZE  0008
* PUSHER  00F6R
* RATER   00FAR
* RETERN  0130R
* RMAX2   0016R
* RTESTC  00CAR
* SAVEC   00C2R
* SEX     00A0R
* SEY     00ACR
  SQFLAG  0088R
  STEND   00C4R
  STORE   0000
  STORE2  0002
* TANDIF  00E6R
* TANDRI  0012R
* TANDRV  0000R
* TANGNT  00DER
* TRNTST  00E2R

**************************************************************
```

```
0000R                    ENTRY GETSQ,SEX,SEY

0007           WRK2      EQU   7

0000R 0777     GETSQ     XHR   WRK2,WRK2
0002R 4070               STH   WRK2,DATA
      0068R
0006R E110               SVC   1,RDSQ
      0060R
000AR 4870               LH    WRK2,STAT
      0062R
000ER 4310               BNM   NOEND
      001ER
0012R C870     NODATA    LHI   WRK2,X'8000'
      8000
0016R 4070               STH   WRK2,SEX
      006AR
001AR 4300               B     EXIT
      005ER
001ER 4870     NOEND     LH    WRK2,DATA
      0068R
0022R 4330               BZ    NODATA
      0012R
0026R 2772               SIS   WRK2,2
0028R 4330               BZ    SQF
      0042R
002CR E110               SVC   1,RDSQ
      0060R
0030R 4870               LH    WRK2,DATA
      0068R
0034R 2771     RDLOOP    SIS   WRK2,1
0036R 4210               BM    GETSQ
      0000R
003AR E110               SVC   1,RDSQ
      0060R
003ER 4300               B     RDLOOP
      0034R
0042R E110     SQF       SVC   1,RDSQ
      0060R
0046R E110               SVC   1,RDSQ
      0060R
004AR 4870               LH    WRK2,DATA
      0068R
004ER 4070               STH   WRK2,SEX
      006AR
0052R E110               SVC   1,RDSQ
      0060R
0056R 4870               LH    WRK2,DATA
      0068R
005AR 4070               STH   WRK2,SEY
      006CR
005ER 0300     EXIT      BR    0
```

```
 0060R 4002     RDSQ     DC     X'4002'
 0062R 0000     STAT     DC     0
 0064R 0068R             DC     DATA
 0066R 0069R             DC     DATA+1
 0068R 0000     DATA     DC     0
 006AR 0000     SEX      DC     0
 006CR 0000     SEY      DC     0
 006ER                   END

NO ERRORS

  DATA     0068R
  EXIT     005ER
* GETSQ    0000R
  NODATA   0012R
  NOEND    001ER
  RDLOOP   0034R
  RDSQ     0060R
* SEX      006AR
* SEY      006CR
  SQF      0042R
  STAT     0062R
  WRK2     0007
```

****

```
00000R                         ENTRY PUSHER,PMAX1,PMAX2,RPFIG
 0000R                         EXTRN INTERV

 0004            STORE4   EQU   4
 0006            INCREM   EQU   6

 0000R D0D0      PUSHER   STM   14,SAV2
       002ER
 0004R 08E9               LHR   14,9
 0006R 08F9               LHR   15,9
 0008R 4AB0               AH    15,INTERV
       0000F
 000CR 48 E      LOOP     LH    0,STORE4(14)
       0004
 0010R C0 0               SRHL  0,2
       0002
 0014R 45 0               CLH   0,PMAX2
       004CR
 0018R 4280               BL    HOP1
       0020R
 001CR 4000               STH   0,PMAX2
       004CR
 0020R 26E6      HOP1     AIS   14,INCREM
 0022R 05FE               CLHR  15,14
 0024R 4380               BNL   LOOP
       000CR
 0028R D1B0               LM    14,SAV2
       002ER
 002CR 030F               BR    15

 002ER           SAV2     DS    4

 0032R D0B0      RPFIG    STM   14,SAV2
       002ER
 0036R C8B0               LHI   15,16
       0010
 0038R           SIXTEN   EQU   *-2
 003AR 0BF0               SHR   15,0
 003CR 0CEB               MHR   14,11
 003ER 4DE0               DH    14,SIXTEN
       0038R
 0042R 08BF               LHR   11,15
 0044R D1E0               LM    14,SAV2
       002ER
 0048R 030F               BR    15

 004AR 0000      PMAX1    DC    0
 004CR 000       PMAX2    DC    0
 004ER                    END

NO ERRORS

 HOP1    0020R
```

```
  INCREM   0006
* INTERV   000AR
  LOOP     000CR
* PMAX1    004AR
* PMAX2    004CR
* PUSHER  0000R
* RPFIG    0032R
  SAV2     002ER
  SIXTEN   0038R
  STORE4  0004
```

****

```
0000R                        ENTRY CSTART,LINE,TANFAC,SLOPER,SLOPE
0000R                        ENTRY SAVEC,THOLD
0000R                        EXTRN DATP
0000R                        EXTRN NOENI,TRNTST,TANDIF,TANGNT
0000R                        EXTRN TANDRI,TAN,FCORN
0000R                        EXTRN CORNCT,CORNER,INTERV
0000R                        EXTRN DISKST,RTESTC
0000R                        EXTRN INTERH,RMAX1,RMAX2
0000R                        EXTRN OFFSET

0000             STORE       EQU   0
0002             STORE2      EQU   2

                 *REGISTERS:       0--BAL
                 *                 1--WORKING
                 *                 2--CORNCT
                 *                 3--
                 *                 4--
                 *                 9--STORE POINTER
                 *                 11-

0006             INCREM      EQU   6

0000R 2796       CSTART      SIS   9,INCREM
0002R 2752                   SIS   5,2
0004R 4820                   LH    2,CORNCT
      0000F
0008R 2622                   AIS   2,2
000AR 4100                   BAL   0,SAVEC
      007ER
000ER 4810                   LH    1,DISKST
      0000F
0012R CD10                   SLHL  1,7
      0007
0016R 0809                   LHR   0,9
0018R 4B00                   SH    0,OFFSET
      0000F
001CR 0A10                   AHR   1,0
001ER 4012                   STH   1,DATP(2)
      0000F
0022R 4020                   STH    ,CORNCT
      0006R
0026R 4100                   BAL   0,LINE
      00ACR
002AR 4100       NOEND1      BAL   0,NOEND
      0000F
002ER 4100                   BAL   0,TANGNT
      0000F
0032R 4100                   BAL   0,TRNTST
      0000F
0036R 0811                   LHR   1,1
0038R 4330                   BZ    NOEND1
```

```
      002AR
003CR 4510              CLH   1,TANDIF
      0000F
0040R 4380              BNL   NCEND1
      002AR
0044R 2796              SIS   9,INCREM
0046R 4820              LH    2,CORNCT
      0024R
004AR 2622              AIS   2,2
004CR 4100              BAL   0,SAVEC
      007ER
0050R 4800              LH    0,DISKST
      0010R
0054R CD00              SLHL  0,7
      0007
0058R 0BB9              LHR   11,9
005AR 4BB0              SH    11,OFFSET
      001AR
005ER 0A0B              AHR   0,11
0060R 4002              STH   0,DATP(2)
      0020R
0064R 4020              STH   ,CORNCT
      0048R
0068R 2622              AIS   2,2
006AR C520              CLHI  2,8
      0008
006CR           VIII    EQU   *-2
006ER 4230              BNE   FCORN
      0000F
0072R 48B0              LH    11,RMAX2
      0000F
0076R 40B0              STH   11,RMAX1
      0000F
007AR 4300              B     TANDRI
      0000F
                **
                *

007ER 4010      SAVEC   STH   1,SAV1
      00A4R
0082R 40A0              STH   10,SAVA
      00A8R
0086R C8A0              LHI   10,THOLI
      013CR
008AR 0AA2              AHR   10,2
008CR 0AA2              AHR   10,2
008ER 4819              LH    1,STORE(9)
      0000
0092R 401A              STH   1,STORE(10)
      0000
0096R 4819              LH    1,STORE2(9)
      0002
```

```
009AR 401A            STH    1,STORE2(10)
      0002
009ER 40A2            STH    10,CORNER(2)
      000F
00A2R C810            LHI    1,0
      0000
00A4R          SAV1   EQU    *-2
00A6R C8A0            LHI    10,0
      0000
00A8R          SAVA   EQU    *-2
00AAR 030F            BR     15
               *
00ACR          LINE   EQU    *
00ACR CB50     OUT    SHI    5,2
      0002
00B0R 4815            LH     1,TAN(5)
      000F
00B4R 0855            LHR    5,5
00B6R 4320            BNP    OKT
      00C2R
00BAR C510            CLHI   1,X'64AE'
      64AE
00BCR          TWOPI  EQU    *-2
00BER 4330            BE     OUT
      00ACR
00C2R 4010     OKT    STH    1,TAN
      00B2R
00C6R 4820            LH     2,CORNCT
      0066R
00CAR 41F0            BAL    15,SLOPER
      00D6R
00CER 4020            STH    2,CORNCT
      00C8R
00D2R 2452            LIS    5,2
00D4R 030F            BR     15
               *
               *
00D6R 40F0     SLOPER STH    15,H15
      00F4R
00DAR 4812            LH     1,CORNER(2)
      00A0R
00DER 4831            LH     3,STORE(1)
      0000
00E2R 4851            LH     5,STORE2(1)
      0002
00E6R 2722            SIS    2,2
00E8R 41F0            BAL    15,SLOPE1
      00F6R
00ECR 2624            AIS    2,4
00EER 4052            STH    5,CORNER(2)
      00DCR
00F2R 4300            B      *
```

```
        00F2R
00F4R               H15      EQU    *-2
                    *


                    *
00F6R 4812          SLOPE1   LH     1,CORNER(2)
      00F0R
00FAR 4B51                   SH     5,STORE2(1)
      0002
00FER 4B31                   SH     3,STORE(1)
      0000
0102R 4230                   BNZ    FINITE
      010CR
0106R 2431                   LIS    3,1
0108R 4C40                   MH     4,VIII
      006CR
010CR 4C40          FINITE   MH     4,TANFAC
      013AR
0110R 0874          LOOP1    LHR    7,4
0112R 0885                   LHR    8,5
0114R 0D43                   DHR    4,3
0116R 0585                   CLHR   8,5
0118R 4230                   BNE    OK
      0138R
011CR 0574                   CLHR   7,4
011ER 4230                   BNE    OK
      0138R
0122R 0844                   LHR    4,4
0124R 4330                   BZ     OK
      0138R
0128R 4210                   BM     MINUS
      0134R
012CR C850                   LHI    5,X'7FFF'
      7FFF
0130R 4300                   B      OK
      0138R
0134R C850          MINUS    LHI    5,X'8000'
      8000
0138R 030F          OK       BR     15
                    *
013AR 0040          TANFAC   DC     X'40'
013CR               THOLD    DS     32
015CR                        END

NO ERRORS

* CORNCT  000D0R
* CORNER  00F8R
* CSTART  0000R
* DATP    0062R
* DISKST  0052R
* FCORN   0070R
```

```
   FINITE  010CR
   H15     00F4R
   INCREM  0006
**INTERH   0000
**INTERV   0000
*  LINE    00ACR
   LOOP1   0110R
   MINUS   0134R
   NCEND1  002AR
*  NOEND   002CR
*  OFFSET  005CR
   OK      0138R
   OKT     00C2R
   OUT     00ACR
*  RMAX1   0078R
*  RMAX2   0074R
**RTESTC   0000
   SAV1    00A4R
   SAVA    00A8R
*  SAVEC   007ER
*  SLOPE1  00F6R
*  SLOPER  00D6R
   STORE   0000
   STORE2  0002
*  TAN     00C4R
*  TANDIF  003ER
*  TANDRI  007CR
*  TANFAC  013AR
*  TANGNT  0030R
*  THOLD   013CR
*  TRNTST  0034R
   TWOPI   00BCR
   VIII    006CR
```

****

```
0000R                  EXTRN STABS,ATANUR
0000R                  ENTRY TAN,DIST,INTERH
0000R                  ENTRY TANGNT,TRNTST,INTERV,TANDIF

0006          INCREM   EQU   6

0000          STORE    EQU   0
0002          STORE2   EQU   2

              *
              *
              * TANGNT:  READS POINTS FROM STORE, FINDS DEL
              *        SEGMENTS, FINDS ARCTANGNT OF ANGLE
              *        AND STORES IT IN A LIST OF ARCTANGENTS
              *       R1 HAS STORE(9)
              *       R3 HAS STORE2(9)
              *       R9 HAS INDEX FROM POINTS
              *       R5 HAS TAN INDEX
              *       R4 WORKING
              *       R15 BAL ATANUR,STABS
              *       R0 RETURN ADDRESS
              *
              *
0000R 4A90    TANGNT   AH    9,INTERV
      0106R
0004R 4B39             SH    3,STORE2(9)      DELTA Y
      0002
0008R 4B19             SH    1,STORE(9)       DELTA X
      0000
000CR 4230             BNZ   FINITE
      0028R
0010R 2411             LIS   1,1
0012R 0833             LHR   3,3
0014R 4230             BNZ   ENLARG
      0024R
0018R C810    NIL      LHI   1,X'64AE'
      64AE
001AR         TWOPI    EQU   *-2
001CR 4015             STH   1,TAN(5)
      00C2R
0020R 4300             B     ENIT
      0054R
0024R CF30    ENLARG   SLHA  3,4
      0004
0028R 41F0    FINITE   BAL   15,DIST
      00A8R
002CR 4010             STH   1,DELTAX
      010AR
0030R 4030             STH   3,DELTAY
      010CR
0034R 41F0             BAL   15,ATANUR
      0000F
```

```
0038R 010CR            DC     A(DELTAY)
003AR 010AR            DC     A(DELTAX)
003CR 010ER            DC     A(ANGLE)
003ER 4810             LH     1,ANGLE
      010ER
0042R 4830             LH     3,ANGLE+2
      0110R
0046R CF10             SLHA   1,12
      000C
004AR CE30             SRHA   3,3
      0003
004ER 0A13             AHR    1,3
0050R 4015             STH    1,TAN(5)
      00C2R
0054R C450     ENDT    NHI    5,X'3F'
      003F
0058R 4015             STH    1,TAN(5)
      00C2R
005CR 4B90             SH     9,INTERV
      0D06R
0060R 2696             AIS    9,INCREM
0062R 0300             BR     0
               *TRNTST:  LOOKS AT A LIST OF ARCTANGENTS TO S
               *          A TURN OCCURS SOMEWHERE WITHIN THEM
               *
               *
               *USES REGS 0(RETURN),1,2,5(WHICH HAS VALUE OF
               *                   TAN CHECKED),15(BAL)
               *
0064R 0845     TRNTST  LHR    4,5
0066R 4815             LH     1,TAN(5)
      00C2R
006AR 4910             CH     1,TWOPI
      001AR
006ER 4380             BNL    ZERO
      00A2R
0072R 2742     PILOOP  SIS    4,2
0074R 4210             BM     ZERO
      00A2R
0078R 4814             LH     1,TAN(4)
      00C2R
007CR 4510             CLH    1,TWOPI
      001AR
0080R 4330             BE     PILOOP
      0072R
0084R 4B15             SH     1,TAN(5)
      00C2R
0088R 41F0             BAL    15,STABS
      000F
008CR 0821             LHR    2,1
008ER 4B10             SH     1,TWOPI
      001AR
```

```
0092R 41F0              BAL     15,STABS
      008AR
0096R 0521              CLHR    2,1
0098R 4380              BNL     END
      009ER
009CR 0812              LHR     1,2
009ER 2652      END     AIS     5,2
00A0R 0300              BR      0


00A2R 0B11      ZERO    SHR     1,1
00A4R 4300              B       END
      009ER
                *



                *
00A8R 0873      DIST    LHR     7,3
00AAR 08D1              LHR     13,1
00ACR 0CCD              MHR     12,13
00AER 0C67              MHR     6,7
00B0R 0AD7              AHR     13,7
00B2R 0EC6              ACHR    12,6
00B4R 08CC              LHR     12,12
00B6R 023F              BNZR    15
00B8R C5D0      DISTFL  CLHI    13,X'10'
      0010
00BCR 4280              BL      NIL
      0018R
00C0R 030F              BR      15
                *
                *
00C2R           TAN     DS      66
0104R           TANDIF  DS      2
0106R           INTERV  DS      2
0108R           INTERH  DS      2
010AR           DELTAX  DS      2
010CR           DELTAY  DS      2
010ER           ANGLE   DS      2
0110R           ANGLE2  DS      2
0112R                   END

NO ERRORS

  ANGLE     010ER
  ANGLE2    0110R
* ATANUR    0036R
  DELTAX    010AR
  DELTAY    010CR
* DIST      00A8R
  DISTFL    00B8R
  END       009ER
```

```
  ENDT     0054R
  ENLARG   0024R
  FINITE   0028R
  INCREM   0006
* INTERH   0108R
* INTERV   0106R
  NIL      0018R
  PILOOP   0072R
* STABS    0094R
  STORE    0000
  STORE2   0002
* TAN      00C2R
* TANDIF   0104R
* TANGNT   0000R
* TRNTST   0064R
  TWOPI    001AR
  ZERO     00A2R
```

****

```
                 *RATER READJUSTS RATES EVERY 12 POINTS
                 *THIS VERSION USES A GENERAL FUNCTION
                 *  INTERH = INTERV = INTERVAL BETWEEN SLOPE C
                 *  DELTH1 = DELT11 = DX FOR END TO END MATCH
                 *  DELTH2 = DELT22 = DY FOR END TO END MATCH
                 *  DELTH3 = DELTA3 = Y DIF IN CHEKR (CFIX)
                 *  DELTH4 = DELTA4 = DX FOR INTERSECTIONS
                 *  DELTH5 = DELTA5 = DY FOR INTERSECTIONS
                 *  TANDIH = TANDIF = ANGLE CHANGE PERMISSIBLE
                 *
                 *
                 *  DELTA1-3:  1/32 IN. TO 3/8 IN.
                 *               12 COUNTS + 8(RATE)
                 *  DELTA4-5:  1/16 IN. TO 3/8+ IN.
                 *               23 COUNTS + 8(RATE)
                 *  INTERV = 4 * (18 - R)/2 (SKIP H TO 8 POINT
                 *  TANDIF = PI/90 + (PI/9 ) * R) (4 TO 34 DEGR
                 *
                 *

0005             INCREM  EQU   5

0000R                    EXTRN INTERV,REFIG
0000R                    EXTRN INTERH,TANDIF
0000R                    ENTRY TANDIH,RATER,RMAX1,RMAX2,RTESTC
0000R                    ENTRY T1,EIGHTH
0000R                    EXTRN FUNCT,OFFSET

0000             STORE   EQU   0
0002             STORE2  EQU   2

0000R 48D0       RATER   LH    D0,RTESTC          HAV ENOUGH POIN
      010AR
0004R 4AD0               AH    D0,INTERV          ELAPSED SINCE I
      0000F
0008R 40D0               STH   D0,RTESTC          REFIGURED THE P
      010AR
000CR 45D0               CLH   D0,RTEST           IF NO
      010CR
0010R 028F               BLR   15                 RETURN
0012R 4000               STH   0,ST0              ELSE SET UP FOR
      00BER
0016R 4090               STH   9,ST9
      00C2R
001AR 40F0               STH   15,ST15
      00C6R
001ER C8A9               LHI   10,-INCREM-INCREM(9)
      FFF4
0022R 0766               XHR   6,6
0024R 4060               STH   6,LENGTH
      0110R
0028R C800               LHI   12,X'8000'
```

```
       F000
002CR  2796    LOWER   SIS    9,INCREM       LOOK AHEAD
002ER  4590            CLH    9,OFFSET
       0000F
0032R  4280            BL     UP1
       0046R
0036R  49C9            CH     12,STORE(9)
       0000
003AR  4310            BNM    UP1
       0046R
003ER  05A9            CLHR   10,9
0040R  4280            BL     LOWER
       002CR
0044R  2102            BTFS   0,2
0046R  2696    UP1     AIS    9,INCREM
0048R  48B9    LOOP1   LH     11,STORE(9)    OTHERWISE
       0000
004CR  48D9            LH     13,STORE2(9)   STEP THRU GETLE
       0002
0050R  2696            AIS    9,INCREM       TO COME UP
0052R  41F0            BAL    15,GETL        WITH RATE
       00C8R
0056R  C560            CLHI   6,4
       0004
005AR  4280            BL     LOOP1
       0048R
005ER  48D0    NOW     LH     13,LENGTH
       0110R
0062R  C8B0            LHI    11,16
       0010
0066R  0CCB            MHR    12,11
0068R  4DC0            DH     12,EIGHTH
       00E8R
006CR  0ACC            AHR    12,12
006ER  450C            CLH    12,EIGHTH
       00E8R
0072R  2382            BFFS   8,2
0074R  26D1            AIS    13,1
0076R  08DD            LHR    13,13
0078R  2232            BFBS   3,2
007AR  0CA6            MHR    10,6
007CR  0DAD            DHR    10,13
007ER  086B            LHR    6,11
0080R  C8B0    LONG    LHI    11,16
       0010
0084R  C560            CLHI   6,16
       0010
0088R  4320            BNP    RATEUP
       0090R
008CR  C860            LHI    6,16
       0010
0090R  0BB6    RATEUP  SHR    11,6           R11 HAS RATE
```

```
0092R 41F0         BAL    15,RPFIG
      0000F
0096R 45B0         CLH    11,RMAX2
      0114R
009AR 4280         BL     PARAMS
      00A2R
009ER 40B0         STH    11,RMAX2
      0114R
00A2R 4100  PARAMS BAL    0,T1
      00F4R
00A6R 40D0         STH    13,TANDIH
      00D0ER
00AAR C8D0  SAV12  LHI    13,INCREM+INCREM
      000C
00AER 40D0         STH    13,INTERV
      0006R
00B2R 40D0         STH    13,INTERH
      0000F
00B6R 0B99         SHR    9,9
00B8R 4090         STH    9,RTESTC
      010AR
00BCR C800         LHI    0,0
      0000
00BER       STC    EQU    *-2
00C0R C890         LHI    9,0
      0000
00C2R       ST9    EQU    *-2
00C4R 4300         B      *
      00C4R
00C6R       ST15   EQU    *-2


00C8R 2661  GETL   AIS    6,1
00CAR 48A9         LH     10,STORE(9)
      0000
00CER C9A0         CHI    10,X'B000'
      F000
00D2R 4320         BNP    NOW
      005ER
00D6R 0BBA         SHR    11,10
00D8R 4BD9         SH     13,STORE2(9)
      0002
00DCR 0CAB         MHR    10,11
00DER 0CCD         MHR    12,13
00E0R 0ABD         AHR    11,13
00E2R 4AB0         AH     11,LENGTH
      0110R
00E6R C5B0         CLHI   11,X'1300'      (X'45' COUNTS)*
      1300
00E8R       EIGHTH EQU    *-2
```

```
00EAR 4380           BNL    LONG
      0080R
00EER 40B0           STH    11,LENGTH
      0110R
00F2R 03CF           BR     15

00F4R 41F0    T1     BAL    15,FUNCT
      0000F
00F8R 0000    AT1    DC     0
00FAR 0064           DC     100
00FCR 0000    BT1    DC     0
00FER 0064           DC     100
0100R 0300    CT1    DC     768
0102R 0064           DC     100
0104R 028A    DT1    DC     650
0106R 0000F          DC     A(TANDIF)
0108R 0300           BR     0



010AR         RTESTC DS     2
010CR 0030    RTEST  DC     48
010ER         TANDIH DS     2
0110R         LENGTH DS     2
0112R         RMAX1  DS     2
0114R         RMAX2  DS     2
0116R                END

NO ERRORS

  AT1     00F8R
  BT1     00FCR
  CT1     0100R
  DT1     0104R
* EIGHTH  00E8R
* FUNCT   00F6R
  GETL    00C8R
  INCREM  0006
* INTERH  00B4R
* INTERV  00B0R
  LENGTH  0110R
  LONG    0080R
  LOOP1   0048R
  LOWER   002CR
  NOW     005ER
* OFFSET  0030R
  PARAMS  00A2R
* RATER   0000R
  RATEUP  0090R
```

```
* RMAX1    0112R
* RMAX2    0114R
* RPFIG    0094R
  RTEST    010CR
* RTESTC   010AR
  SAV12    00AAR
  ST0      00BER
  ST15     00C6R
  ST9      00C2R
  STORE    0000
  STORE2   0002
* T1       00F4R
* TANDIF   0106R
* TANDIH   010ER
  UP1      0046R
```

****

```
 0000R                   ENTRY FUNCT
                 *FUNCTION---R11 = RATE
                 *    F(RATE)=AA'(RATE)**3+B '(RATE)**2+CC'(RAT
                 *    WHERE A', B', & C' HAVE NEGATIVE EXPONENT
 0000R 08DB      FUNCT   LHR    13,11
 0002R 0CCB              MHR    12,11
 0004R 0CCB              MHR    12,11
 0006R 4CCF              MH     12,0(15)
       0000
 000AR 4DCF              DH     12,2(15)
       0002
 000ER 08AD              LHR    10,13
 0010R 08DB              LHR    13,11
 0012R 0CCB              MHR    12,11
 0014R 4CCF              MH     12,4(15)
       0004
 0018R 4DCF              DH     12,6(15)
       0006
 001CR 0AAD              AHR    10,13
 001ER 08DB              LHR    13,11
 0020R 4CCF              MH     12,8(15)
       0008
 0024R 4DCF              DH     12,10(15)
       000A
 0028R 4ADF              AH     13,12(15)
       000C
 002CR 0ADA              AHR    13,10
 002ER 48CF              LH     12,14(15)
       000E
 0032R 40DC              STH    13,0(12)
       0000
 0036R 430F              B      16(15)
       0010
 003AR                   END

NO ERRORS

* FUNCT   0000R
```

****

```
0000R                     EXTRN  PMAX1,PMAX2
0000R                     EXTRN  RMAX1,RMAX2
0000R                     EXTRN  CORNCT,INTERV,CORNER,LINE
0000R                     EXTRN  CFIX,LINER
0000R                     EXTRN  TANDRI,INTERH,DAMP
0000R                     EXTRN  DISKST,CASA
0000R                     ENTRY  GOTBAC,LINER2,CENDER
0000R                     ENTRY  LINER2,HOLDEN
0000R                     ENTRY  ENDSEG,FCORN
0000R                     EXTRN  THOLD,BSTORE
0000R                     EXTRN  OFFSET

0000              STORE   EQU    0
0002              STORE2  EQU    2
0004              STORE4  EQU    4
000C              STOREC  EQU    12

0006              INCREM  EQU    6

0000R 4820        ENDSEG  LH     2,CORNCT
      0000F
0004R 4080                STH    8,HOLD
      00BCR
0008R 2686                AIS    8,INCREM
000AR 4898                LH     9,STORE(8)
      0000
000ER C990                CHI    9,X'F000'         IF TWO FLAGS, G
      F000
0012R 4220                BP     SKIP
      0018R
0016R 0819                LHR    1,9               INTO REGISTER
0018R CB80        SKIP    SHI    8,INCREM+INCREM
      000C
001CR 0898                LHR    9,8               R9 POINTS 2 POI
001ER C410                NHI    1,X'C000'
      C000
0022R 4800                LH     0,DISKST
      0000F
0026R CD00                SLHL   0,7
      0007
002AR 0869                LHR    6,9
002CR 4B60                SH     6,OFFSET
      0000F
0030R 0616                OHR    1,6
0032R 0610                OHR    1,0
0034R C520                CLHI   2,10
      000A
0038R 4330                BE     GOT1
      005AR
003CR C520                CLHI   2,4
      0004
```

```
0040R 4330            BE     GOT1
      005AR
0044R 2622            AIS    2,2
0046R 4092            STH    9,CORNER(2)
      0000F
004AR 4012            STH    1,DATP(2)
      0000F
004ER 4020            STH     ,CORNCT
      0002R
0052R 4100            BAL     ,LINE
      0000F
0056R 4300            B      GOT2
      0062R
005AR 2722   GOT1     SIS    2,2
005CR 4012            STH    1,DATP(2)
      004CR
0060R 2622            AIS    2,2
0062R C520   GOT2     CLHI   2,4
      0004
0066R 4330            BE     LINER2
      00A2R
006AR 4100   GOTTEN   BAL    0,CFSA
      0000F
006ER 4100            BAL     ,CFIX
      0000F
0072R 00A2R           DC     LINER2
0074R 4860   GOTBAC   LH     6,PMAX1
      0000F
0078R CD60            SLHL   6,4
      0004
007CR 4660            OH     6,RMAX1
      0000F
0080R 0B22            SHR    2,2
0082R 4100            BAL     ,LINER
      0000F
0086R 2626            AIS    2,6
0088R 4860            LH     6,PMAX2
      0000F
008CR CD60            SLHL   6,4
      0004
0090R 4660            OH     6,RMAX2
      0000F
0094R 4D00            BAL     ,LINER
      0084R
0098R 0B22            SHR    2,2
009AR 4020            STH     ,CORNCT
      0050R
009ER 4300            B      ENDED
      00EAR
00A2R 4860   LINER2   LH     6,PMAX2
      008AR
00A6R CD60            SLHL   6,4
```

```
        0004
00AAR   4660                OH      6,RMPX2
        0032R
00AER   0B22                SHR     2,2
00B0R   4100                BAL     0,LINER
        0096R
00B4R   0B22                SHR     2,2
00B6R   4020                STH     2,CORNCT
        009CR
                    *

00BAR   C890        ENDED   LHI     9,0
        0000
00BCR               HOLDEN  EQU     *-2
00BCR               HOLD    EQU     *-2
00BER   4020                STH     2,DATP
        005ER
00C2R   0711                XHR     1,1
00C4R   40D0                STH     1,ESTORE
        0000F
00C8R   4810        ENDER   LH      1,INTER
        0000F
00CCR   40D0                STH     1,INTERV
        0000F
00D0R   4300                B       TANDAI
        0000F
                    *

                    *
00D4R   4D00        FCORN   BAL     0,CFSA
        006CR
00D8R   4D00                BAL     0,CFIX
        0070R
00DCR   014CR               DC      CENDER
00DER   4860                LH      6,PMAX1
        0076R
00E2R   CD60                SLHL    6,4
        0004
00E6R   4660                OH      6,RMAX1
        007ER
00EAR   4820                LH      2,RMAX2
        00ACR
00EER   4020                STH     2,RMAX1
        00E8R
00F2R   4820                LH      2,PMAX2
        00A4R
00F6R   4020                STH     2,PMAX1
        00E0R
00FAR   0B22                SHR     2,2
00FCR   4D00                BAL     0,LINER
```

```
      00B2R
0100R 2626              AIS    2,6
0102R 0744              XHR    4,4
0104R 4832      SHLOOP  LH     3,DATP(2)
      00C0R
0108R 4034              STH     ,DATP(4)
      0D06R
010CR 2642              AIS    4,2
010ER 2622              AIS    2,2
0110R C520              CLHI   2,14
      000E
0114R 4280              BL     SHLOOP
      0D04R
0118R 2742              SIS    4,2
011AR 4040              STH    4,CORNCT
      00B8R
011ER C830              LHI    3,THOLD
      000F
0122R D0B0              STM    14,SAV2
      0152R
0126R 0722              XHR    2,2
0128R D1E3      STLOOP  LM     14,X'C'(3)
      000C
012CR D0E3              STM    14,0(3)
      0000
0130R 2634              AIS    3,4
0132R 2621              AIS    2,1
0134R C520              CLHI   2,4
      0004
0138R 4280              BL     STLOOP
      0128R
013CR 2454              LIS    5,4
013ER 242A              LIS    2,10
0140R 4832              LH     3,CORNER(2)
      0048R
0144R 4035              STH     ,CORNER(5)
      0142R
0148R D1E0              LM     14,SAV2
      0152R
014CR 08B9      CENDER  LHR    11,9
014ER 4300              B      ENDER
      00C8R
                *
0152R           SAV2    DS
0156R                   END

NO ERRORS

* BSTORE   00C6R
* CENDER   014CR
* CFIX     00DAR
* CFSA     00D6R
* CORNCT   011CR
```

```
* CORNER   0146R
* DATP     0010AR
* DISKST   0024R
  ENDED    00BAR
  ENDER    00C8R
* ENDSEG   0000R
* FCORN    00D4R
  GOT1     005AR
  GOT2     0062R
* GOTBAC   0074R
  GOTTEN   006AR
  HOLD     00BCR
* HOLDEN   00BCR
  INCREM   0006
* INTERH   00CAR
* INTERV   00CER
* LINE     0054R
* LINER    00FER
* LINER2   00A2R
* OFFSET   002ER
* PMAX1    00F8R
* PMAX2    00F4R
* RMAX1    00F0R
* RMAX2    00ECR
  SAV2     0152R
  SHLOOP   0104R
  SKIP     0018R
  STLOOP   0128R
  STORE    0000
  STORE2   0002
  STORE4   0004
  STOREC   000C
* TANDRI   00D2R
* THOLD    0120R

*****************************************************************
```

```
0000R                      ENTRY  CFSA,MINIM
0000R                      EXTRN  ATANUR,CORNER,DAIP,BSTORE
0000R                      EXTRN  STABS,INDEX,STOREX,STOREY
0000R                      EXTRN  KIT,CFRTRN,PTMAX,GPOINT

0000             STORE     EQU    0
0002             STORE2    EQU    2

3258             PI        EQU    X'3258'
64AE             TWOPI     EQU    X'64AE'

0008             CORNR     EQU    8

0000R 4000       CFSA      STH    ,BACK+2
      015CR
0004R 2604                 AIS    0,4
0006R 4000                 STH    ,CFRTRN              IN CFIX
      0000F
000AR C880                 LHI    CORNR,CORNER
      0000F
000ER 4828                 LH     2,2(CORNR)
      0002
0012R 4832                 LH     3,STORE(2)
      0000
0016R 4842                 LH     4,STORE2(2)
      0002
001AR 4828                 LH     2,0(CORNR)
      0000
001ER 4810                 LH     1,PTMAX
      0000F
0022R 4811                 LH     1,6(1)
      0006
0026R 0512                 CLHR   1,2
0028R 4280                 BL     GOON1
      0058R
002CR 4020                 STH    2,ANGLE
      0190R
0030R 41F0                 BAL    15,GPOINT
      0000F
0034R 000A                 DC     10
0036R 0020R                DC     PTMAX
0038R 0190R                DC     ANGLE
003AR 0188R                DC     ONE
003CR 018CR                DC     DELTAX
003ER 41B0                 BAL    15,GPOINT
      0032R
0042R 000A                 DC     10
0044R 0036R                DC     PTMAX
0046R 0190R                DC     ANGLE
0048R 018AR                DC     TWO
004AR 018ER                DC     DELTAY
004CR 4B30                 SH     ,DELTAX
```

```
       018CR
0050R  4B40                SH     4,DELTAY
       018ER
0054R  4300                B      GOTAN
       0060R
0058R  4B32      GOON1     SH     3,STORE(2)
       0000
005CR  4B42                SH     4,STORE2(2)
       0002
0060R  4D00      GOTAN     BAL    0,ATNR
       0162R
0064R  0815                LHR    1,5
0066R  4828                LH     2,6(CORNR)
       0006
006AR  4832                LH     3,STORE(2)
       0000
006ER  4842                LH     4,STORE2(2)
       0002
0072R  4828                LH     2,8(CORNR)
       0008
0076R  4B32                SH     3,STORE(2)
       0000
007AR  4B42                SH     4,STORE2(2)
       0002
007ER  4100                BAL    1,ATNR
       0162R
0082R  0B15                SHR    1,5
0084R  41B0                BAL    15,STABS
       000F
0088R  C510                CLHI   1,PI
       3258
008CR  4280                BL     COMPAR
       0098R
0090R  C850                LHI    5,TWOPI
       64AE
0094R  0B51                SHR    5,1
0096R  0815                LHR    1,5
0098R  C510      COMPAR    CLHI   1,X'600'             ^^20 DEGREES
       0600
009AR            MINIM     EQU    *-2
009CR  4280                BL     GOON
       00A8R
00A0R  C810                LHI    1,-1
       FFFF
00A4R  4300                B      GOON+2
       00AAR
00A8R  0711      GOON      XHR    1,1
00AAR  4010                STH    1,SFLAG+2
       0158R
00AER  4010                STH    1,NOFX+2
       010ER
00B2R  4810                LH     1,ESTORE
```

```
      0000F
00B6R 4330              BZ     NOEX
      010CR
0008              DAT   EQU    8
00BAR C880              LHI    DAT,DAT+
      0000F
00BER 4838              LH     3,0(DAT)
      0000
00C2R C430              NHI    3,X'3FFF'
      3FFF
00C6R 4828              LH     2,2(DAT)
      0002
00CAR C420              NHI    2,X'3FFF'
      3FFF
00CER 0A32              AHR    3,2
00D0R CC30              SRHL   3,1              GET 'AVERAGE' I
      0001
00D4R 4848              LH     4,6(DAT)
      0006
00D8R C440              NHI    4,X'3FFF'
      3FFF
00DCR 4828              LH     2,8(DAT)
      0008
00E0R C420              NHI    2,X'3FFF'
      3FFF
00E4R 0A42              AHR    4,2
00E6R CC40              SRHL   4,1              GET 'AVERAGE' I
      0001
00EAR 0722              XHR    2,2
00ECR 4532        CLOOP CLH    3,INDEX(2)
      0000F
00F0R 4280              BL     HNEXT
      00FCR
00F4R 4020              STH    2,NOEX+2
      010ER
00F8R 4300              B      NEXT
      0104R
00FCR 4542        HNEXT CLH    4,INDEX(2)
      00EER
0100R 4380              BNL    FOUND
      0124R
0104R 2622        NEXT  AIS    2,2
0106R 0521              CLHR   2,1
0108R 4280              BL     CLOOP
      00ECR
010CR C820        NOEX  LHI    2,0
      0000
0110R 2412              LIS    1,2
0112R 0A21              AHR    2,1
0114R 4841              LH     4,CORNER(1)
      000CR
0118R 4874              LH     7,STORE(4)
```

```
         0000
011CR    4834                LH      3,STORE2(4)
         0002
0120R    4300                B       SHIFT
         012CR
0124R    4872      FOUND     LH      7,STOREX(2)
         0000F
0128R    4832                LH      3,STOREY(2)
         0000F
012CR    0744      SHIFT     XHR     4,4
012ER    2452                LIS     5,2
0130R    4862      CLOOP1    LH      6,STOREX(2)
         0126R
0134R    4064                STH     6,STOREX(4)
         0132R
0138R    4862                LH      6,STOREY(2)
         012AR
013CR    4064                STH     6,STOREY(4)
         013AR
0140R    4862                LH      6,INDEX(2)
         00FER
0144R    4064                STH     6,INDEX(4)
         0142R
0148R    0A45                AHR     4,5
014AR    0A25                AHR     2,5
014CR    0521                CLHR    2,1
014ER    4280                BL      CLOOP1
         0130R
0152R    4040                STH     4,BSTORE
         00B4R
0156R    C840      SFLAG     LHI     4,0
         0000
015AR    4210      BACK      BM      *
         015AR
015ER    4300                B       KIT
         0000F


0162R    4030      ATNR      STH      ,DELTAX
         018CR
0166R    4040                STH     4,DELTAY
         018ER
016AR    41F0                BAL     15,ATANUR
         0000F
016ER    018CR               DC      DELTAX
0170R    018ER               DC      DELTAY
0172R    0190R               DC      ANGLE
0174R    4850                LH      5,ANGLE
         0190R
0178R    4860                LH      6,ANGLE+2
         0192R
017CR    CF50                SLHA    5,12
```

```
         000C
  0130R CE60              SRHA   5,3
         0003
  0184R 0A56              AHR    5,6
  0186R 0300              BR     0

  0188R 0001      ONE     DC     1
  018AR 0002      TWO     DC     2
  018CR 0000      DELTAX  DC     0
  018ER 0000      DELTAY  DC     0
  0190R 0000      ANGLE   DC     0,0
        0000
  0194R                   END

NO ERRORS

  ANGLE    0190R
* ATANUR   016CR
  ATNR     0162R
  BACK     015AR
* BSTORE   0154R
* CFRTRN   0008R
* CFSA     0000R
  CLOOP    00ECR
  CLOOP1   0130R
  COMPAR   0098R
* CORNER   0116R
  CORNR    0008
  DAT      0008
* DATP     00BCR
  DELTAX   018CR
  DELTAY   018ER
  FOUND    0124R
  GOON     00A8R
  GOON1    0058R
  GOTAN    0060R
* GPOINT   0040R
  HNEXT    00FCR
* INDEX    0146R
* MINIM    009AR
  NEXT     0104R
  NOEX     010CR
  ONE      0188R
  PI       3258
* PTMAX    0044R
  SFLAG    0156R
  SHIFT    012CR
* STABS    0086R
  STORE    0000
  STORE2   0002
* STOREX   0136R
* STOREY   013ER
  TWO      018AR
```

```
  TWOPI    64AE
* XIT      0160F

*********************************************************************
```

```
*ENTRY BAL 1C,CFIX
*     THIS ROUTINE TAKES 2 LINE SEGMENTS
*     IN 'CORNER' & CALCULATES THEIR INTERSEC
*     THE INTERSECTION IS STORED HIGH IN
*     STORE AND THE POINTERS TO THE INTERSECT
*     IN CORNER ARE ALTERED TO IT
*
*R0--BAL; B & D FROM BD
*R1--WRKG
*R2--WRKG,PTR TO CORNER IN SLOPED
*R3--B,D FROM BD; Y FROM BY,DY
*R4--WRKG
*R5--WRKG
*R6--WRKG; PTR TO HOLD IN SLOPED
*R7--WRKG
*R12-BAL SETTER
*R14-BAL SLOPED
*R15-BAL SLOPE1,STABS,BD,BY,DY


*  Y1=AX1+B
*  Y2=CX2+D
*     AT INTERSECTION:
*        Y1=Y2
*        X1=X2
*     THEREFORE: AX+B=CX+D AT INTERS
*  AX-CX=D-B
*  X(A-C)=D-B
*  X(INTERS)=(D-B)/(A-C)
*  Y(INTERS)=A*X(INTERS)+B=
*            C*X(INTERS)+D


0000R                 ENTRY CFIX,DELTA3,CFRTRN,XIT
0000R                 EXTRN CORNCT,SLOPER
0000R                 EXTRN INOUTS
0000R                 EXTRN DATP,THOLD
0000R                 EXTRN CORNER,STABS
0000R                 EXTRN ATANUR

0000          STORE   EQU   0
0002          STORE2  EQU   2
000E          STOREE  EQU   14
000C          STOREC  EQU   12

0000R 4000    CFIX    STH   0,RETRN
      0238R
0004R 2442            LIS   4,2              SET PTR TO GET
0006R 41F0            BAL   15,BD            GET B
      008ER
000AR 4000            STH   0,B
```

```
      030ER
000ER 2448          LIS   4,8            SET PTR TO GET
0010R 41F0          BAL   15,BD          GET D
      008ER
0014R 4000          STH   0,D
      0310R
0018R C900          CHI   0,X'9000'      IF D<900
      9000
001CR 4210          BM    DXY            LINE2 IS VERTIC
      00C6R
0020R C900          CHI   0,X'7000'      IF D>700
      7000
0024R 4220          BP    DXY            LINE2 IS VERTIC
      00C6R
0028R 4810          LH    1,B
      030ER
002CR C910          CHI   1,X'9000'      IF B<900
      9000
0030R 4210          BM    DXY            LINE1 IS VERTIC
      0164R
0034R C910          CHI   1,X'7000'      IF B>700
      7000
0038R 4220          BP    DXY            LINE1 IS VERTIC
      0164R
003CR 0B10          SHR   1,0            R1=B-D
003ER 4240          BTC   4,BOT          IF SUB. FAILS,S
      00DAR
0042R 4010          MH    1,TANFAC       ADD IN ROUNDOFF
      031CR
0046R 244A          LIS   4,10
0048R 4854          LH    5,CORNER(4)    R5 HAS C*TANFAC
      0000F
004CR 2746          SIS   4,6
004ER 4B54          SH    5,CORNER(4)    R5=(C-A)*TANFAC
      004AR
0052R 0820          LHR   2,0
0054R 0831          LHR   3,1
0056R 0D05          DHR   0,5            R1 HAS X AT COR
              *               =(D-B)*TANFAC/((A-C)*TANFA
0058R 0531          CLHR  3,1
005AR 4230          BNE   CHECK          CHECK FOR DIV F
      019AR
005ER 0520          CLHR  2,0
0060R 4230          BNE   CHECK          IF NONE GO TO C
      019AR
0064R 0811          LHR   1,1
0066R 4330          BZ    CHECK
      019AR
006AR C550          CLHI  5,1
      0001
006ER 4330          BE    CHECK
      019AR
```

```
0072R 4810           LH     1,B               OTHERWISE ONE L
      030ER
0076R 41F0           BAL    15,STABS          DECIDE WHICH
      0000F
007AR 0801           LHR    0,1
007CR 4810           LH     1,D
      0310R
0080R 41F0           BAL    15,STABS          AND GO TO APPRO
      0078R
0084R 0510           CLHR   1,0
0086R 4380           BNL    EXY
      00C6R
008AR 4300           B      DXY
      0164R

               *        ***************

               *
               *ENTRY BAL 15,BD
               *      THIS ROUTINE EXTRACTS B FROM THE
               *      EQUASION Y=AX+B
               *      B=Y-AX
               *
008ER 4814     BD     LH     1,CORNER(4)       R4=PTR TO 2ND L
      0050R
0092R 4831            LH     3,STORE(1)        R3=X
      0000
0096R 2642            AIS    4,2               R4 HAS  PTR TO
0098R 41C0            BAL    12,SETTER         IF RETURNED
      00A4R
               *                  R3 HAS AX
               *                  ELSE X INTERCEPT NEAR INFIN
009CR 4801            LH     0,STORE2(1)       R0 HAS Y
      0002
00A0R 0B03            SHR    0,3               R0=B
00A2R 030F            BR     15



               *
               *ENTRY BAL 12,SETTER
               *      R3 HAS X ON ENTRY
               *      R4=PTR TO SLOPE OF LINE (A)
               *      R2/3 = AX ON EXIT
               *
00A4R 4C24     SETTER MH     2,CORNER(4)
      0090R
00A8R 0852            LHR    5,2
00AAR 0863            LHR    6,3
00ACR 4230            BNZ    HOP
      00B4R
```

```
00B0R 0822            LHR   2,2
00B2R 033C            BFCR  3,12
00B4R 4D20    HOP     DH     ,TANFAC          REMOVE ROUNDOFF
      031CR
00B8R 0536            CLHR  3,6
00BAR 023C            BTCR  3,12              CHECK FOR DIVID
00BCR 0525            CLHR  2,5               IF NONE RETURN
00BER 023C            BTCR  3,12
00C0R C800            LHI   0,X'8000'         ELSE LOAD R0=B=
      8000
00C4R 030F            BR    15                RETURN TO CALLE
              *


              *       ******************

              * ENTRY E (B)XY
              *  BXY & DXY ARE IDENTICAL EXCEPT
              *  YOU USE BXY WHEN LINE2 IS VERTICAL
              *  USE DXY WHEN LINE1 IS VERTICAL.

              *WITH ONE LINE VERTICAL, X ALONG THAT
              *LINE WILL NOT CHANGE MUCH.  IF YOU
              *TAKE AN X NEAR THE INTERSECTION, IT CAN
              *BE SAFELY ASSUMED TO BE THE X AT THE
              *INTERSECTION.  SUBSTITUTING THIS X I.
              *THE EQUASION FOR THE OTHER LINE GIVES
              *Y(INTERS)


              *
00C6R 4810    BXY     LH    1,B
      030ER
00CAR C910            CHI   1,X'9000'         SEE IF BOTH LIN
      9000
00CER 4210            BM    BOTH
      00DAR
00D2R C910            CHI   1,X'7000'
      7000
00D6R 4320            BNP   NOT               IF NOT  GO TO N
      014AR
00DAR 48F0    BOTH    LH    15,RETRN          IF FROM INTERS
      0238R
00DER 480F            LH    0,0(15)
      0000
00E2R C500            CLHI  0,INOUTS
      000F
00E6R 0330            BER   0                 RETURN
00E8R 2442            LIS   4,2
00EAR 2438            LIS   3,8               ELSE YOU HAVE A
00ECR 0824            LHR   2,4
```

```
00EER 4813      LOOP      LH      1,CORNER(3)       FORGET IT &
      00A6R
00F2R 4014                STH     1,CORNER(4)       TO LOOK FOR NEX
      00F0R
00F6R 4813                LH      1,IATP(3)
      0000F
00FAR 4014                STH     1,IATP(4)
      00F8R
00FER 0A32                AHR     3,2
0100R 0A42                AHR     4,2
0102R C540                CLHI    4,8
      000B
0106R 4280                BL      LOOP
      00EER
010AR 4840                LH      4,CORNCT
      0000F
010ER 2746                SIS     4,6
0110R 4040                STH     4,CORNCT
      010CR
0114R 41F0                BAL     15,SLOPER
      0000F
0118R C830                LHI     3,THOLD
      0000F
011CR 2634                AIS     3,4
011ER 4843                LH      4,STOREC(3)
      000C
0122R 4043                STH     4,STORE(3)
      0000
0126R 4843                LH      4,STOREE(3)
      000E
012AR 4043                STH     4,STORE2(3)
      0002
012ER 2638                AIS     3,8
0130R 4843                LH      4,STOREC(3)
      000C
0134R 4043                STH     4,STORE(3)
      0000
0138R 4843                LH      4,STOREE(3)
      000E
013CR 4043                STH     4,STORE2(3)
      0002
0140R 48F0                LH      15,RETRN
      0238R
0144R 480F                LH      0,0(15)
      0000
0148R 0300                BR      0
014AR 2446      NOT       LIS     4,6               GET END OF LINE
014CR 4824                LH      2,CORNER(4)       NEAREST INTERSE
      00F4R
0150R 4812                LH      1,STORE(2)        GET ITS X COORD
      0000
0154R 41F0                BAL     15,BY             CALCULATE Y
```

```
      017ER
0158R 4030              STH    3,Y1
      030AR
015CR 4030              STH    3,Y2              STORE IT FOR L1
      030CR
0160R 4300              B      CHEKR             SKIP CALCULATIO
      01AAR


0164R 2442    DXY       LIS    4,2
0166R 4824              LH     2,CORNER(4)
      014ER
016AR 4812              LH     1,STORE(2)
      0000
016ER 41F0              BAL    15,DY
      018CR
0172R 4030              STH    3,Y1
      030AR
0176R 4030              STH    3,Y2
      030CR
017AR 4300              B      CHEKR
      01AAR



              *
              *ENTRY BAL 15,(B)Y
              *  BY & DY ARE IDENTICAL; THEY ARE
              *  USED TO CALCULATE Y WHEN X IS
              *  KNOWN.  BY IS USED FOR LINE1; DY
              *  FOR LINE2.
              *ON ENTRY, R1 HAS X-COORD AT THE
              *  INTERSECTION
              *ON RETURN, R3 HAS Y
              *
017ER 0831    BY        LHR    3,1
0180R 2444              LIS    4,4
0182R 41C0              BAL    12,SETTER         GET AX
      00A4R
0186R 4A30              AH     3,B               =AX+
      030ER
018AR 030F              BR     15


018CR 0831    DY        LHR    3,1
018ER 244A              LIS    4,10
0190R 41C0              BAL    12,SETTER
      00A4R
0194R 4A30              AH     3,D
      0310R
0198R 030F              BR     15
```

```
                 *       **************


                 *
019AR 41F0  CHECK   BAL   15,BY            GET Y AT INTERS
      017ER
019ER 4030          STH   3,Y1             FOR LINE1
      030AR
01A2R 41F0          BAL   15,DY            GET INTERSECTIO
      018CR
01A6R 4030          STH   3,Y2             FOR LINE2
      030CR

                 *     YOU'VE NOW GOT TWO POSSIBLE INTERSECTIO
                 *     X,Y1 & X,Y2.  YOU WOULD LIKE TO FIND
                 *     FIND THE ONE WHICH IS CLOSEST
                 *     TO THE INTENDED CORNER
                 *FIND THE LINE ALONG WHICH THE DIFFERENCE
                 * IN LINE SLOPE

*************************************************************

                 * IS GREATER (BETWEEN X,Y1 & X,Y2)  THEN FIND
                 * THE X,Y COORD WHICH GIVES THE LINE THE SLOP
                 * CLOSER TO THE ONE ORIGINALLY CALCULATED
                 *

01AAR 4010  CHEKR   STH   1,H1
      0218R
01AER 0B66          SHR   6,6
01B0R 0B22          SHR   2,2
01B2R 41E0          BAL   14,SLOPED        GET DIF BETWEEN
      023ER
                 *                     FOR LINES X,Y1-CORNER(0
                 *                       X,Y2-CORNER(0)
01B6R 4010          STH   1,DEL1           STORE THE DIFFE
      031AR
01BAR 2426          LIS   2,6
01BCR 2464          LIS   6,4
01BER 41E0          BAL   14,SLOPED        SAME FOR CORNER
      023ER
01C2R 4510          CLH   1,DEL1           FIND WHICH LINE
      031AR
01C6R 4380          BNL   SCND
      01D8R
01CAR 0B66          SHR   6,6
01CCR 2422          LIS   2,2
01CER 4812          LH    1,CORNER(2)
      0168R
```

```
01D2R 0722              XHR    2,2
01D4R 4300              B      RET1
      01DER
01D8R 2426     SCND     LIS    2,6
01DAR 4812              LH     1,CORNER(2)
      01D0R
01DER 4851     RET1     LH     5,STORE2(1)
      0002
01E2R 4831              LH     3,STORE(1)
      0000
01E6R 41B0              BAL    15,DIFFER
      0288R
01EAR 4816              LH     1,HOLD(6)
      0312R
01EER 0B15              SHR    1,5               GET DIF BETW CA
               *                  SLOPE FOR X,Y1 & SLOPE OF
               *                  LINE SEGMENT NEAREST
01F0R 41D0              BAL    13,PITEST
      026AR
01F4R 4010              STH    1,DEL1
      031AR
01F8R 4816              LH     1,HOLD1(6)
      0314R
01FCR 0B15              SHR    1,5               SAME FOR X,Y2
01FER 41D0              BAL    13,PITEST
      026AR
0202R 4510              CLH    1,DEL1            FIND WHICH IS L
      031AR
0206R 4280              BL     SEC
      0212R
020AR 4830              LH     3,Y1              LOAD R3 WITH NE
      030AR
020ER 4300              B      RET2
      0216R
0212R 4830     SEC      LH     3,Y2
      030CR
0216R C870     RET2     LHI    7,0
      0000
0218R          H1       EQU    *-2
021AR 2416     XIT      LIS    1,6
021CR 4841              LH     4,CORNER(1)       GET POINTER TO
      01DCR
0220R 4074              STH    7,STORE(4)
      0000
0224R 4034              STH    3,STORE2(4)
      0002
0228R 2714              SIS    1,4
022AR 4841              LH     4,CORNER(1)
      021ER
022ER 4074              STH    7,STORE(4)
      0000
0232R 4034              STH    3,STORE2(4)
```

```
      0002
0236R C800            LHI    0,0
      0000
0238R         RETRN   EQU    *-2
0238R         CFRTRN  EQU    *-2
023AR 2602            AIS    0,2
023CR 0300            BR     0


              *
              *ENTRY BAL 14,SLOPED
              *      R15--BAL
              *      R14--RETURN ADDR
              *      R2--CORNER PTR
              *      R1--STABS(SLOPE DIF) ON RETURN
              *      R6--PTR TO HOLD
              *      R3,R5--WRKG

023ER 4850    SLOPED  LH     5,Y1
      030AR
0242R 4830            LH     3,H1              H1 HAS X COORD
      0218R
0246R 41F0            BAL    15,DIFFER
      0288R
024AR 4056            STH    5,HOLD(6)         R5=SLOPE (X,Y1-
      0312R
024ER 4830            LH     3,H1
      0218R
0252R 4850            LH     5,Y2
      030CR
0256R 41F0            BAL    15,DIFFER
      0288R
025AR 4056            STH    5,HOLD1(6)        R5=SLOPE (X,Y2-
      0314R
025ER 4816            LH     1,HOLD(6)
      0312R
0262R 0B15            SHR    1,5
0264R 41D0            BAL    13,PITEST
      026AR
0268R 030E    EXIT    BR     14


026AR 41F0    PITEST  BAL    15,STABS
      0082R
026ER C510            CLHI   1,X'3257'
      3257
0270R         PI      EQU    *-2
0272R 028D            BTCR   8,13
0274R 4230            BNE    NOTBAC
      027CR
```

```
0278R 0B11              SHR     1,1
027AR 030D              BR      13
027CR C820     NOTBAC   LHI     2,X'64AE'
      64AE
027ER          TWOPI    EQU     *-2
0280R 0B12              SHR     1,2
0282R 41F0              BAL     15,STABS
      026CR
0286R 030D              BR      13

0288R 40F0     DIFFER   STH     15,HOLDF
      0306R
028CR 4812              LH      1,CORNER(2)
      022CR
0290R 0875              LHR     7,5
0292R 0843              LHR     4,3
0294R 4B51              SH      5,STORE2(1)
      0002
0298R 4B31              SH      3,STORE(1)
      0000
029CR 2622              AIS     2,2
029ER 4812              LH      1,CORNER(2)
      028ER
02A2R 2722              SIS     2,2
02A4R 4B71              SH      7,STORE2(1)
      0002
02A8R 4B41              SH      4,STORE(1)
      0000
02ACR 0817              LHR     1,7
02AER 41F0              BAL     15,STABS
      0284R
02B2R 4010              STH     1,TEMPH
      02D6R
02B6R 0814              LHR     1,4
02B8R 41F0              BAL     15,STABS
      02B0R
02BCR 6110              AHM     1,TEMPH
      02D6R
02C0R 0815              LHR     1,5
02C2R 41F0              BAL     15,STABS
      02BAR
02C6R 4010              STH     1,TEMPH1
      02D2R
02CAR 0813              LHR     1,3
02CCR 41F0              BAL     15,STABS
      02C4R
02D0R CA10              AHI     1,0
      0000
02D2R          TEMPH1   EQU     *-2
02D4R C510              CLHI    1,0
      0000
02D6R          TEMPH    EQU     *-2
```

```
 02D8R 4380                BNL   OK
       02E0R
 02DCR 0857                LHR   5,7
 02DER 0834                LHR   3,4
 02E0R 4030     OK         STH   5,DELTAX
       0320R
 02E4R 4050                STH   5,DELTAY
       031ER
 02E8R 41F0                BAL   15,ATANUR
       0000F
 02ECR 031ER               DC    A(DELTAY),A(DELTAX),A(ANGLE)
       0320R
       0322R
 02F2R 4850                LH    5,ANGLE
       0322R
 02F6R 4830                LH    3,ANGLE2
       0324R
 02FAR CF50                SLHA  5,12
       000C
 02FER CE30                SRHA  3,3
       0003
 0302R 0A53                AHR   5,3
 0304R 4300                B     *
       0304R
 0306R          HOLDF      EQU   *-2


 0308R          DELTA3     DS    2
 030AR          Y1         DS    2
 030CR          Y2         DS    2
 030ER          B          DS    2
 0310R          D          DS    2
 0312R          HOLD       DS    2
 0314R          HOLD1      DS    2
 0316R          HOLD2      DS    2
 0318R          HOLD3      DS    2
 031AR          DEL1       DS    2
 031CR 0040     TANFAC     DC    X'40'
 031ER          DELTAY     DS    2
 0320R          DELTAX     DS    2
 0322R          ANGLE      DS    2
 0324R          ANGLE2     DS    2
 0326R                     END
 ANGLE    0322R
 ANGLE2   0324R
* ATANUR  02EAR
 B        030ER
 BD       008ER
 BOTH     00DAR
 BXY      00C6R
 BY       017ER
* CFIX    0000R
```

```
* CFRTRN   0238R
  CHECK    019AR
  CHEKR    01AAR
* CORNCT   0112R
* CORNER   02A0R
  D        0310R
* DATP     00FCR
  DEL1     031AR
* DELTA3   0308R
  DELTAX   0320R
  DELTAY   031ER
  DIFFER   0288R
  DXY      0164R
  DY       018CR
  EXIT     0268R
  H1       0218R
  HOLD     0312R
  HOLD1    0314R
  HOLD2    0316R
  HOLD3    0318R
  HOLDF    0306R
  HOP      00B4R
* INOUTS   00E4R
  LOOP     00EER
  NOT      014AR
  NOTBAC   027CR
  OK       02E0R
  PI       0270R
  PITEST   026AR
  RET1     01DER
  RET2     0216R
  RETRN    0238R
  SCND     01D8R
  SEC      0212R
  SETTER   00A4R
  SLOPED   023ER
* SLOPER   0116R
* STABS    02CER
  STORE    0000
  STORE2   0002
  STOREC   000C
  STOREE   000E
  TANFAC   031CR
  TEMPH    02D6R
  TEMPH1   02D2R
* THOLD    011AR
  TWOPI    027ER
* XIT      021AR
  Y1       030AR
  Y2       030CR
```

```
0000R                    ENTRY DELT11,DELT22
0000R                    ENTRY LINER,DELTA1,DELTA2
0000R                    EXTRN CORNER,GPOINT
0000R                    EXTRN PRLOOP,WNWOVE
0000R                    EXTRN LAID,PPFIDF,FAID
0000R                    EXTRN DATP
0000R                    ENTRY FLINE,FLINE2
0000R                    EXTRN PTMAX

0000          STORE      EQU   0
0006          STORE6     EQU   6

              *REGS: 0 RETURN,BAL
              *      1
              *      2 CONTAINS CORNCT
              *      3
              *      4
              *      5
              *      6 CONTAINS RMAX
              *      7
              *      8
              *      9
              *      10 PTR TO LINE END FROM PLOOP
              *      12 MULTIPLY,DIVIDE--
              *      13 DATA CHANGES
              *      15 BAL
0000R 4000    LINER      STH   0,RETRN
      00C0R
0004R 4020               STH   2,HOLD
      00B8R
0008R 4090               STH   9,HOLD2
      00BCR
000CR 4060               STH   6,HRATE
      0148R
0010R 4810               LH    1,DELT11
      0140R
0014R 4010               STH   1,DELTA1
      013CR
0018R 4810               LH    1,DELT22
      0142R
001CR 4010               STH   1,DELTA2
      013ER
0020R 4812               LH    1,DATP(2)
      0000F
0024R 4210               BM    GETPT
      0030R
0028R 4810               LH    1,HOLDPT
      015ER
002CR 4012               STH   1,CORNER(2)
      0000F
0030R 41F0    GETPT      BAL   15,PLOOP2
```

```
        00CAR
 0034R  40A0        STH    10,FLINE2
        0146R
 0038R  2622        AIS    2,2
 003AR  41F0        BAL    15,PLOOP2
        00CAR
 003ER  40A0        STH    10,HOLDPT
        015ER
 0042R  40A0        STH    10,FLINE
        0144R
 0046R  41F0        BAL    15,LADD
        0000F
 004AR  000A        DC     10
 004CR  0000F       DC     PTMAX
 004ER  0144R       DC     FLINE
 0050R  0146R       DC     FLINE+2
 0052R  014AR       DC     SIZE
 0054R  08EE        LHR    14,14
 0056R  4230        BNZ    PRLOOP
        0000F
 005AR  41F0        BAL    15,PPFLDF
        0000F
 005ER  000E        DC     14
 0060R  004CR       DC     PTMAX
 0062R  0144R       DC     FLINE
 0064R  0146R       DC     FLINE+2
 0066R  015CR       DC     FIELD1
 0068R  015AR       DC     TWO
 006AR  0148R       DC     HRATE
 006CR  08EE        LHR    14,14
 006ER  4230        BNZ    PRLOOP
        0058R
 0072R  41F0        BAL    15,GPOINT
        0000F
 0076R  000A        DC     10
 0078R  0060R       DC     PTMAX
 007AR  0144R       DC     FLINE
 007CR  0158R       DC     ONE
 007ER  00C2R       DC     X1
 0080R  41F0        BAL    15,GPOINT
        0074R
 0084R  000A        DC     10
 0086R  0078R       DC     PTMAX
 0088R  0144R       DC     FLINE
 008AR  015AR       DC     TWO
 008CR  00C4R       DC     Y1
 008ER  41F0        BAL    15,GPOINT
        0082R
 0092R  000A        DC     10
 0094R  0086R       DC     PTMAX
 0096R  0146R       DC     FLINE+2
 0098R  0158R       DC     ONE
```

```
009AR 00C6R            DC     X2
009CR 41F0             BAL    15,GPOINT
      0090R
00A0R 000A             DC     10
00A2R 0094R            DC     PTMAX
00A4R 0146R            DC     FLINE+2
00A6R 015AR            DC     TWO
00A8R 00C8R            DC     Y2
00AAR C890             LHI    9,X1
      00C2R
00AER C8C0             LHI    12,X2
      00C6R
00B2R 4DD0             BAL    13,WNWONE
      0000F
00B6R C820     RETRY2  LHI    2,0
      0000
00B8R          HOLD    EQU    *-2
00BAR C890             LHI    9,HOLD2
      00BCR
00BCR          HOLD2   EQU    *-2
00BER 4300             B      *
      00BER
00C0R          RETRN   EQU    *-2
               *
00C2R          X1      DS     2
00C4R          Y1      DS     2
00C6R          X2      DS     2
00C8R          Y2      DS     2
               *

00CAR D000     PLOOP2  STM    12,SAV4
      0134R
00CER 4060             STH    6,SAV6+2
      0130R
00D2R 48A2             LH     10,CORNER(2)
      002ER
00D6R 4860             LH     6,PTMAX
      00A2R
00DAR 45A6             CLH    10,6(6)
      0006
00DER 4280             BL     KNOWN
      012AR
00E2R 4330             BE     KNOWN
      012AR
00E6R 40A0             STH    10,X
      00F8R
00EAR 26A2             AIS    10,2
00ECR 40A0             STH    10,Y
      00FAR
00F0R 41F0             BAL    15,PADD
      0000F
00F4R 0008             DC     8
```

```
00F6R 00D8R             DC      PTMAX
00F8R 0000      X       DC      0
00FAR 0000      Y       DC      0
00FCR 08AE              LHR     10,14
00FER 40E0              STH     14,VPN
      0150R
0102R 41F0              BAL     15,LADD
      0048R
0106R 000A              DC      10
0108R 00F6R             DC      PTMAX
010AR 0150R             DC      VPN
010CR 014ER             DC      ZERO
010ER 0156R             DC      LSIZE
0110R 48D2              LH      13,DATP(2)
      0022R
0114R 40D0              STH     13,PLACE
      0152R
0118R 41F0              BAL     15,PPFLDH
      005CR
011CR 000E              DC      14
011ER 0108R             DC      PTMAX
0120R 0150R             DC      VPN
0122R 014ER             DC      ZERO
0124R 0154R             DC      FIELD2
0126R 014CR             DC      FOUR
0128R 0152R             DC      PLACE
012AR D1C0      KNOWN   LM      12,SAV4
      0134R
012ER C860      SAV6    LHI     6,0
      0000
0132R 030F              BR      15

                *
0134R           SAV4    DS      6
013CR           DELTA1  DS      2
013ER           DELTA2  DS      2
0140R           DELT11  DS      2
0142R           DELT22  DS      2
0144R           FLINE   DS      2
0146R           FLINE2  DS      2
0148R 0000      HRATE   DC      0
014AR 000C      SIZE    DC      12
014CR 0004      FOUR    DC      4
014ER 0000      ZERO    DC      0
0150R 0001      VPN     DC      1
0152R 0000      PLACE   DC      0
0154R 0009      FIELD2  DC      9
0156R 000C      LSIZE   DC      12
0158R 0001      ONE     DC      1
015AR 0002      TWO     DC      2
015CR 0007      FIELD1  DC      7
015ER 0000      HOLDPT  DC      0
```

```
 0160R                    END

NO ERRORS

* CORNER  00D4R
* DATP    0112R
* DELT11  0140R
* DELT22  0142R
* DELTA1  013CR
* DELTA2  013ER
  FIELD1  015CR
  FIELD2  0154R
* FLINE   0144R
* FLINE2  0146R
  FOUR    014CR
  GETPT   0030R
* GPOINT  009ER
  HOLD    00B8R
  HOLD2   00BCR
  HOLDPT  015ER
  HRATE   0148R
  KNOWN   012AR
* LADD    0104R
* LINER   0000R
  LSIZE   0156R
  ONE     0158R
* PADD    00F2R
  PLACE   0152R
  PLOOP2  00CAR
* PPFLDF  011AR
* PRLOOP  0070R
* PTMAX   011ER
  RETRN   00C0R
  RETRY2  00B6R
  SAV4    0134R
  SAV6    012ER
  SIZE    014AR
  STORE   0000
  STORE6  0006
  TWO     015AR
  VPN     0150R
* WNWONE  00B4R
  X       00F8R
  X1      00C2R
  X2      00C6R
  Y       00FAR
  Y1      00C4R
  Y2      00C8R
  ZERO    014ER
```

****

```
004CR 4280          BL     NEXT          PT IS EXTREME I
      00EAR
0050R 4570          CLH    7,GREAT1      4B6>+DIFF>0192
      013ER
0054R 4280          BL     EXTREM
      0070R
0058R 4300          B      NEXT          ELSE LOOK AT NE
      00EAR
005CR 4570   LOWLM  CLH    7,SMALL       PT IS EXTREME I
      013CR
0060R 4380          BNL    NEXT          FE6E>-DIFF>FB40
      00EAR
0064R 4570          CLH    7,SMALL1
      0140R
0068R 4380          BNL    EXTREM
      0070R
006CR 4300          B      NEXT          ELSE LOOK AT NE
      00EAR
0070R 48B0   EXTREM LH     11,BSTORE
      0182R
0074R CBB0          SHI    11,2
      0002
0078R 4310          BNM    DTEST
      0084R
007CR CAB0          AHI    11,2
      0002
0080R 4300          B      GOES
      00B6R
0084R CAD0   DTEST  AHI    13,INCREM
      0006
0088R 48FD          LH     15,STORE(13)
      002AR
008CR 487D          LH     7,STORE2(13)
      0038R
0090R 4BFB          SH     15,STOREX(11)
      0154R
0094R 4B7B          SH     7,STOREY(11)
      0166R
0098R 0CEF          MHR    14,15
009AR 0C67          MHR    6,7
009CR CBD0          SHI    13,INCREM
      0006
00A0R CAB0          AHI    11,2
      0002
00A4R 0AF7          AHR    15,7
00A6R 0EE6          ACHR   14,6
00A8R 08EE          LHR    14,14
00AAR 4230          BNZ    GOES
      00B6R
00AER 45F0          CLH    15,MIN        SEE IF EXTREMES
      0138R
00B2R 4280          BL     NEXT
```

```
 00EAR

00B6R 4870      GOES    LH    7,DISKST
      0000F
00BAR CD70              SLHL  7,7
      0007
00BER 08FD              LHR   15,13
00C0R 4BF0              SH    15,OFFSET
      0000F
00C4R 067F              OHR   7,15
00C6R 407B              STH   7,INDEX(11)
      0142R
00CAR 48FD              LH    15,STORE(13)
      008AR
00CER 40FB              STH   15,STOREX(11)
      0154R
00D2R 48FD              LH    15,STORE2(13)
      008ER
00D6R 40FB              STH   15,STOREY(11)
      0166R
00DAR CAB0              AHI   11,2
      0002
00DER 40B0              STH   11,BSTORE
      0182R
00E2R 4050              STH   5,SLOP3
      0186R
00E6R 4300              B     INCR
      00F2R
00EAR 48F0      NEXT    LH    15,SLOP2
      0184R
00EER 40F0              STH   15,SLOP3
      0186R
00F2R 4050      INCR    STH   5,SLOP2
      0184R
00F6R           BACK    EQU   *
00F6R C850      SAV5    LHI   5,0
      0000
00FAR C860      SAV6    LHI   6,0
      0000
00FER C870      SAV7    LHI   7,0
      0000
0102R C8B0      SAV11   LHI   11,0
      0000
0106R C8D0      SAV13   LHI   13,0
      0000
010AR C8E0      SAV14   LHI   14,0
      0000
010ER 4300      SAV15   B     *
      010ER
```

```
0006            INCREM  EQU    6

0000R                   EXTRN  STORE,STORE2,ATANUR
0000R                   ENTRY  TFG
0000R                   ENTRY  EXTRMR
0000R                   ENTRY  BSTORE,SLOP2,SLOP3,GREAT,GREAT1
0000R                   ENTRY  SMALL,SMALL1,TAN1,STOREX,STOREY
0000R                   ENTRY  MIN,INDEX
0000R                   EXTRN  STORE,STORE2
0000R                   EXTRN  OFFSET,DISKST

                *
                * EXTRMR EXPECTS PTR TO CURRENT POINT IN R13
0000R 4050      EXTRMR  STH    5,SAV5+2
      00F8R
0004R 4060              STH    6,SAV6+2
      00FCR
0008R 4070              STH    7,SAV7+2
      0100R
000CR 40B0              STH    11,SAV11+2
      0104R
0010R 40D0              STH    13,SAV13+2
      0108R
0014R 40E0              STH    14,SAV14+2
      010CR
0018R 40F0              STH    15,SAV15+2
      0110R
001CR 485D              LH     5,STORE(13)       R5=X2
      0000F
0020R 486D              LH     6,STORE2(13)      R6=Y2
      0000F
0024R CBD0      GO      SHI    13,INCREM
      0006
0028R 487D              LH     7,STORE(13)
      001ER
002CR C570              CLHI   7,X'8000'
      8000
0030R 4330              BE     GO
      0024R
0034R 0B57              SHR    5,7               X2-X1
0036R 4B6D              SH     6,STORE2(13)      Y2-Y1
      0022R
003AR 41E0              BAL    14,TAN1           CALL ARCTAN SUB
      0112R
003ER 4870              LH     7,SLOP3
      0186R
0042R 0B75              SHR    7,5               BECAUSE RE=0 IN
0044R 4210              BM     LOWLM             -90<1ST SLOP<+9
      005CR
0048R 4570              CLH    7,GREAT           NOT STORED AS 1
      013AR
```

```
0112R 4050     TAN1     STH    5,DX
      017AR
0116R 4060              STH    6,DY
      0178R
011AR 41F0              BAL    15,ATANUR          CALL FLOATING P
      0000F
011ER 0178R             DC     A(DY),A(DX),A(RESULT)
      017AR
      017CR
0124R 4850              LH     5,RESULT           TO EXPRESS FLOA
      017CR
0128R CF50              SLHA   5,8                IN ONE HALF WOR
      0008
012CR 4860              LH     6,FRACTN
      017ER
0130R CE60              SRHA   6,7                SO THAT THE 3RD
      0007
0134R 0A56              AHR    5,6                IS 1ST SIGNIFIC
0136R 030E              BR     14
0138R 0211     MIN      DC     X'211'
013AR 0192     GREAT    DC     X'0192'            PI/2 OR 90 DEGR
013CR FE6E     SMALL    DC     X'FE6E'            -PI/2 OR -90 DE
013ER 04B6     GREAT1   DC     X'04B6'            3PI/2 OR 270 DE
0140R FB40     SMALL1   DC     X'FB40'            -3PI/2 OR -270
0142R          INDEX    DS     18
0154R          STOREX   DS     18
0166R          STOREY   DS     18
0178R          DY       DS     2
017AR          DX       DS     2
017CR          RESULT   DS     2
017ER          FRACTN   DS     2
0180R          TAG      DS     2
0182R          BSTORE   DS     2
0184R          SLOP2    DS     2
0186R          SLOP3    DS     2
0188R                   END

NO ERRORS

* ATANUR   011CR
  BACK     00F6R
* BSTORE   0182R
* DISKST   00B8R
  DTEST    0084R
  DX       017AR
  DY       0178R
  EXTREM   0070R
* EXTRMR   0000R
  FRACTN   017ER
  GO       0024R
  GOES     00B6R
* GREAT    013AR
* GREAT1   013ER
```

```
  INCR    00F2R
  INCREM  0006
* INDEX   0142R
  LOWLM   005CR
* MIN     0138R
  NEXT    00EAR
* OFFSET  00C2R
  RESULT  017CR
  SAV11   0102R
  SAV13   0106R
  SAV14   010AR
  SAV15   010ER
  SAV5    00F6R
  SAV6    00FAR
  SAV7    00FER
* SLOP2   0184R
* SLOP3   0186R
* SMALL   013CR
* SMALL1  0140R
* STORE   00CCR
* STORE2  00D4R
* STOREX  0154R
* STOREY  0166R
* TAG     0180R
* TAN1    0112R

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