WINDOW: A FORMALLY-SPECIFIED GRAPHICS-BASED TEXT EDITOR

Douglas Gerhardt and D. L. Parnas

Computer Science Department

Carnegie-Mellon University

June, 1973

This work was supported by the National Science Foundation under Grant GJ 30127 and Grant GJ 37728 to Carnegie-Mellon University and also by the Advanced Research Projects Agency of the Office of the Secretary of Defense (F44620-70-C-0107), monitored by the Air Force Office of Scientific Research.

PREFACE

WINDOW is a formally-specified text editing program which exploits the graphics capabilities of crt terminals [1]. Terminal screens are divided into several "windows". Each window displays text from any of a number of simultaneously open files. Through the notion of linked "pointers", operations upon one file may invoke corresponding operations upon other files.

D. L. Parnas designed and produced the formal specification for its kernel editing system. Douglas Oerhardt implemented the kernel according to the specification and developed a command interpreter.

This paper has three main sections covering the interface and structure of the kernel, the relationship between the kernel and the command interpreter, and our experiences with this application of formal specification.

Drafts of this paper were edited using the implementation of WINDOW described in [1].

1. Gerhardt, D. L., "WINDOW: User's Manual," June, 1973. Available from the Carnegie-Mellon University Computer Science Department as "DSKB: WINDOW.MAN [C331DG15]/A."

INTRODUCTION

INTERFACE SPECIFICATION

A technique [2] has been described for specifying the interface between parts of software systems. In this paper, we have applied the same technique to the format specification of a man-machine interface [31

At first glance, such a specification appears to be a program written In a high-order language. It is not. A program describes a process by listing a sequence of actions to be performed by a lower level machine. A specification does not admit the existense of such a machine. All of the functions mentioned in a formal specification are available to the user. They are described, not be giving their implementations, but by enumerating their effects upon each other. The result is a "black box" description.

2. Parnas, D. L, "A Technique lor Software Module Specification with Examples," May, 1972 COMMUNICATIONS QF THE ACM {Programming Techniques Department).

3 Parnas, D. L., "Sample Man Machine Interface Specification A Graphics Based Line Editor" in DISPLAY USE FOR MAN-MACHINE DIALOG (W. Handler, J. Weizenbaum, eds.), published fay Carl Hanser Verlag Munchen, 1972.

Interface Specification

The black box description in this paper suggests a simple implementation because we abstract files as arrays, an unworkable implementation for most real situations. The actual implementation is more complex but the details of it are hidden. They are not necessary for making good use of the system.

The formal specification is inherently complete. As with most formal structures, however, a human being needs a description of the intended interpretation of the structure in order to comprehend it. Such commentary is not a part of the specification, nor is it complete.

GRAPHICS-BASED TEXT EDITOR

Text editing often involves creating or modifying one file on the basis of information contained in other files. As a great deal of time and effort is spent shifting physical focus among the files, we realized that our work would be assisted by an editing program which would allow us to look at several files on one screen. We wanted the ability to divide the screen into "windows", each capable of displaying a section from any of a number of files. The division into windows and the assignment of windows to file sections would not be fixed. An additional useful property would be to have the center line of each window move through a file as our attention moved so that the line of interest could always be found at a fixed point in the display. The ability to link pointers to several files would enable a change in one pointer to invoke a corresponding change in all pointers linked to it. The WINDOW kernel described in Section One encompasses the above features.

An understanding of WINDOW must begin with the notion of "painters". Every pointer is a triple consisting of a file number, a line number relative to the beginning of the file, and a character position relative to the beginning of a line. All editing is performed on characters indicated by a pointer. The first action taken after opening a file is the definition of a pointer through which the file may be accessed. A particular pointer may be declared the "current pointer" so that it is not always necessary to name **a** specific pointer in the various editing functions of the kernel.

The text displayed through **a** window is determined by a pointer which is associated with that window when the window is defined; this pointer must be one which has previously been defined upon a file. Thus **a** window might be said to display a single character. However, surrounding text, always at least one line, is also displayed. The number of lines displayed (the width of a window) is specified when the window is defined.

Any change to a pointer is reflected through the text displayed in all windows associated with that pointer. Thus il the line-part af a pointer is repeatedly incremented so that it points to successive lines in its file, the text displayed will likewise appear to move in a scroll-like fashion as the center line of each window shows those successive lines.

SECTION ONE

INTERFACE AND STRUCTURE OF THE KERNEL

The structure of the kernel system is a three-level hierarchy consisting of a file subsystem, a graphics subsystem, and an editing subsystem, respectively. The interface presented by each level is composed of function references which either indicate a state of the kernel system or effect a change in that state.

The following is a commentary on the specification of the kernel. Functions are provided here with informal parameter lists. Implicit parameters are enclosed within square brackets. Explicit parameters are enclosed within parentheses. The formal specification is located in Appendix One.

FILE SYSTEM

Indicators	Effectors
UFIEX (file f) - true iff its parameter is the identifier of an open file	FILIN (file f) makes UFIEX - true FILOUT (file f) makes UFIEX = false
ULIEX (file fj line 1) - true iff its parameter is the identifier of an existing line in an open file	INSLIN ["current pointer"] makes FLWES«-FLINES+1 DELINE ["current pointer"] makes FLINES.-FLINES-1
FLINES (file f) - number of lines in an open file	
UMAXCH (file f; line I) = number of characters in an existing line in an open file	IN5ACHAR (painter p; character z) makes UMAXCH«-UMAXCH+1 UFS at end of line «- *z* DELACHAR (pointer p) makes UMAXCH.-UMAXCH-1 delete from end of line
UFS (file f; line I; position c) = character in an existing line in an open file	ALTCHAR (pointer p; character **2)** alters UFS

Note: Functions INSLIN, DELINE, INSACHAR, DELACHAR, and ALTCHAR may affect SCREEN. Functions INSLIN and DELINE may also affect SRCLIN.

GRAPHICS SYSTEM

Indicators	Effectors
WINEXISTS (window w) « true iff its parameter is the identifier of an existing window	DEFWIND (window w; pointer p; screenline xl, x2) makes WINEXISTS - true DELWIND (window w) makes WINEXISTS false
TWIND (window w) • identifier of bottom line of existing window	
BWIND (window w) = identifier of top line of existing window	
SRCFIL (screenline x) = identifier of file associated with line on screen	
SRCLIN (screenline x) « identifier of line associated with line on screen	
WINPOINT (window w) = identifier of pointer associated with an existing window	
SCREEN (screenline x; position c) - physical display	

Note: Functions DEFWIND and DELWIND affect SCREEN.

EDITING SYSTEM

Indicators	Effectors
PILE (pointer p) = identifier of open file associated with an existing pointer	REDEFAPOINT ["current pointer"] (file f; line I; position c) moves painter to a particular file, line, character
LINE (pointer p) - identilier of existing line associated with an existing pointer	MOVPNT ["current pointer"] (line I; position c) moves pointer to a particular line and character
	INCPOINT ["current pointer"] (displacement i) moves pointer to a line relative to current line
	NEKTLINE ["current pointer"] moves pointer ahead one line
	PREVLINE ["current painter"] moves pointer back one line
CHAR (pointer p) = character position associated with existing pointer	NEXTCHAR (painter p) makes CHAR<-CHAR+1
	BACKCHAR (pointer p) makes CHAR<-CHAR-1

Note: Functions REDEFAPOINT, MOVPNT, INCPOINT, NEXTLINE, and PREVLINE may affect SRCFIL, SRCLIN, and SCREEN.

ISAPOINT (pointer p)

= true iff its parameter is the identifier of an existing pointer

DEFPOINT (pointer p; file f; line I; position c)
makes ISAPOINT - true
DELPOINT (pointer p)
makes ISAPOINT - false

LINKED (pointer pi, p2)
• true iff its parameters are linked existing pointers

LINK (pointer pi, p2)
makes LINKED • true
UNLINK (pointer pi, p2)
makes LINKED « false

OPENED ["current pointer"]

true iff a "current pointer" is declared

OPENIT (pointer p)
makes CURPNT<-p
makes OPENED « true
UNOPEN
makes OPENED - false

CURPNT * identifier of "current pointer" iff OPENED * true

ISLNKD ["current pointer"]
* true iff the "current pointer's" file is linked through painters to itself or any other file(s)

Note: Function DELPOINT may affect WINEXISTS.

SECTION TWO

RELATIONSHIP BETWEEN THE KERNEL AND THE COMMAND INTERPRETER

The relationship between the kernel and the command interpreter is that of a two-level hierarchy with the kernel on the lower level. Note that all of the kernel functions could be accessed directly by the user, as specified. They would comprise a comprehensive graphics-based text editor. However, this direct-access implementation would prove too tedious and too complex for any person to use effectively. The command interpreter instead plays the role of the user of the kernel and in turn provides its own set of editing functions to the next-higher-level user; in the current implementation, that user is assumed to be, but is not limited to being, a person. This new set of functions is transparent in the sense that no valuable editing capabilities have been lost fay performing the abstraction. It is also more "useful" in the sense that the user is now provided with what appears to be a "conventional" text editing program — with unconventional graphics capabilities.

The tallowing examples illustrate the abstraction:

* The kernel refers to files by integer numbers. The command interpreter can deal with file numbers; it can also deal with user-defined file names. It maps names to numbers and vice versa while communicating between the user and the kernel.

* Many functions of the command interpreter map directly onto single kernel functions. The command "DFP 2 1" causes a reference of the kernel function "DEFPOINT(pointer 2; file 1; line 1; position l)". If the user defines the name "MYFILE" equivalent to file number 1, then the command "DFP 2 *MYF1LE" results In exactly the same reference of the kernel function.

* Other commands result in a programmed sequence of kernel function references. The command "I" enables the user to insert line after line of text into a file without the need for any intervening commands. This is similar in observable effect to insertions using conventional text editors. For every line of text entered, the kernel function "INSLIN" is referenced, followed by as many "NEXTCHAR" and "INSACHAR" references-as there are characters in the line of text.

The usefulness of the WINDOW kernel is not limited to this one application; it may be considered the basis for a **family** of text editors. The behavior of a member of the family would be dependent upon its abstraction of the kernel's facilities.

SECTION THREE

OUR EXPERIENCE WITH THIS APPLICATION OF FORMAL SPECIFICATION

The formal specification of the WINDOW kernel was produced long before its implementation. During the process of implementing the kernel according to its specification, many system design changes were made.

In particular, the original specification called for the "PREVLINE" and "NEXTLINE" functions to take a painter as an explicit parameter. We decided to eliminate that parameter and to implicitly use the "current pointer" instead. The role of the "current pointer" was similarly expanded throughout the kernel. Thus, textual revisions to the formal specification were made in parallel with program development when those changes involved the semantics of the specification.

The original specification was found to be incomplete with respect to the **exiBtense** of some state-indicating functions without any complementary state-effecting functions. That was the case for the "CURPNT" and "OPENED" functions. "OPENIT" and "UNOPEN" were added during implementation.

Many other functions have come and gone in the process of fine-tuning the kernel. For example, the "ISLNKD" function was added after the kernel implementation was complete. It reduced the notational complexity of the specification, reduced the size of the kernel source and object programs, and reduced the execution-times of many kernel and command interpreter functions. When the kernel had formerly relied upon a sequence of function calls to determine file linkages through painters, repeated tests were redundant because no memory existed between function interfaces of previous calls. In the current implementation, one test is performed in "LINK" and one in "UNLINK"; the result is simply recorded within "ISLNKD" for future reference.

The decomposition indicated by the formal specification proved an excellent basis for a statistical analysis of performance. The execution times and frequency counts of every function can be gathered, and in tabulated form point directly to areas of inefficiency. Statistics prompted, for example, the inclusion of the "FLINES" function after implementation was complete.

The formal specification served as the source of information in the production of the commentary of Section One. The specification was also used during implementation of the command interpreter as the definitive statement of the effects of referencing specific kernel functions.

The formal specification can be the basis for proving assertions about properties of the kernel. On an informal basis alone, simple properties, such as the assertion that the UNLINK function can not be driven to dissociate a pointer from itself, can be proven readily from the observation that the formal specification indicates an error trap within that function <"ERR0R(25)[8]) for that special case (V<f).

In conclusion, had the formal interface specification not existed, the interface between the kernel and the command interpreter would have been less rigorously defined. Their individual responsibilities, intended to be disjoint, would have overlapped, resulting in a more difficult program development. Furthermore, the kernel would have lost much of its value as the basis for a family of text editing programs. The existense of shared responsibilities, leading to shared knowledge of their implementations, would have demanded of all other potential command interpreters that they too share the same responsibilities and knowledge. That would have greatly restricted the classes of programs which could belong to the family.

APPENDIX ONE

FORMAL SPECIFICATION

Let DISP(p,i)- if defined then 'ULIEX't 'FILE'(p), 'LINE'(p)+i)
else undefined

Function UFIEX
possible values: (boolean) true, false
initial value: false
parameters: integer f
effect:

call ERROR(BB) if [f < 8 .or. f > pi]

Function ULIEX
possible values: (boolean) if 'FUNES\f)>-l then true else false
initial value: false
parameters: integer f, I
effect:

call ERROR(BB) if [f < B .or. f > pi]
call ERROR(IG) if ['UFIEX'(f) - false]
call ERROR(Bl) if [1 < 1 .or. I > p2]

Function UMAXCH
possible values: integer B:p3
initial value: undefined
parameters: integer f, 1
effect:

call ERROR(BB) if [f < B .or. f > pi]
call ERR0R(16) if ['UFIEX'(f) = false]
call ERROR(Bl) if [I < 1 .or. I > p2]
call ERR0R(17) if ['ULIEX'(f,l) - false]

Function UFS
possible values: integer 8:127
initial value: undefined
parameters: integer f, I, c
effect:

call ERROR(BB) if [f < 8 .or. f > pi]
call ERROR(IB) if ['UFIEX'(f) = false]
call ERROR(Bl) if [I < 1 .or. I > p2]
call ERR0RU7) if ['ULIEX'(f,l) = false]
• call ERR0R(82) if [c < 1 .or. c> p3]
call ERR0R(85) if [c> 'UMAXCH'(f,l)]

WINDOW
Formal Specification

Function ISAPOINT
possible values: (boolean) true, false
initial value: false
parameters: integer p
effect:

call ERR0R(B3) if [p < 1 .or. p > p6]

Function FILE
possible values: integer B:pl
initial value: undefined
parameters: integer p
effect:

call ERRQR(83) if [p < 1 .or. p > p6]
call ERR0RU5) if [**'ISAPOINT**<p) « false]

Function LINE
possible values: l:p2
initial value: undefined
parameters: integer p
effect:

call ERR0R(83) if [p < 1 .or. p > pB]
call ERR0R(15) if [**'ISAPQINr**(p) - false]

Function CHAR
passible values: 8:p3
initial value: undefined
parameters: integer p
effect:

call ERROR(B3) if [p < 1 .or. p > pB]
call ERR0R(15) if [**'ISAPOINr**(p) « false]

Function **LINKED**
possible values: (boolean) true, false
initial value: false
parameters: integer p, q
effect:

call ERR0Pt(83) if [p < 1 .or. p > pS]
call ERR0R(84) if [q < 1 .or. q > p6]
call ERR0R(15) if [**'ISAPOINT**'(p) = false]
call ERR0R(15) if [**'ISAPOINr**(q) = false]

Function DEFPOINT
possible values: none
initial value: not applicable
parameters: integer p, f, I, c
effect:

call ERR0R(B3) if [p < 1 .or. p > pB]
callERR0R(14) if ['lSAPOINT(p) = true]
call ERROR(BB) if [f < B .or. f > pi]
call ERROR(Bl) if [1 < 1 .or. I > p2 1
call ERRQR(82) if [c < 1 .or. c> p3]
call ERR0R(16) if ['UFIEX'(f) - false]
call ERR0R(17) if ['ULIEX*(f, 1) = false]
call ERR0R(B5) if [c > 'UMAXCH'(f, 1)]
ISAPOINT(p)= true
FILE(p) = f
LINE(p) - 1
CHAR(p) = c
LINKED<p, p)= true

```
Function DELPOINT
possible values: none
initial value: not applicable
parameters: integer p
effect:

  call ERR0R(83) if [ p < 1 .or. p > p6 ]
  call ERR0R(15) if [ 'ISAPQINT'(p) « false ]
  ISAPOINT<p)= false
  FILE(p) - undefined
  LINE(p) = undefined
  CHAR(p) = undefined
  for all q [ LINKED(p, q) - LINKED(q, p) = false ]
  for all w [if 'WINEXISTS'(w).and.'WINPOINT'(w)=p then DELWIND(w)]
  if [ 'CURPNT' - p .and. 'OPENED' - true ] then UNOPEN
```

```
Function LINK
possible values: none
initial value: not applicable
parameters: integer p, q
effect:

  call ERR0R(83) if [ p < 1 .or. p > p6 ]
  call ERR0R(B4> if [ q < 1 .or. q > pB ]
  call ERROR(IS) if [ 'ISAPOINT'(p) « false ]
  call ERR0R(15) if [ 'ISAPOINT'(q) « false ]
  call ERR0R(41) if [ 'LINKED'(p, q) - true ]
  call ERR0R(87) if [ 'LINKED'(q, p) = true ]
  LINKED(p, q)« true
  LINKED(qy p)= true
  for 'FILE'(p) and 'FILE'(q) [ ISLNKD - true ]
```

```
Function UNLINK
possible values: none
initial   value: not applicable
parameters: integer p, q
effect:

  call ERR0R(B3) if [ p < 1  .or.  p > pG ]
  call ERR0R(84> if [ q < 1  .or.  q > p6 ]
  call ERR0R(15) if [ 'ISAPOINT'(p) - false ]
  call £RR0R{15) if [ 'iSAPOlNT'(q) - false }
  call ERROR(12) if [ 'LINKED'(p, q) = false ]
  call ERR0R(13) if [ 'LINKED'(q, p) = false ]
  call ERR0R(25) if [ p = q ]
  LINKED{q, p)= false
  LINKED<p, q)= false
  for all f such that ('UFIEK'(f) = true)
    [ if there exists any qq such that
          <'ISAPOINT'<qq) « true .and. 'FILE'{qq) - f)
      and
         there exists any pp such that
           ('ISAPOINT'(pp) - true .and. 'FILE'(pp) - f)
      and
         ((pp .neq. p) .and. (pp .neq. q))
      and
         ((qq .neq. p) .and. (qq .neq. q))
      and
         ((pp .neq. qq) .and. <'LINKED'(pp,qq> - true))
      then
           ISLNKD - true for f
      else
           ISLNKD = false far f ]

Function WIN EXISTS
possible values: (boolean) true, false
initial   values: false
parameters: integer w
effect:

  call ERR0R(89) if [ w < 1  .or.  w > p4 div 2 ]
```

```
Function TWIND
possible values: l:p4
initial   value: undefined
parameters: integer w
effect:

  call ERR0R<B9) if [ w < 1  .or.  w > p4 div 2 ]
  call ERROR(ll) if [ 'WINEXISTS'(w) - false ]


Function BWIND
passible values: l:p4
initial   value: undefined
parameters: integer w
effect:

  call ERHOR(09) if [ w < 1  .or.  w > p4 div 2 ]
  call ERROR(ll) if [ 'WINEXISTS'(w) . false ]


Function SRCFIL
possible values: 8;pi
initial   value: undefined
parameters: integer r
effect:

  call ERR0R(B8) if [ r < 1  .or.  r > p4 ]


Function SRCUN
possible values: l:p2
initial   value: undefined
parameters: integer r
effect:

  call ERROR(BB) if [ r < 1  .or.  r > p4 ]
```

```
Function WINPOINT
possible values: l:p6
initial    value: undefined
parameters: integer w
effect:

  call ERR0R<89) if [ w < 1  .or.  w > p4 div 2 ]
  call ERROR(ll) if [ 'WINEXISTS'(w) - false ]



Function DELW1ND
possible values: none
initial    value: not applicable
parameters: integer w
effect:

  call ERR0R(B9) if [ w < 1  .or.  w > p4 div 2 ]
  call ERROR(ll) if [ 'WINEXISTS'(w) - false ]
  for all r such that { 'BWIND'(w) <- r <- TWIND'(w) )
      [ SRCFIL(r) = undefined
        SRCLIN(r) = undefined
        for all c such that (1 <= c <= p5) SCREEN(r^)-" "]
  TWIND(w) = undefined
  BWIND(w) ~ undefined
  WINPOINT(w)= undefined
  WINEXISTS(w)- false
```

```
Function DEFWIND
passible values: none
initial   value: not applicable
parameters: integer w, p, bw, tw
effect:

  call ERR0R(89) if [ w < 1  .or.  w > p4 div 2 ]
  call ERR0RU9) if [ 'WINEXISTS'(w) - true ]
  call ERR0R(21) if [ tw < 1  .or.  tw > p4 ]
  call ERR0R(22) if [ bw < 1  .or.  bw > p4 ]
  call ERR0R{23) if [ bw >- tw - 1 ]
  call ERR0R<43.or.44) if [exists j such 'WINEXISTS'<j)«true.and.
      [ 'BWIND'(i) <- bw < 'TWIND'(j) .or.
        'BWIND'(i) < tw <- TWIND'(j)] ]
  call ERR0R(B3) if [ p < 1  .or.  p > pB ]
  call ERR0RO5) if [ 'ISAP0INT'<p> = false 1
  TWIND(w) - tw
  BWIND(w) = bw
  WINEXISTS(w)= true
  WINP0INT(w)= p
  SRCFIL(bw) - SRCFIL(tw) - 'FILE'tp)
  SRCLIN(bw) = SRCLIN(tw) = undefined
  let m= entier« tw + bw ) / 2)
  fqr all r such that ( bw < r < tw )
        [ SRCFIL(r)= 'FILE'<p)
          SRCLIN(r)= 'DISP^p, r-m)
          for all c such that (1 <• c <= pS)
             SCREEN(r,c)~ 'UFS'<SRCFIL(r),SRCLIN(r),c)
                if defined else " "]


Function NEXTCHAR
possible values: none
initial   value: not applicable
parameters: p
effect:

  call ERR0R(83) if [ p < 1  .or.  p > p6 ]
  call ERR0RO5) if [ 'ISAPOINT'(p) - false ]
  call ERR0R(24> if [ 'CHAR'<p) - p3 ]
  GHAR(p) - 'CHAR'(p) + 1
```

```
Function BACKCHAR
possible values: none
initial    value: not applicable
parameters: p
effect:

  call ERR0R(B3) if [ p < 1  .or.  p > p6 ]
  call ERR0R(1S> if [ 'ISAPOINT'<p) - false ]
  call ERR0R(38) if [ 'CHAR'(p) - 1 ]
  CHAR(p)= >CHAR'(p) - 1



Function INCPOINT
possible values: none
initial    value: not applicable
parameters: integer i
effect:

  call ERROR(IB) if [ 'OPENED' « false ]
  let p = 'CURPNT'
  call ERR0R(27) if [ 'DISP'(p.i) - undefined ]
  call ERR0R(28) if [ 'ISLNKDMrue.and.for any q.neq.p such that
                ( 'LINKED'<p,q) = true)
      [ 'DISP'(q,i) = undefined ]
  for all q such that ( 'HNMED'(p,q) « true )
      [ UNE(q)= 'DISP'(q,i)
      for all w such that ('WINEXISTS'(W)=true.and.'WINPOINr(w>-q)
            [ let m= entier(( 'TWIND'(w) + 'BWIND'(w)) / 2)
              for all r such that { 'BWIND'(w) < r < TWlND'(w))
                    [ SRCLIN(r)= DISP(q, r-m)
                      for all c such that (1 <» c <« pS)
                         SCREEN(r,c)« 'UFS'CSRCFIL'(r),
                                        SRCLIN(r),c)
                           if defined else " "]]]
```

Function OPENIT
possible values: none
initial value: not applicable
parameters: integer p
effect:

call ERR0R<83) if [p < 1 .or. p > p6]
call ERPtOR<15> if ['ISAPOINT'(p) - false]
call ERR0R(29) if ['OPENED' - true]
OPENED" true
CURPNT-p

Function UNOPEN
possible values: none
initial value: not applicable
parameters: none
effect:

call ERRQR(IB) if ['OPENED' - false]
OPENED - false
CURPNT- undefined

Function OPENED
possible values: (boolean) true, false
initial value: false
parameters: none
effect:

```
Function FILIN
possible values: none
initial   value: not applicable
parameters: integer f
effect:

  call ERROR(BB) if [ f < 6  .or. f > pi ]
  call ERR0R(42) if [ 'UFIEX'(f) - true ]
  UFIEX(f) - true



Function FILOUT
passible values: none
initial   value: not applicable
parameters: integer f
effect:

  call ERROR(BB) if [ f < B  .or. f > pi ]
  call ERR0R(16) if [ 'UFIEX'(f) - false ]
  call ERR0R{28) if [ for any p such that  'FILE'(p)
  UFIEK(f)=  false
  for all I
      [ ULIEX(f,l) = false
        UMAXCH(f,l) = undefined
        for all c [ UFS(f,l,c) - undefined ] ]
```

```
Function DELINE
passible values: none
initial   value: not applicable
parameters: none
effect:

  call ERROR(IB) if [ 'OPENED' = false ]
  let p - 'CUHPNT'
  call ERR0Pt<17) if [ 'ULlEXTFILE'(p), 2) - false ]
  call ERR0RO7) if [ 'ISLNKD' = true .and. for any q .neq. p
                     such that <'LINKED'(p,q) - true)
                       [ miEXTFILE'ta), 2) - false ] ]
  for all q such that <'LINKED'<p,q> = true)
    [ FLINESCFILE'(p)) - 'FLINES'fFlLE'(p)) - 1
    for all w such that CWINEXISTS'{W)*true.and.'WINP0INT(w)-q)
        [ let m - entier«'TWIND'(w) + 'BWIND'(w)) / 2)
          for all r such that <'BWIND'(w) < r < 'TWIND'(w))
              [ SRCLIN(r)» DISP(q, r-m)
                for alt c such that (1 <- c <- p5)
                   SCREEN(r,c)- 'UFS'('SRGFIL'(r),
                                  SRCLIN(r),c)
                       if defined else " " ] ] ]
```

```
Function CURPNT
passible values: l:p6
initial   value: undefined
parameters: none
effect:
```

```
Function MOVPNT
possible values: none
initial    value: not applicable
parameters: integer 1, c
effect:

  let p = 'CURPNT'
  call ERRORflB) if [ 'OPENED' - false ]
  call ERROR(01) if [ I < 1  .or.  1 > p2 ]
  call ERR0R07) if [ 'ULIEX'('FILir<p), 1) - false ]
  call ERR0R(35) if [ c < 1 .or. c > 'UMAXCH'<'FILE'(pM)+l]
  call ERR0R<32) if ['ISLNKDMrue.and.for any q.heq.p such that
                    <'LINKED'(p,q) - true)
      [ 'ULIEX'('FILE'(q),l) = false ]]
  call ERR0R(33) if ['ISLNKDMrue.and.for any q.ncq.p such that
                    ('LINKED'(p,q) - true )
      [ c > 'UMAXCH'('FILE'(q),l) + 1 ]]
  if 'ISLNKD' = true then for all q .neq. p such that
                        ('LINKED'(p,q) - true)
      [ LINE(q)= I
        CHAR(q)- c ]
  LINE(p)=l
  CHAR(p)= c
  for all q such that < 'LINKED'<p,q) - true )
      [for all w such that ('WINEXISTS'(w)-true.and.'WINPOINT'(w)-q)
           [ let m = entter«'TWIND'(w) + 'BWINir(w)) / 2)
             for all r such that ('BWIND'(w) < r < TWIND'(w))
                  [ SRCLIN(r)= DISP(q, r-m)
                    for all c such that (1 <•= c <- p5)
                         SCREEN(r,c)= 'UFS'('SRCFIL'(r),
                                        SRCLIN(r),c)
                           if defined else " " ]]]
```

Function REDEFAPOINT
possible values; none
initial value: not applicable
parameters: integer f, I, c
effect:

```
call ERROR(IB) if [ 'OPENED' - false ]
call ERR0R{36) if [ 'ISLNKD' = true .and. exists q such that
                  ( 'LINKED'<'CURPNT',q> - true )]
call ERR0R<88) if [ f < 8  .or. f > pi ]
call ERR0R<81) if [ l< 1  .or.  I > p2 1
call ERR0R<82) if [ c < 1  .or.  c> p3 )
call ERR0R{16) if [ 'UFIEX'(f) - false ]
call ERR0RU7) if [ 'ULIEX'(f,l> = false ]
call ERR0R(85) if [ c > 'UMAXCH'(f,l) ]
LINE(*CURPNT')= I
CHAR('CURPNT> c
FILE<'CURPNT)= f
for all w such that {'WlNEXISTS(w).and.'WINPOINT'<w)-'CURPNr)
    [ let m - entier«'TWIND'<w) + 'BWINir(w)) / 2 )
      for all r such that ('BWIND'(w) < r < TWIND'(w))
            [ SRCFIL(r)- 'FILE'CCURPND
              SRCLIN(r)= DISPCCURPNT', r-m)
              for all c such that (1 <- c <- p5)
                   SCREEN(r,c)- 'UFS'(SRCFIL(r),
                                      SRCLIN{r),c)
                      if defined else " " ]]
```

Function NEXTLINE
possible values: none
initial value: not applicable
parameters: none
effect:

```
call ERROR(IB) if [ 'OPENED' - false ]
call ERR0R<45) if [ for all * such that
                    ( 'UNKEDTCURPNT\q) - true )
                    [ there does not exist 1 such that
                         (I > 'LINE'(q) -and.
                          'ULIEX'CFILE'tqU) - true)]]
lor all q such that ('LINKED'<'CURPNT',q) - true >
    [ LINE(q) = 'LINE'(q) + 1
      CHAR<q> » 1 ]
for all q such that ('LINKED'CCURPNT'.q) - true)
    [ for all w such that <'WINEXISTS'(w).and.'WINPOINT'<w)-q)
        [ let m = entier«'TWlND'(w) + 'BWIND'<w» / 2)
          for all r such that fBWIND'(w) < r < 'TWlNIT{w.))
              [ SRCLIN(r)= DISP(q, r-nt)
                for all c such that <1 <- c <- p5)
                    5CREEN(r,c)= 'UFS'CSRCFIL'(r),
                                 'SRCLttf(r),c)
                        if defined else " " ]]]
```

```
Function PREVLINE
possible values: none
initial   value: not applicable
parameters: none
effect:

  call ERROR(IB) if [ 'OPENED* - false ]
  call ERR0R<45) if [ for all q such that
                    < 'LINKED'(*CURPNT',q) - true )
                    [ there does not exist I such that
                         ( I < 'LINE'(q) .and.
                           'ULIEX'CFILE'(q),l) - true )]]
  for all q such that ('LINKED*('CURPNT\q) - true )
      [ LINE(q)= 'LINE'(q) - 1
        CHAR(q)= 1]
  for all q such that ('LINKED'('CURPNT',q) - true)
      [ for all w such that CWINEXISTS'(w).and.'WlNPOINT<w)-q)
            [ let m= entier(('TWIND'(w) + 'BWIND'(w)) / 2)
              for all r such that <*BWIND'<w) < r < TWlNIT(w))
                    [ SRCLIN(r)= DISP(q, r-m)
                       for all c such that (1 <= c <= p5)
                            SCREEN(r,c)- 'UFS'CSRCFIL'(r),
                                         SRCLIN(r),c)
                            if defined else " " ]]]


Function ALTCHAR
possible values: none
initial   value: not applicable
parameters: integer p, z
effect:

  call ERR0R(B3) if [ p < 1  .or.  p > pB ]
  call ERR0RU5) if [ 'ISAPOINT'(p) - false ]
  call ERR0R<34) if [ z < 8  .or.  z > 127 ]
  call ERROR(BG) if [ 'CHAR'(p) - 8 ]
  UFS<'FILE'{p),'LINE'{p),'CHAR'(p))=
  for all q such that <(q .neq. p) .and. 'LlNKED'(p,q))
     [ for all w such that ('WINEXISTS'(w) .and. 'WINPOINT'(w)-q)
          [ if {('SRCLIN'CBWINDXwJ+l) if defined else 8) <-
               'LINE'(q) <=
               'SRCLIN'CTWIND'(w)-l))
            then SCREEN(entier(('TWIND'{w)+'BWINIT(w))/2),
                      'CHAR'(q)>= z]]
```

```
Function DELACHAR
possible values: none
initial    value: not applicable
parameters: integer p
effect:

  call ERR0R<83) if [ p < 1  .or.  n > pB ]
  call ERROROS) if [ 'ISAPOINT'Cp) = false ]
  call  ERR0R<19>  if  [  'CHAR'<p).neq.'UMAXCHrFILE'(p),*UNir<p>>]
  call  ERR0R(19> if [ 'CHAR'(p) - 0 ]
  UFS('FILE'(p),'LINE'(p>,'CHAR'<p))-  undefined
  UMAXCH<'FILE'(p),'LINE'(p»=
               'UMAXCH('FILE'<p),'LINE'(p)) - 1
  for all q such that «q .neq. p) .and. 'LINKED'(p,q))
     [ for all w such that <'WINEXISTS'(w) .and. 'WINP0IN*r<w)-q)
          [ if <('SRCLIN'('BWIND'(w)+l) if defined else 8) <-
               'LINE'(q)<-
               'SRCLIN'CTWIND'tw)-!))
            then  SCREEN(entier«'TWIND'(w)+'BWIND'<w))/2),
                       'CHAR'<q))» » "]]


Function IN5LIN
possible values: none
initial    value: not applicable
parameters: none
effect:

  let p = TJURPNT*
  call ERROR(IB) if [ 'OPENED' = false ]
  call ERR0R(17) if [ for any q such that ('UNXED'<p,q)-true)
    'FLINES'CFILE'(p)) = p2 ]
  for all q such that ('LINKED'(p,q) = true)
    [ LINE<q)= 'UNE'(q) + 1
       UMAXCH('FILE'(q),'LINE'(q)) = 8
       FLINES('FILE'(q)) - 'FLINES'CFILE'tq)) + 1 ]
  for alt w such that ('WINEXISTS'(w) - true)
      [ let q- 'WINPOINT'(w)
        let m= entier<('TWIND'(w) + 'BWIND'Cw)) / 2)
        for all r such that ('BWIND'(w) < r < TWIND'(w))
               [ SRCLIN(r)-= DISP<q, r-m)
                 for all c such that (1 <= c <= p5)
                     SCREEN(r,c)- 'UFS'CSRCPIL'tr),
                                    SRCLIN(r),c)
                   if defined else " "]]
```

Function ISLNKD
possible values: (boolean) true, false
initial value: false
parameters: none
effect:

```
call ERPiOR(lB) if [ 'OPENED' - false ]
```

Function INSACHAR
possible values: none
initial value: not applicable
parameters: integer p%
effect:

```
call ERR0R{63) if [ p < 1 .or. p > p6 ]
call ERR0R(15) if [ 'ISAPOINT(p) - false ]
call ERR0R<34) if [ z < B nr. z > 127 ]
call ERB0ft(37> if [i:HAR*<p).neo,'UMAXCH'(TILF(PVUI*P{p))+13
UFSXTlLE*<p),LINE(p),'CHAR(p)) - z
for all q such that «q .neq. p) .and. 'LlNKEIT<p,q)>
   [ for all w such that ('WINBXISTS'(w) .and. 'WINPQINT'(w)-q)
        [ if (CSRCLlN'CBWINir(w),l) if defined else 8) <-
             •LINEHq) <-
             'SRCLIirCTWWD'(w)-l))
          then SCRISim(e«tier((TWIND'(w),'BWIND'(w))/2),
                    •CHAR'fo))- *]]
```

Function SCREEN
possible values: string
initial value: " "
parameters: integer r, c
effect:

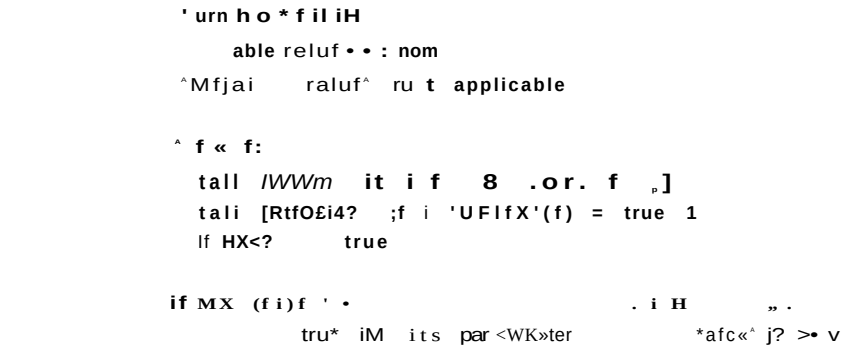

Figure 1.

Figure 1 is a photograph of a crt terminal screen. The screen is displaying text from this paper thrqugh two windows delimited hy lines of asterisks. The upper window's text is from Appendix One; the lower window's text is from the specification commentary of Section One. The value of multiple windows on one screen is illustrated by this juxtaposition of related text concerning function FILIN.