To: Distribution

From: Lee J. Scheffler

Date: November 14, 1974

Subject: New Multics Graphics Package

Attached are preliminary versions of Sections I and II of what is intended to become the Graphics Users' Supplement (GUS) to the MPM. These sections describe the design goals and structure of a new Multics Graphics System.

Several questions important to the Multics development community not covered inside are answered below.

- This graphics system runs entirely in the user ring, depending only on the existence of raw input and output modes.
- A working version of it is available on the MIT Multics, through the SIPB. See me for details; I would like to know who is using it.
- There is not yet a working version of it for use on the Phoenix Multics.
- Command and subroutine writeups are available. A Users' Guide (to become Section III of the GUS) should be available about mid-December.
- There is not yet a write-around module for the old graphics system. Unless there is a great demand for one, one will probably never be written.
- There is a conversion program for converting old graphic data bases into new format.

Questions, comments to Scheffler.MPLS on MIT or Phoenix Multics.

HONEYWELL INFORMATION SYSTEMS INCORPORATED

DATA SYSTEMS OPERATIONS

The Multics Programmers' Manual
Graphics Users' Supplement

Sections I and II only

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Revision 2

Date: 06/11/74

I. Overview of the Multics General Graphics System

The Multics Graphics System provides a general-purpose terminal-independent interface through which user or application programs can create, edit, store, display and animate graphic constructs. There are three major objectives behind the design of this interface.

1. It should be easy and natural to write a graphic program. The set of graphic primitives and operations available should be sufficiently flexible and general that a user need not "bend over backwards" to program common operations.

   Primitives are provided for manipulating a structured picture description composed of lines, points, screen modes, rotations, translations (position shifts) and scalings, in three dimensions. Primitives are also provided for displaying parts of such a graphic structure, for animating an already displayed structure, for obtaining graphic input, and for controlling special terminal functions (such as screen erase). These primitives are suitable for direct use by a knowledgeable programmer.

2. It should be amenable to a wide range of applications, while retaining efficiency and ease of use. The motivations behind this goal are to avoid creating and maintaining a multiplicity of systems, each oriented towards a separate application or terminal; and to avoid the necessity of graphics users having to master the idiosyncracies of entirely separate systems.

   The structured picture description interface primitives, in addition to being well-suited for a wide variety of graphic programming tasks, are also well-suited for use as building blocks for application modules to provide simpler or more application-oriented interfaces. Efficiency is enhanced by providing several alternate forms for storing graphic information that promote efficient editing of frequently changing graphic constructs and efficient storage and "play-back" of background scenes and standard display pictures.

3. It should be highly terminal-independent. That is, as far as possible, a graphic program written for one type of graphic terminal should be operable on another graphic terminal of similar capabilities without modification. A wide variety of

graphic terminal types may be connected to Multics, and this terminal mix changes with time. By making the graphic system interface independent of any particular terminal type, we avoid several problems that arise from terminal-dependent programming.

This has several desirable consequences:

a) User fragmentation is prevented. Users are not isolated by the particular type of graphic terminals they use, but can make use of graphic programs developed on different terminals by other users.

b) Terminal immobility is avoided. Users are not restricted by their programs to using only particular terminal types, but can make use of whatever graphic terminal is available. More importantly, graphic subsystems written for specific terminals can be easily transferred to new and better terminal types.

c) Software duplication is greatly reduced. Most graphics utility routines need be written only once to be usable with most or all of the graphic terminal types on the system.

Terminal-independence is achieved in the Multics Graphics System in the following way. The programming interface of the Multics Graphics System incorporates the union of most useful features of existing terminals and is extensible to allow the addition of new features as graphic terminal capabilities evolve. A user tailors his program to use the features of the terminal types he intends to use. When the program is run, the use of any unavailable feature can be mapped by the system into the most reasonable compromise feature of the terminal being operated. Thus, the user has a reasonable guarantee that his graphic programs will produce a recognizable picture on most any type of graphic terminal connected to Multics. Of course, not all graphic programs will operate equally well at any type of graphic terminal (e.g., animation is not possible on a storage-tube terminal.)

II. Structure of the System

The Multics Graphics System is organized into two distinct functional parts: the terminal-independent or "central" graphics system, and the terminal interfaces, as shown in Figure 1.

User and application programs communicate almost exclusively with the central graphics system. The central graphics system manipulates a database containing a structured representation of a graphic picture. When a user or application program decides to display a portion of the graphic structure, the structure is transformed into a character string representation known as "Multics Standard Graphics Code," which is suitable for transmission through a Multics I/O stream. This code contains both redundant information needed by static storage-tube display terminals, and structure information useful to programmable or "intelligent" terminals.

The terminal-dependent portion of the system examines the Standard Graphics Code, consulting a tabular description of the capabilities of the graphic terminal currently being used to decide if any operations need to be performed on the graphics code before it is sent to the graphic terminal. Typical operations include discarding structure information for static terminals and redundant information for intelligent terminals, performing rotations and scalings for terminals lacking these features, attempting compromise operations where necessary, and translating the standard code to the appropriate characters for controlling the particular terminal.

Graphic input from the terminal is handled in a similar fashion. The terminal interface translates the graphic input into Multics Standard Graphics Code which is interpreted by the central graphics system and returned to user or application programs as return arguments from a request for input.

This particular organization was chosen for reasons of generality and efficiency in performing many operations common to graphic subsystems. The structured database allows graphic pictures to be represented naturally (e.g., a screw as part of a door-knob as part of a door as part of a house as part of a neighborhood), and to be edited efficiently. The terminal-independent Multics Standard Graphics Code can be stored permanently in a Multics segment, to be "played back" with low computational overhead through a terminal interface at a later time to produce a standard background scene on any terminal type. Also, in many cases, the terminal-dependent graphics code produced by a particular terminal interface can also be stored and played back to that particular terminal type at negligible computational overhead.

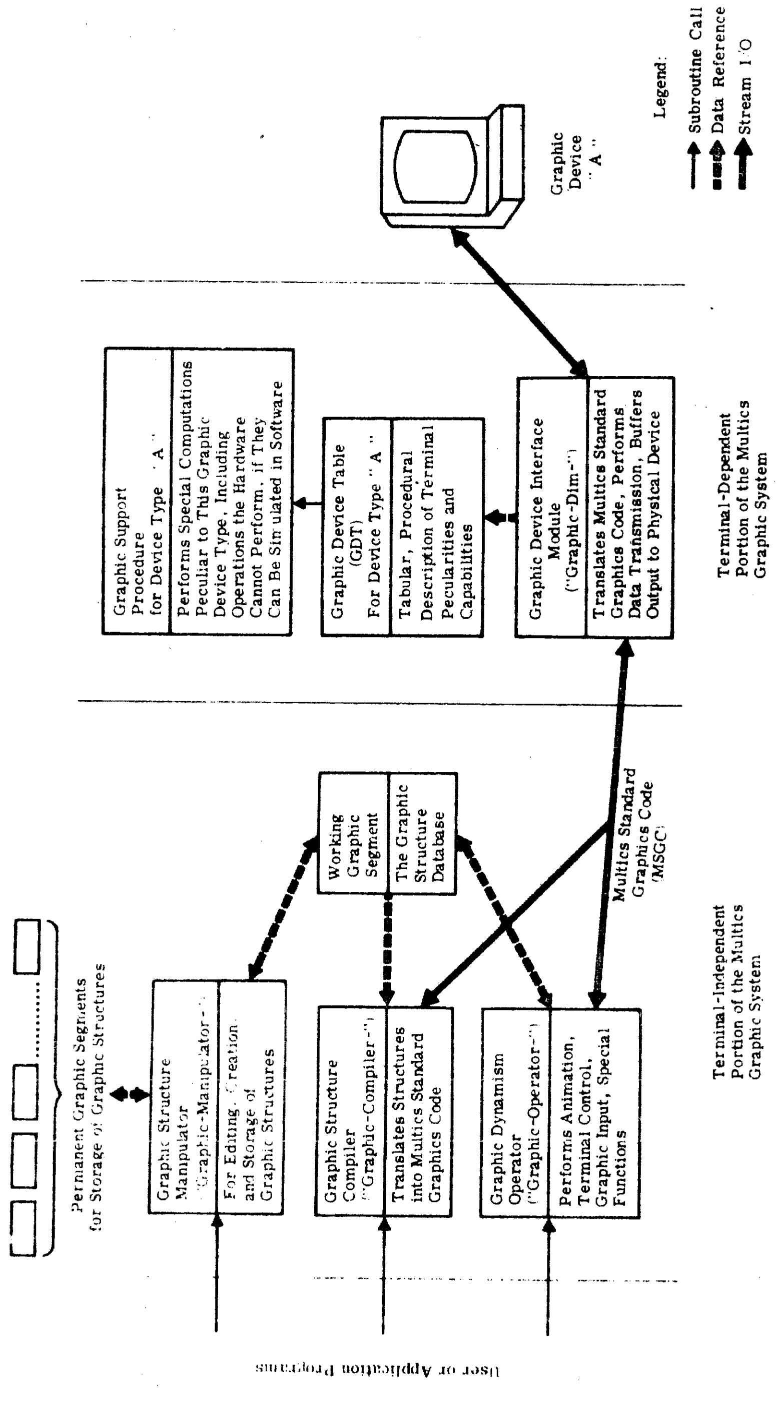


Figure 1
Functional parts of the Multics Graphics System

The tabular description of a graphic terminal capabilities and pecularities allows new terminal types to be added to the system with a minimum of overhead. And the ability to specify system- or user-supplied utility routines to aid graphic code translation promotes terminal independence, and provides a handle for extending the basic capabilities of the Multics Graphics System.

II.1 Graphic Structure Definition

Rather than treat graphic data as an unstructured collection of atomic craphic elements, much as a sketch could be considered an unstructured collection of points, lines, shadings, etc., the Multics Graphics System deals instead with tree-structured descriptions of pictures, where atomic graphic elements form parts of higher-level structures, which in turn may be parts of still higher-level structures. Substructures may be shared within higher-level structures. This organization has three advantages of note. First, it allows for fairly natural representation of graphic data. Recognizable objects (automobiles, doors, houses) can be viewed as both comolex graphic entities while they are being created and edited, and as atomic graphic elements when they are being incorporated into larger scenes. Secondly, the ability to share graphic sub-structures eliminates a great deal of redundancy in specifying a graphic picture. (e.g., all the windows on a skyscraper can be represented by a single window refererced many times in the graphic structure.) Finally, the structured organization makes possible some relatively powerful graphic editing capabilities (such as changing the shape of all the windows below the 34th floor.)

Two types of atomic elements make up a graphic structures: terminal elements and non-terminal elements. Terminal elements represent simple graphic operations most often interpreted directly by graphic terminal hardware. These include screen positioning, line and point drawing operations, screen modes (such as blinking, intensity, dotted, dashed or solid lines, and sensitivity to a light pen), and coordinate rotations and scalings in three dimensions. Non-terminal elements are lists which impose ordering on the elements they contain. Levels of structure are represented by including non-terminal elements within other non-terminal elements. Figure 2 depicts a graphic structure describing a simple house. At the highest level (House-Display), the House is placed in proper screen position by a setpoint, given full screen intensity, and made sensitive to light pen "hits". At the next level, the house is composed of a House-Outline, a Door, and Windows. The House-Outline itself is made up of a Roof, a Foundation, a Chimney and an antenna. The single Window design is shared in two places in the Windows substructure.

Each graphic element in a Multics segment representing a graphic structure is uniquely identified within the segment by a node number which is used to reference that element within the structure and in later operations. Non-terminal elements are simply linear lists of the node numbers of all the elements they contain.

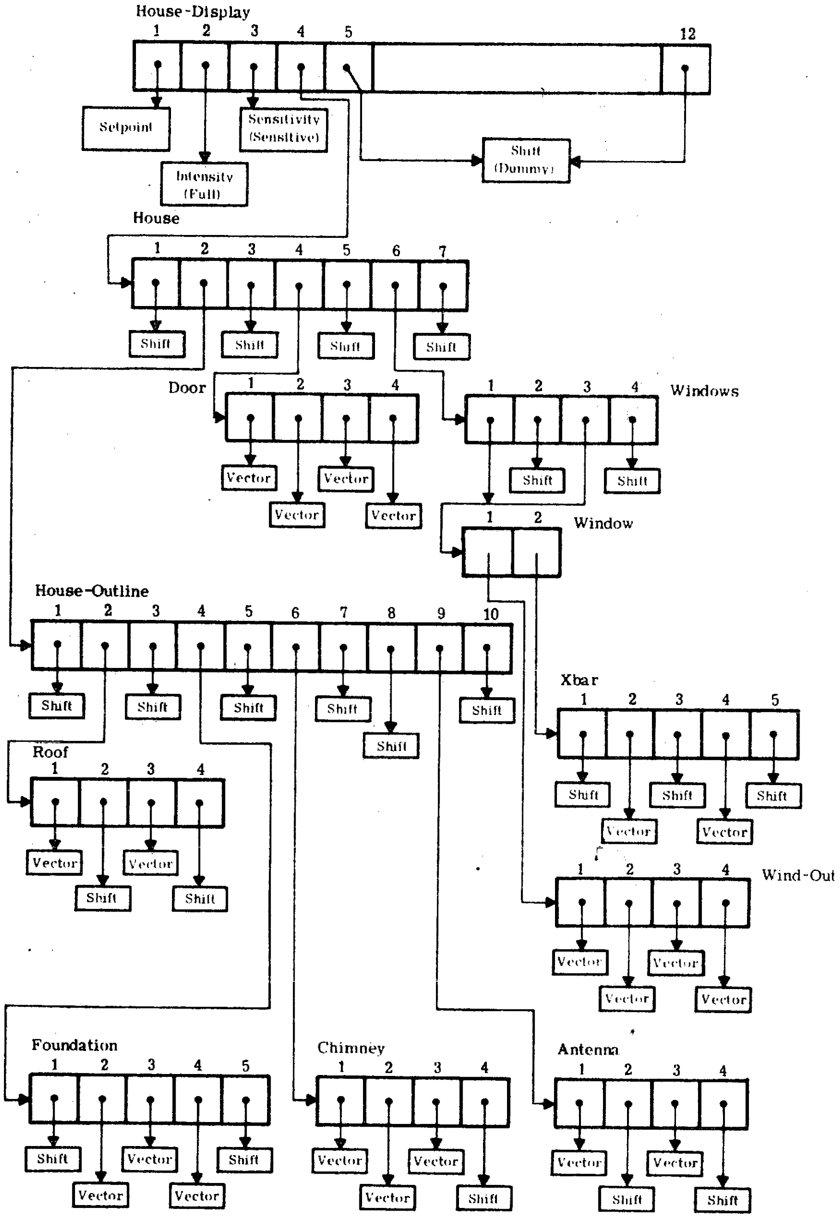


Figure 2
A Typical Graphic Structure Organization

In the following descriptions of the different graphic elements, the notation:

```
     element_type   (argument1, argument2, ... argumentn)
```

is used to convey the essential meaning of each element. The actual semantics of subroutine calls for creating and editing graphic elements is described in the section on Graphic Structure Manipulation.

II.1.1 Non-Terminal Graphic Elements

There are three types of non-terminal graphic elements used in structuring a graphic picture. They are:

lists
arrays
symbols

Lists

Lists are the most straightforward and most often used non-terminal graphic elements. A list is specified by

```
list (element1, element2, ... elementn)
```

where element n is the node number of any graphic element. Lists serve two purposes: to order other graphic elements, and to provide structure to a picture. A list may contain any number of terminal and non-terminal elements. However, circular or recursive lists (those that contain themselves or are part of a chain of list containment that eventually leads back to themselves) have undefined meaning and are therefore illegal. Note that it is possible to refer to a unique element many times within one list or from many different lists. Therefore, there is no concept of a structure being "owned" by a superior structure, since every piece of structure is inherently sharable.

Arrays

An array is structually equivalent to a list, but causes all information about the structure of its elements to be lost when the structure is compiled into Multics Standard Graphic Code. The major use of arrays is to reduce the overhead associated with maintaining and forwarding unneeded structural information. This is useful for static (storage-tube) terminals which do not support dynamic graphics and thus have no use for structural information, and for those substructures which the user does not intend to alter dynamically (e.g., background scenes).

Symbols

Symbols are a special form of non-terminal element used for naming graphic constructs. A symbol consists of two elements:

```
symbol (element, name)
```

where element is the node number of the terminal or non-terminal graphic element, and name is the node number of a terminal text element (see next section) containing the text of the name of the element. Symbols serve several purposes, the primary one being to uniquely identify graphic constructs in a mnemonic way, that may be moved betweer several Multics segments.

II.1.2 Terminal Graphic Elements

Terminal graphic elements are atomic operations often understood directly by graphic terminal hardware or terminal-resident software. The order of appearance of terminal elements in lists or arrays dictates the effect these elements have on other elements in the list.

There are four categories of terminal elements in the Multics Graphic System.

- positional elements
- modal elements
- mapping elements
- miscellaneous elements

Positional Elements

Positional elements affect the screen position (in three dimensions) of what might be thought of as a *graphic cursor*, (or "*current graphic position*",) and cause lines and points to be drawn on the screen. Positions are computed within a *virtual screen* of 1024 x 1024 x 1024 points, with the point (0,0,0) corresponding to the center of the screen. The virtual screen is infinite in all directions but is visible on a display screen only within the limits (-512e0 < x,y,z < 511e0).

The coordinate system is a right-handed Cartesian coordinate system, with the positive x direction toward the right, positive y upwards and positive z "coming out of the screen". Coordinates are supplied and manipulated as fractional quantities to minimize round-off errors in rotation and scaling operations.

There are two types of positional elements: absolute and relative. Absolute positional elements force the graphic cursor to a specific point in the virtual screen. Relative positional elements move the graphic cursor to a new position relative to its current position. The elements are:

setposition, setpoint - absolute positioning
vector, shift, point - relative positioning

setposition (x, y, z)

This element sets the current screen position to (x, y, z) without displaying any points or lines.

setpoint (x, y, z)

This element sets the current screen position to (x, y, z), and displays a visible point.

vector (dx, dy, dz)

This element displays a vector from the current screen position with dimensions dx, dy, and dz.

shift (dx, dy, dz)

This element changes the current screen position by dx, dy, and dz with no visible effect.

point (dx, dy, dz)

This element changes the current screen position by dx, dy, and dz and displays a visible point at the new position.

Relative screen positions are accumulated within a list or array from left to right. Absolute positioning elements (setposition and setpoint) are allowed only in the topmost level structures. Substructures within a list or array may change the screen position, although in general, shared substructures should have a net relative shift of (0,0,0) (i.e., the sum of the relative positioning elements in a shared list or array should normally add up to (0,0,0)).

Modal Elements

Modal elements produce no effects on the screen of themselves, but affect the properties of successive graphic elements in defined manners. The appearance of a modal element in a list overrides a previous setting for that particular mode for the rest of that list. The defined graphic modal elements are:

intensity (brightness)
line-type (solid, dotted, dashed, etc.)
steady/blinking
insensitive/sensitive (to a light pen)

intensity (value)

This element affects the brightness of succeeding graphic elements in a list. Eight levels of intensity (0-7) are defined. Level 0 corresponds to invisible, and level 7 is the default, full intensity.

line-type (type)

This element causes succeeding vectors to be drawn as solid, dashed, or other machine-defined types of lines. Type zero is defined as solid (the default), type one as dashed, type two as dotted. The remaining type codes are reserved for future expansion.

steady/blinking (value)

This element causes succeeding graphic elements to be displayed steadily (the default), or to blink.

insensitive/sensitive (value)

This element causes succeeding graphic elements to be sensitive or insensitive (the default) to detection by a light pen.

color (red_intensity, green_intensity, blue_intensity)

This element causes succeeding graphic elements to be displayed in the color specified by the intensities of the three primary colors in the additive color spectrum.

Modal elements establish a local graphic environment which governs the properties of lines and points drawn within the scope of that environment. There are several rules governing the application of modal elements depending on structure level and order in a list (or array):

1) When a modal element occurs in a list, it effects all successive elements in that list up to the next modal element of the same type.

2) A modal element overrides a previous modal element of the same type in the same list.

3) The local graphic environment (mode settings, rotations, scalings, and clippings) at the start of a substructure is defined as that environment in effect in the parent list at the point the substructure is referenced. This environment is changed by successive modal elements in the substructure. It is discarded at the end of the substructure and the modes are restored to the current values in the parent list. (In other words, modes are automatically reset to their previous values at the end of a substructure. This makes it impossible to have a substructure that changes modes.)

Mapping Elements

Mapping elements cause no visible effect by themselves, but affect how succeeding graphic elements are mapped onto the screen. There are three mapping elements:

rotation
scaling
clipping

rotation (<x, <y, <z)

This element causes succeeding graphic elements to undergo a rotation about the x, y, and z axes in that order. These axes are stationary relative to the screen. The units of rotation are positive degrees. Rotations are taken modulus 360 degrees.

scaling (*x, *y, *z)

This element causes succeeding graphic elements to undergo scaling in the three separate directions defined by the stationary coordinate system. Scalings may be negative to produce mirror images.

clipping (left, right, bottom, top, back, front)

This element causes all succeeding normally visible graphic elements to be clipped (become invisible) if they fall outside of a rectangular solid defined by its parameters. (The parameters are relative displacements from the current screen position of each of six planes defining a rectangular solid.) If a graphic element straddles the boundary, only the part within the rectangular solid will be visible.

Mapping elements change the local graphic environment in somewhat the same manner as modal elements, according to three rules:

1) Successive mapping elements override previous mapping elements of the same type in the same list.

2) When a mapping element occurs in a list, the net mapping is the result of applying the mapping element to the mapping currently active in the parent list.

3) Mapping elements in a sub-list have no effect on the mappings in a parent list.

Because mappings are non-commutative vector operations, the order of application of mapping elements to constructs in a list is important. A scene that is first scaled and then rotated will in general appear different than one that is first rotated and then scaled. Within a list, scaling is performed first, then rotation then clipping. This order may be overridden by using several levels of structure to achieve the desired order of application. The modes "closest to the object" (on the lowest structural level) are "more binding", and are applied first. The mapping elements are defined to apply to all graphic elements with the exception of text strings. For efficiency, the central graphic system assumes the use of character generating facilities in the terminal processor. Thus, the orientation and size of text strings are not altered by mapping elements. However, the positions at which text strings occur are altered.

Miscellaneous Graphic Elements

There are two other graphic elements that may be included in a graphic structure. They are:

text - for displaying textual information

data block - for storing user data within the graphic structure, or extension of the basic capabilities of the Multics Graphic System

text

The purpose of the text element is to allow labels and other textual information to be included in a graphic structure. Its format is:

```
text (alignment, string)
```

string is a text string of any length (although in general it will be smaller than the text line length of most graphic terminals).

alignment is a number from 1 to 6 which specifies that the text string is to be aligned in one of 6 ways relative to the current screen position, as follows:

Alignment	Portion of String at Current Screen Position
1	Upper left
2	Upper center
3	Upper right
4	Lower left
5	Lower center
6	Lower right

The string is subject to active screen modes, but not to mappings. However, the initial position of the string is subject to mappings.

datablock

The datablock graphic element allows arbitrary user-defined bit strings representing user data to be stored as part of a graphic structure. The data is passed to the graphic terminal just as any graphic effector is, which makes it possible for a user with special applications to use a datablock to contain terminal-dependent information or commands. This provides a straightforward and powerful facility for extending the basic capabilities of the Multics Graphic System by allowing user program-to-graphic terminal conventions.

The datablock is defined by:

```
datablock (user_data)
```

where user_data is any string of any length. There are no system-defined type codes for marking the user_data as representing integers, characters, etc., although the user may include his own such description as part of his data.

Datablocks have no system-defined effect on other graphic elements in the same list or in subordinate graphic structures.

II.2 Graphic Structure Manipulation

Graphic structures are created, edited amd stored in a temporary segment in the user's process directory known as the Working Graphic Segment (WGS). User programs call entry points in a program called the Graphic Manipulator (graphic_manipulator_) to perform several categories of operations on graphic structures in the WGS:

creation of new elements and structures
examination of existing structures
alteration of elements and structures
permanent storage of named structures

Graphic elements in the WGS are referenced by node numbers, valid only within the current WGS. When a new graphic element is created, the node number of the created element is returned to the user program as a sort of "receipt". This node number is used in all later references to this element. Lists of graphic elements are simply PL/I- or FORTRAN-like arrays of node numbers of the elements in the list. Permanent storage of all or a portion of a graphic structure is accomplished by attaching a symbol (name) to the structure. Entry points in the Graphic Manipulator can then be used to move such named structures between the temporary WGS and one or more Permanent Graphic Segments (PGS) anywhere in the Multics storage hierarchy.

Node numbers are used for graphic structure creation and editing for efficiency. The node number of an element presently corresponds to its word offset in the WGS. (This correspondence is not guaranteed to remain valid.) Names are used for permanent storage because they are more mnemonic, and because the operation of copying a graphic structure into a PGS performs an implicit storage compaction and garbage collection function, thereby changing the node numbers of most graphic elements copied.

See the writeup of graphic_manipulator_ for the details of the various graphic structure manipulation entry points.

II.3 Graphic Structure Compilation

When a user has created and edited a graphic structure to his satisfaction, he can then produce a character string representation of this structure for transmission through the Multics I/O system by using the Graphic Compiler (graphic_compiler_). The input to the compiler is a graphic structure resident in the WGS. The structure is designated to the graphic structure compiler by the node number or name of its top-level list. The compiler transforms this structure into an equivalent representation in Multics Standard Graphics Code, a standard intermediate form which is terminal-independent. This code is written over the I/O stream "graphic_output". This stream may be attached to a terminal interface, thereby directing the code to a particular graphic terminal; or it may be attached to a Multics segment, producing a permanent copy of this terminal-independent code that can be "played back" through any terminal interface at a later time.

Several different entries are provided in the graphic structure compiler to perform some commonly necessary operations on the remote terminal (such as erasing the screen, or specifying that the structure is to be loaded into an intelligent terminal's memory, but not immediately displayed).

II.3.1 Multics Standard Graphics Code

Multics Standard Graphics Code (MSGC) allows graphic structures and graphic operators to be represented as character strings suitable for transmission over a Multics I/O stream. It allows the representation of structural information useful to intelligent terminals and redundant information necessary to display shared substructures on non-intelligent terminals.

Multics Standard Graphics Code is terminal-independent in two senses: it contains no specification of any particular terminal type, and it contains all information necessary to produce graphics on all supported terminals.

The MSGC for a graphic structure is produced by a left-most tree walk of the structure in the current working graphic segment. Terminal graphic elements are represented simply as a single ASCII character element code followed by argument values coded into ASCII characters in standard formats:

```
     element_code  arg1 arg2 ... argn
```

Levels of list structure are represented by nestings of paired parentheses, and include a list/array indicator and a node number followed by the list elements, in order:

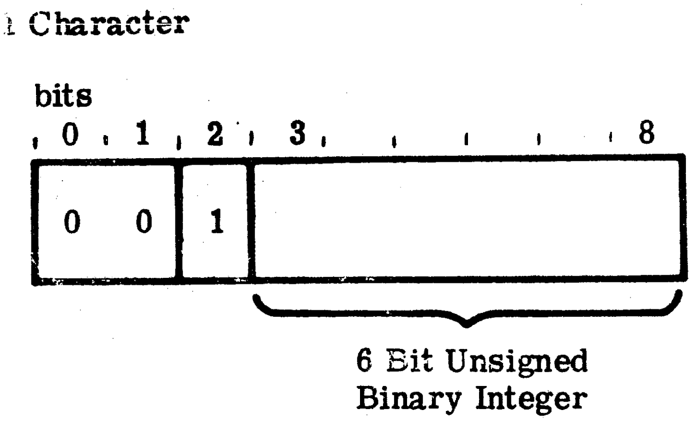
```
     (list_indicator node_no element1 element2 ... elementn)
```

The node number is retained to aid intelligent terminals in constructing their internal representations of graphic structures, and to allow identification of shared substructures. Other graphic operations (animation, input, etc.) are also represented by a single ASCII character operator code followed by arguments:

```
     operator_code arg1 arg2 ...argn
```

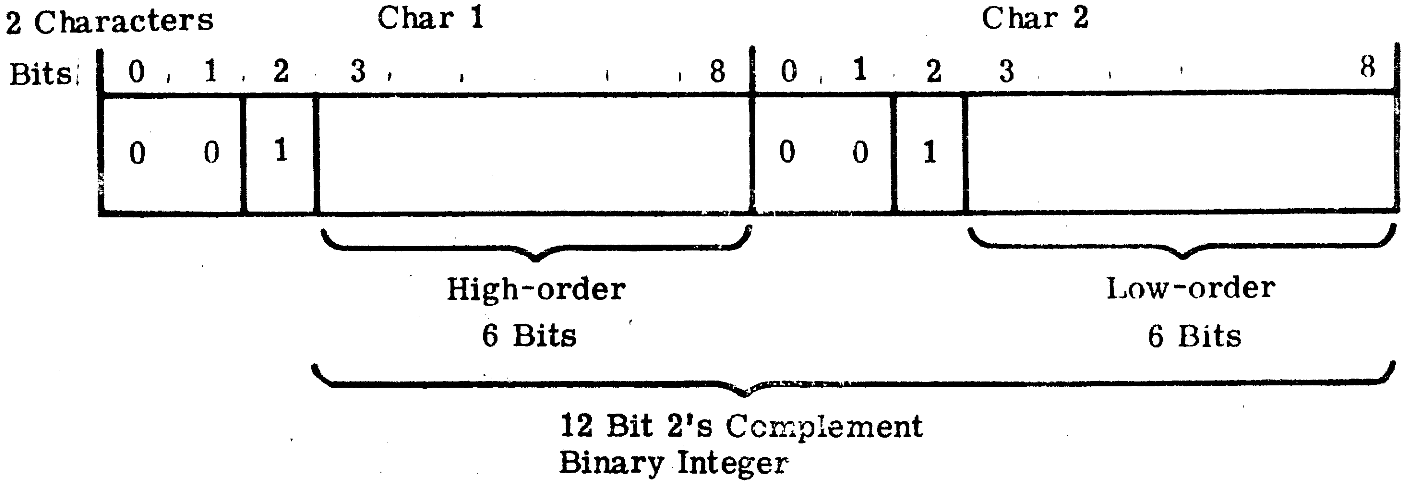
MSGC is designed around the printing ASCII characters (from 40 to 177 octal) to prevent confusion with the ASCII control characters (0 to 37 octal). Element and operator codes occupy the ASCII characters from 40 to 77 octal. Argument values are encoded in the ASCII characters from 100 to 177 octal, with the six low order bits in each character representing data values.

There are four formats for transmission of argument values in Multics Standard Graphics Code, depicted in the following pictures:



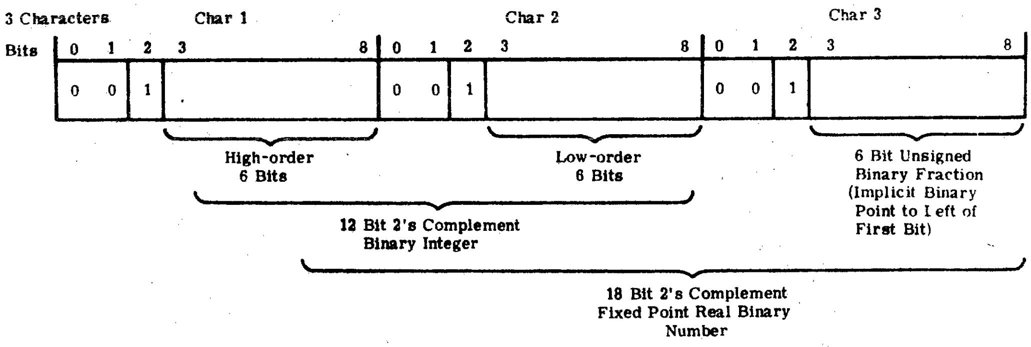
(First)

Single Precision Integer (SPI) format is used for transmission of small non-negative values from 0 to 63.

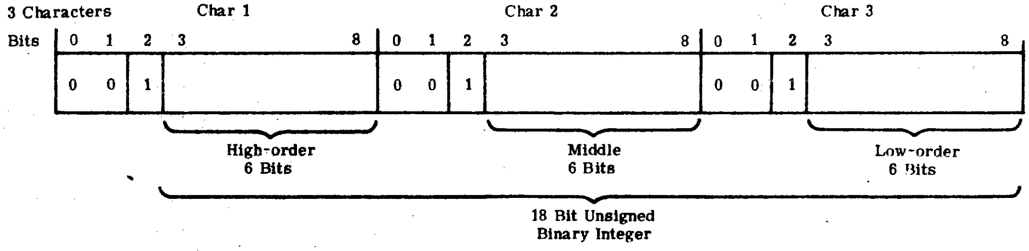


(Second)

Double Precision Integer (DPI) format is used for signed integers ranging from -2048 to 2047.


3 Characters
Char 1
Char 2
Char 3
Bits
0 1 2 3 8
0 1 2 3 8
0 1 2 3 8
0 0 1
0 0 1
0 0 1
High-order 6 Bits
Low-order 6 Bits
6 Bit Unsigned Binary Fraction (Implicit Binary Point to Left of First Bit)
12 Bit 2's Complement Binary Integer
18 Bit 2's Complement Fixed Point Real Binary Number

Scaled Fixed Point (SCL) format is used for numbers with fractional parts. It has the same range as the DPI format, but is accurate to fractional parts of 1/64.



Unique ID (UID) format is used to transmit 18-bit node numbers.

Following are the character codes and argument list formats for the operators in Multics Standard Graphics Code. (See Section II.4 on Dynamic Graphic Operations for descriptions of the functions of the animation, input and terminal control operators.)

Positional Operators

```
                       \
setposition ("0")  !
setpoint    ("1")  !
vector      ("2")  }  xpos       ypos       zpos
shift       ("3")  !  (DPI)      (DPI)      (DPI)
point       ("4")  !
                   /
```

where xpos, ypos, and zpos are the coordinates of the desired positioning operation in DPI format.

Mapping Operators

```
scale      ("5")      xscale      yscale      zscale
                      (SCL)       (SCL)       (SCL)
```

where xscale, yscale and zscale are the scale factors along the three stationary coordinate axes, in the SCL format.

```
rotate     ("6")      xangle      yangle      zangle
                      (DPI)       (DPI)       (DPI)
```

where xangle, yangle and zangle are the numbers of degrees of rotation around each of the three stationary axes, in DPI format.

```
clip       ("7")    right    left    top    bottom    front    back
                    (DPI)    (DPI)   (DPI)  (DPI)     (DPI)    (DPI)
```

where the arguments are the relative displacements of six planes forming a rectangular solid "clipping box", all in DPI format.

Modal Operators

```
intensity  ("8")    value
                    (SPI)
```

where value is a number from 0 (invisible) to 7 (fully visible) in SPI format.

```
line_type  ("9")   value
                    (SPI)
```

where value is one of the following:

```
0 -   solid line
1 -   dashed line
2 -   dotted line
3-63  reserved for expansion
```

```
blink/steady     (";")     value
                           (SPI)
```

where value is either 0 (steady) or 1 (blinking).

```
sensitivity (":")  value
                   (SPI)
```

where value is either 0 (insensitive) or 1 (sensitive).

```
color     ("<")   red_intensity   green_intensity   blue_intensity
                      (SPI)            (SPI)            (SPI)
```

where the arguments are the intensities of the three primary additive colors with 0 representing no intensity and 63 representing full intensity.

Miscellaneous Operators

```
text   (">")     alignment     length     string
                 (SPI)         (DPI)      (ASCII)
```

where alignment controls the positioning of the character string relative to the current screen position. Values for the alignment are described earlier in this section.

length is the number of characters in the following text string.

```
data     ("?")     length     string
                   (DPI)      (ASCII)
```

where length is the number of data bits to follow and string is a character string with data bits packed six to a character in the low order bits.

Structural Operators

```
node_begin ("(")     struc_type    node_no
                     (SPI)         (UID)
```

where struc_type is either 0 (list) or 1 (array) and node_no is the unique ID associated with the list or array.

```
node_end      (")")     (no arguments)
```

```
symbol        ("=")     length      name
                        (DPI)       (ASCII)
```

where length and name are the number of characters and the text of the symbol name associated with the immediately following graphic structure.

```
reference     ("%")    node_no
                        (UID)
```

where noce_no is the unique ID of a node already resident in terminal memory, and is used in successive references to shared substructures. Users wishing to construct and output their own graphic code should refrain from using this operator, as it will limit their graphic code to intelligent terminals. This operator is normally inserted into the graphic stream at run time by the graphic device interface module.

Animation Operators

```
increment    ("{")    node_no     times     delay    template_node
                      (UID)       (DPI)     (SCL)
```

node_no is the unique ID of a node already resident in the terminal memory that is to be incremented.

times is the number of times the increment is to be performed.

delay is the amount of time the terminal is to delay before each increment.

template_node is the graphic element containing the relative increment to be performed. and includes the element code in its own format.

```
synchronize   (".")    (no arguments)


alter         ("'")    node_no      index      new_node
                        (UID)       (DPI)       (UID)
```

node_no is the unique ID of the list or array node being altered.

index is the index in the list of the element to be replaced.

new_node is the unique ID of the new node to be inserted in the list.

Input and User Interaction

```
query      (",")     input_type       input_device
                     (SPI)            (SPI)
```

input_type is the type of graphic input desired (1 = where, 2 = which, 3 = what)

input_device is the graphic input device to be used to generate the indicated input.

0 -	terminal processor or program
1 -	keyboard
2 -	mouse
3 -	joystick
4 -	tablet and pen
5 -	light pen
6 -	track ball
7-62	reserved for expansion
63-	any device

```
control    ("*")     node_no
                      (UID)
```

node_no is the unique ID of a node to be controlled by the terminal or user.

```
pause      ("¢")       (no arguments)
```

<u>Terminal Control</u>

```
erase      ("-")      (no arguments)


display    ("+")      node_no
                       (UID)
```

node_no is the unique ID of the top_level list node to be displayed.

```
delete     ("/")      node_no
```

node_no is the unique ID of a node resident in the terminal memory that is to be deleted. If node_no is zero, all nodes are deleted.

II.4 Dynamic Graphic Operations

There are several classes of graphic operations that involve user interaction or take advantage of refreshed display screens and real-time computation in intelligent terminals:

animation
graphic input and user interaction
terminal control

The basic design philosophy relating to such dynamic operations is that the graphic structures resident in Multics and those in the graphic terminal memory should be isomorphic (structurally equivalent). In other words, there are no provisions for the user or his terminal to make changes in a terminal-resident graphic structure without mirroring them in the Multics-resident structure. All dynamic graphic operations are initiated at the request of a user or application program in Multics.

There are several reasons for adopting the philosophy. First, it allows a simple and well-defined interface to a graphic terminal. Multics programs are never faced with the difficulty of passing arbitrary inputs from a terminal, but need only expect inputs in standard formats, and only in response to an operation that requests information. Second, terminal-resident programming is simplified, reducing the amount of memory required at the terminal. Finally, the problems inherent in maintaining separate copies of a database (in this case a graphic structure) are eliminated. The nature of the dynamic graphic operators is such that both Multics-resident and terminal-resident structures are identical before and after each operation.

Dynamic graphic operations are initiated by calls to entry points in the Graphic Dynamism Operator (graphic_operator_). These entry points emit characters in Multics Standard Graphics Code to cause a terminal to perform the desired operations, and return to the user program any information returned by the terminal. The details of these entry points may be found in the module writeup on graphic_operator_.

II.4.1 Animation

Animation involves moving graphic constructs on a terminal screen in a controlled manner, and dynamically changing the structure of a graphic construct being displayed.

There are three dynamic operators which accomplish movement:

increment
synchronize
alter

increment

The increment operator allows a single positional or mapping element in the terminal memory to be changed some number of times with a specified real time delay between changes. Its format is

```
increment  node_no no_times delay template
```

node_no uniquely identifies the element to be changed

no_times is the number of times the incrementation is to be performed

delay is the real-time the terminal is to wait between successive increments

template is a positional mode or mapping element whose arguments are the increments to each of the parameters in the element being incremented.

The increment operator is defined to enable asynchronous operation with all other activities at the graphic terminal, including other increments. This allows several graphic constructs to move independently of each other. Note that this incrementation allows only straight-line trajectories to be specified in each occurrence of an increment operator. Curves may be realized by using several separate increment operators.

synchronize

Because several constructs may be moving simultaneously, there is a need to be able to coordinate movements to allow events to be properly sequenced (e.g., balls bouncing off each other). The synchronize primitive has no arguments. It simply commands the graphic terminal to complete all operations received before the synchronize before beginning any subsequently received operators.

alter

The alter operator effects changes in the structure of graphic constructs already in terminal memory by allowing list elements to be replaced.

```
     alter list_id index new_element
```

list_id is the node number of a list already resident in terminal memory

index is the index of the element of the list to be replaced.

new_element is the node number of the new element, which must also be resident in terminal memory.

The indicated list is updated both in the working graphic segment in Multics, and in the terminal-resident structure.

II.4.2 Graphic Input and User Interaction

There are three operators for graphic interaction with users:

```
query
control
pause
```

Query

It is often desirable to obtain input from a user that is more easily expressible with a graphic input device (such as a light pen) than by keyboard characters. There are three general classes of graphic input built into the Multics Graphics System:

where (coordinate postion) - the user indicates one position in the stationary x,y,z coordinate system.

which (structure specification) - the user indicates a particular subtree of a displayed graphic structure.

what (new structure) - the user creates some new graphic structures at his terminal and returns them to Multics.

These three input types are all initiated with a single "query" dynamic operator of the form

```
query input_type device_type
```

input_type is a code indicating which of the three inputs are desired.

device_type indicates the graphic input device from which the input is desired. (It may also indicate that the user is to be given his choice of input devices.)

Control

There is also a fairly stylized form of graphic input that allows the user to experiment with the current displayed structure to see what it looks like before reflecting a change to Multics. This kind of operation is implemented by the "control" dynamic operator:

```
control device_type node_no
```

device_type is the same as in the "query" operator.

node_no is the unique ID of a positional modal or mapping element in the terminal memory whose value is to be placed under control of the user via some input device.

A typical use of this facility is to place the endpoint of a line or the starting position of a construct under control of a light pen, to allow the user to move it around, or to place the orientation (rotation) of a scene under control of a trackball. Upon completion of a control interaction, the structure resident in Multics is updated to mirror the changes made.

Pause

Occasionally it is desirable to allow a user to proceed step by step through a sequence of displays at his own speed. If there is no new computation required of Multics between steps, there is no reason for an interaction with Multics between steps. The "pause" operation causes the terminal to delay processing of subsequently received graphic data until the user indicates that he is ready to proceed. In this way, all graphic operations for such a session can be pre-loaded into the terminal and operated with a minimum of Multics interaction.

II.4.3 Terminal Control

There are various housekeeping functions that need to be performed when dealing with graphic terminals.

screen control
terminal memory management
communications control and error handling

Screen Control

Screen control consists of erasing all graphics currently displayed on the screen, and selectively displaying graphic structures already resident in terminal memory. The former is accomplished with the "erase" operator:

```
erase (no arguments)
```

The latter function is accomplished with the "display" operator

```
display node_no
```

node_no is the unique ID of the top-level of a graphic structure already resident in terminal memory that is to be displayed.

Memory Management

Memory management deals with loading new graphic structures into terminal memory and deleting structures that are no longer needed. Loading is accomplished implicitly simply by sending a new graphic structure to the terminal. The "delete" operator allows individual structures to be deleted, presumably freeing space in terminal memory.

```
delete node_no
```

node_no is the unique ID of the top-level list of a graphic structure to be deleted. If is it zero, all graphic structures in terminal memory are deleted.

Communications Control and Error Handling

There are several problems that fall under the heading of communications control. It is necessary to distinguish character strings representing graphic structures and operations from normal text. Since most intelligent terminals are mini-computers with limited memory, there will often be limits on the speed with which the terminal can process incoming graphics and the size of terminal communications buffers. And because fairly complex structures all being transmitted, some high-level protocol for discovering and reporting errors to Multics is necessary.

For dynamic terminals, two ASCII control characters are defined to have the following meanings:

DC1 (octal 021)	Enter graphic mode
DC2 (octal 022)	Enter text mode

DC1 indicates that all subsequent characters should be interpreted as representing graphic structures and operators.

DC2 indicates that succeeding characters are normal text.

The problems of finite terminal input buffers and error reporting are solved by a Multics output buffering and status reporting protocol. The Graphic Device Table describing a terminal contains an indication of the size of the terminal's input buffer. The strategy is to dispatch no more than this number of characters to the terminal, followed by a request for status character (ASCII 035). The terminal then responds with a status message in a standard format preceded by a left parenthesis ("(") and followed by a right parenthesis and a new-line character (")<NL>")

Character	Format	Represents
1	SPI	error code for discovered error
(If the error code is zero, meaning no errors detected, the following characters need not be sent.)		
2	ASCII	character code of graphic operator in which error occurred
3-5	UID	unique ID of top-level node in graphic structure in which error was detected
6	SPI	depth of error in list structure
7	SPI	list index of top level list element
8	SPI	list index of next level list element
9 on	SPI	list indices of succeeding elements until done

If the error code returned is 0, then the next buffer of characters is output to the terminal. Otherwise, the error is reflected back to the user program and the as yet unsent characters are destroyed.

Many graphic operators must be sent immediately to the terminal, because they require terminal response before more graphic data is generated. However, it is desirable to keep the frequency of status request interactions to a minimum because half-duplex communications protocols insert rather substantial delays. Control over when the Multics output buffer is sent is exercised in two ways. First, in the Graphic Device Table describing a terminal, one can specify for each graphic operator in Multics Standard Graphics Code whether or not the buffer must be sent. Normally, the buffer must be sent only on query and control operators, where input from the terminal is necessary. Secondly, an entry point in the Graphic Operator (graphic_operator_) sets an internal mode known as the "immediacy" mode. When immediacy is turned on, all graphic operators are sent immediately as they are generated, each followed by a request-for-status message. When immediacy is off, graphic output is buffered until the buffer is full or until a graphic operator is encountered that must be sent immediately, in which case the entire buffer is sent.