

APPARATUS AND METHOD FOR USING A TEST WINDOW IN A GRAPHICS SUBSYSTEM WHICH
INCORPORATES HARDWARE TO PERFORM CLIPPING OF IMAGES

SUMMARY OF THE INVENTION

The present invention is directed to an apparatus and method for using a test window to improve the efficiency of clipping images which are to be displayed by a graphic display subsystem. Specifically, according to the present invention, a test window is defined which surrounds a window (the clip window) within which it is desired to render graphical images. Objects are then tested to see if their vertices are outside the test window. The utilization of this test window allows for a performance optimization to be made between processing of a clipped object by a hardware based graphics subsystem which incorporates the present invention or by graphics software executed by a general purpose CPU which also interfaces to the graphics display. By properly defining the test window size relative to the clip window, objects which fall totally within the test window, although clipped and potentially requiring numerous non-visible pixels to be processed, will be rendered faster by the graphics subsystem rather than deferring the object to graphics software which, through algorithms and methods well known in the art, can restrict the pixels processed to just those that are visible and will ultimately be output to the video display. Objects with vertices that fall outside the test window would be deferred to graphics software to render since the time to render the visible portion(s) of the object would be less than if the graphics subsystem handled the object. This optimization of when specialized graphics hardware should handle a clipped object and when it should not can have significant effect on the overall performance of the graphics system.

The present invention will be described with reference to a graphics subsystem in which comparisons necessary to perform clipping are performed in hardware. A by product of the comparisons makes available certain information which is needed to determine the relationship between the vertices of an object and a window in which the object may be drawn.

The present invention forms part of an apparatus which performs clipping of images to be displayed on a video display in hardware whenever possible, leaving for software only those images, or portions of images which cannot be reliably or, for performance reasons, optimally clipped using the graphics subsystem of the present invention.

In our co-pending application GB 8920728.6 entitled "Hardware implementation of clipping and inter-coordinate comparison logic" there is described and claimed an apparatus for facilitating the clipping and rendering of an object in a graphics display system for displaying said object defined by a plurality of object coordinates, said system utilizing a clip window defined by a plurality of clip coordinates for clipping said object prior to display, and a test window defined by a plurality of predetermined offsets from said clip coordinates such that said test window is larger than, and outside of, said clip window, said test window for operating in conjunction with said clip window to selectively determined whether said object should be clipped in accordance with a first method of clipping or a second method of clipping.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a block overview diagram of a graphics subsystem for a work station according to the present invention.

FIGURE 2 is a block diagram of the coordinate staging section of the invented graphics subsystem.

FIGURE 3 is a detailed block diagram of adder 31 and multiplexor 35.

FIGURE 4 is a detailed block diagram of X/Y coordinate registers 37.

FIGURE 5 is a detailed block diagram of clip coordinate registers 39.

FIGURE 6 is a detailed block diagram of raster offset register 41.

FIGURE 7 is a detailed block diagram of text window control 45.

FIGURE 8 is a detailed block diagram of comparison logic and result storage 47.

FIGURE 9 is a table showing relative timings for loading control state machine 35 and comparisons performed by comparison logic and result storage 47.

FIGURE 10 is a truth table utilizing comparison results for the X0 coordinate.

FIGURES 11a and 11b are a truth table utilizing comparisons between each of the four X vertices and each of the four Y vertices.

FIGURES 12a-12d define a truth table utilizing comparisons between the four X and the four Y vertices and the clipping boundaries.

FIGURE 13 defines a truth table utilizing comparisons between the four X and the four Y vertices and the test window boundaries.

FIGURE 14 defines a truth table showing the direction in which to draw objects or perform blits.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a graphics subsystem of an engineering workstation, and specifically, a hardware implementation of processing graphical information which is to be displayed within a defined window. By using information made available by the comparison hardware, it is possible to determine whether the vertices of the object lie outside a test window which surrounds the window. With such information available, it is frequently possible to determine that the object lies entirely outside the real window thereby eliminating the need to perform the calculations necessary to draw the object.

Specifically, the invention supports a secondary clipping boundary referred to as a test window. The test window provides a means of determining the tradeoff between the hardware processing an object with some clipped (obscured) portions or having the hardware reject the object which would imply the CPU software would handle its rendering. The method used by software in the prior art involves doing some mathematics to find the intersection(s) of the object and the clipping boundaries. Since this is a time consuming (requiring numerous clock cycles) task, in many cases it is actually faster to allow the hardware to handle the object even though it may spend many cycles processing obscured portions of the object. The decision criteria used to decide whether or not the hardware should handle any given clipped object is made based on whether the vertices for the object fall inside or outside the test window which, by definition, always encompasses the clip window entirely. The size of the test window is set based on prior knowledge of the performance of the

hardware and the performance of the host CPU when calculating the intersections and rendering the visible portions of the object. In support of the test window and the decisions related to it, the coordinate comparison logic also performs comparisons of each vertex to the appropriate (either X or Y) minimum and maximum test window boundary. As will be explained in detail below, this information is used by status generation logic 51 to generate the signals HW and SW which respectively define whether the rendering of the object should be handled by the graphics subsystem or by the software.

The coordinate staging and coordinate comparison logic blocks (see Figure 1) are provided to provide the necessary storage and comparison information required for the support of arbitrary quadrilateral rendering with clipping, as well as Block Image Transfers (BLIT) with clipping. In both cases, it is necessary to specify four X/Y coordinate pairs and to specify the clipping window boundaries.

To support quadrilateral rendering implies the availability of four vertices which will define the quadrilateral. The disclosed embodiment of the invention puts very few restrictions on these vertices. They are stored in four register pairs (a register pair consists of one register for the X coordinate and one register for the Y coordinate) and are referenced with the vertex numbers 0 thru 3. It is implied that vertex 0 is connected to vertex 1, vertex 1 to vertex 2, vertex 2 to vertex 3, and vertex 3 to vertex 0. No connection is intended between vertices 0 and 2, or vertices 1 and 3 for instance. The coordinate staging and comparison logic form the initial stages of a pipeline that will eventually accomplish the rendering of the specified quadrilateral into the display memory. The subsequent pipeline

stages require information concerning the relationship of each adjacent vertex to its neighbors (i.e. for vertex 1; X_1 vs X_0 , Y_1 vs Y_0 , X_1 vs X_2 , and Y_1 vs Y_2). This information is needed to properly supply the functional addressing block with a series of trapezoids that when composited, accurately represent the original quadrilateral. The decomposition of the arbitrary quadrilateral is accomplished by the coordinate sequencing logic.

Additionally, in order to support the clipping of the quadrilateral to the clipping boundaries in subsequent pipeline stages, the relationship of the vertices to the appropriate clipping boundaries is required. This means for example all X vertices compared to both the minimum X clip boundary as well as to the maximum X clip boundary. A similar set of comparisons is required for the Y vertices as well. In some cases, these comparisons can indicate whether or not an object has any visible portions (non-clipped) at all. By identifying the objects that will not be visible in advance, the utilization of the subsequent pipeline stages can be avoided since no visible pixels will ever be identified for writing to the display memory. This represents a performance advantage in that the rendering of the quadrilateral can be considered to have occurred immediately once the clipping information has been analyzed.

The preferred embodiment of the graphics system being described utilizes 16-bit 2's complement math when determining the pixel's associated with a line segment. This math involves taking the difference of the two X and two Y vertices of the line segment. In order to avoid mathematical overflow, the numeric range of the X and Y vertex values must be restricted to be representable in 15 bits or be between -2^{14} and

(2¹⁴ - 1). In support of this, a check of the numeric range of the vertices is made by the coordinate comparison logic.

The support of BLITs also requires 4 vertices -two specify the opposite corners of a source (SRC) rectangle and two specifying the opposite corners of a destination (DEST) rectangle. The intent of the BLIT operation is to copy the pixels contained in the SRC rectangle to the DEST rectangle. In the current embodiment, the upper left corner of the SRC rectangle is stored in vertex 0 while the lower right SRC corner is in vertex 1. Similarly, the upper left DEST corner is in vertex 2 and the lower right in vertex 3. In order to properly copy the SRC to the DEST, care must be taken in the event the two rectangles overlap. When this occurs, the order in which pixels are copied is constrained if the correct result is to be obtained. This is a well known problem to persons skilled in the art. The information required to properly determine the pixel copying constraints involve comparison of the SRC rectangle boundaries to the DEST rectangle boundaries. This is needed both for the X and the Y coordinates involved.

Additionally, to support clipping of both the SRC and DEST rectangles in subsequent pipeline stages, the relationship of the SRC and DEST vertices to the appropriate clipping boundaries is required. Once again, this may indicate that either the SRC or DEST rectangle are totally obscured (non-visible) and may negate the need to utilize the subsequent pipeline stages. This represents a performance advantage in that the execution of the BLIT can be considered to have occurred immediately once the clipping information has been analyzed.

The coordinate staging control logic supports multiple ways for the coordinate values to be acquired. Correspondingly, the coordinate comparison logic maintains the necessary comparison information regardless of the manner in which the coordinate values are provided. The different methods for coordinate acquisition can be summarized as: absolute, indexed, and relative. The specific method used is determined by the address of the register that the CPU uses to identify the register(s) to be loaded. An absolute coordinate value is loaded by storing the actual value supplied by the CPU into the addressed register. This method of loading is used for loading of the clipping boundary registers and the raster offset registers as will be described below, as well as individual coordinate registers. The second method, indexed, is used to efficiently load multiple coordinates with the same values. In this case, the CPU supplied value is first added to the appropriate raster offset register (either raster offset X or Y) before being made available for storage in one or more coordinate registers. The addition of the raster offset provides a means of offsetting the X/Y address space provided by the CPU to a different area of the display memory.

The indexed loading mechanism utilizes a two-bit index to guide itself and identify how many and which coordinate registers to load during any given cycle. It is this mechanism that allows the CPU to specify only one X/Y pair to identify the degenerate quadrilateral - a point, or two X/Y pairs for a line, or three X/Y pairs for a triangle. When one of the aforementioned degenerate quadrilaterals is loaded into the four vertex registers, one or more vertices may be repeated. This is necessary so that subsequent stages of the pipeline can always interpret the object defined

as a quadrilateral (even though degenerate) and not treat as a special case all lower order objects (i.e., point, line, triangle). The indexed loading scheme also allows for only the opposite corners of a rectangle to be entered to properly define all four corners of the corresponding quadrilateral.

The last loading method, relative, is used to allow the CPU to just specify the difference between the last coordinate entered and the intended new coordinate value. In this case a CPU supplied delta or offset is added to the previously loaded coordinate before being loading into one or more registers. The 2-bit index is used to identify the last coordinate entered $[\text{vertex (index-1) mod 4}]$ for the necessary addition plus identifies which register or registers need to be loaded as in the indexed loading case.

In the end result, the CPU is free to choose to load the coordinate registers in any manner supported. When the operation, either a quadrilateral rendering or BLIT, is actually requested (after the coordinates have already been loaded) the current state of the four vertices are utilized directly without regard to how they were acquired. This provides the utmost in flexibility for the CPU.

Figure 1 is an overview of a graphics subsystem in which the present invention may be utilized. Bus interface logic 11 is connected through address, data and control buses to a central processing unit (not shown). The functional components of the graphics subsystem are data path and memory interface 13, coordinate staging section 15, coordinate sequencing

section 17, functional addressing block 19, mask generation block 21 and linear address generator 23.

Data path and memory interface 13 update a frame buffer (not shown) which is a memory which stores graphical information to be displayed on a video display such as a CRT. That is, data which is loaded into the frame buffer is accessed by video circuitry which converts the data to appropriate electrical signals which, in turn, turn individual pixels of the video display on and off. The data from bus interface logic is modified by mask generation block 21 and linear address generator 23 based upon processing performed by coordinate staging section 15, coordinate sequencing section 17 and functional addressing stage 19. Functional addressing stage 19 also accomplishes a portion of the clipping necessary to fit particular graphic objects to the clip window in which they are to be displayed, and then transfers the signals to mask generation stage 21 which arranges the information into sixteen pixel portions that traverse from the beginning to the end of the visible object for each scan line and are used for addressing the data path and memory interface stage 13.

The mask generation signals are also furnished to linear address generator 23 which translates the addresses provided by the mask generation stage 21 into signals for linearly addressing the frame buffer for transfer to the output display.

The present invention is directed to circuitry in coordinate staging block 15 which performs certain operations based upon its inputs, the specifics of which will be described below with reference to figures 2-14 generating information in the nature of control signals to enable a graphics subsystem to perform arbitrary quadrilateral rendering with clipping and block image transfers (BLITs) with clipping. Thus, the present invention is directed to specific circuitry within coordinate staging section 15.

Implementation of the various timing and control signals needed for the proper operation of the foregoing functional blocks comprising a video display subsystem are well known to persons skilled in the art and, therefore, will not be described herein except as necessary for a proper understanding of the invention.

Referring now to figure 2, a block overview diagram of coordinate staging section 15 is shown. Coordinate staging section 15 comprises adder 31, loading control state machine 33, multiplexer 35, XY coordinate registers 37, clip coordinate registers 39, raster offset registers 41, index logic 43, test window control logic 45, comparison logic and result storage 47, comparison control state machine 49, and status generation logic 51.

Before setting forth the specifics of the present invention, a brief description of the manner in which objects are represented follows to aid the understanding of the manner in which the present invention is implemented.

XY pairs of vertices represent video display coordinates. For a typical display, X ranges between 0-1151 and Y ranges between 0-899. Each X coordinate and each Y coordinate is stored in a separate 32 bit register or a pair of 16 bit registers. Although 16 bits are more than adequate to store the largest screen coordinate (i.e., up to 65535 or -32768 to +32767), 32 bits of information are stored because it is the data type most prevalent in graphics software and provides a large enough range to handle most real life objects which may span areas much larger than the video display.

Quadrilateral objects are represented as combinations of four pairs of vertices (X₀,Y₀), (X₁,Y₁), (X₂,Y₂), and (X₃,Y₃). If an object is a point, then all four pairs of vertices are the same or three points repeated. If an object is a line, then two of the four (or three of the four) pairs of vertices are replicated. If an object is a triangle, then one pair of vertices out of the four pairs is replicated. If an object is a quadrilateral then all four pairs are distinct. Objects (i.e., point, line, triangle or quadrilateral) are most efficiently defined using the minimum number of unique vertices necessary to completely define the object, i.e., for a point - 1, for a line - 2, for a triangle - 3, for a quadrilateral - 4 and for a rectangle - 2 (opposite corners).

If a block image transfer (BLIT) operation is to be performed, then the four X/Y registers have the following interpretation and are loaded accordingly:

X0 - X coordinate for upper left corner of the source block.

Y0 - Y coordinate for upper left corner of the source block.

X1 - X coordinate for lower right corner of the source block.

Y1 - Y coordinate for lower right corner of the source block.

X2 - X coordinate for upper left corner of the destination block.

Y2 - Y coordinate for upper left corner of the destination block.

X3 - X coordinate for lower right corner of the destination block.

Y3 - Y coordinate for lower right corner of the destination block.

Images to be displayed on a display such as a CRT are formed as discrete pixels which are stored in a random access memory (RAM) known as a frame buffer in one or more planes (or bits), the number of planes typically being eight for a color system. Data stored in the frame buffer is addressed by a pair of coordinates, X and Y, where an X,Y pair identifies a particular pixel in all planes, X being the row and Y being the column. A pixel is defined by a single bit from each plane. Thus, if eight planes are utilized, each displayed pixel is defined by eight bits in the frame buffer. In this manner, one bit of a pixel can be used to specify whether it is on or off, with the remaining seven bits specifying the color of the pixel, or all eight pixels can be used to specify the color, with one of the colors being the same as the background color of the display to turn the pixel off.

The present invention lies mainly in its implementation of test window control logic 45 and status generation logic 51. In this connection, with respect to the other functional blocks shown in Figure 2, their operation and implementation will be described only in such detail as is necessary for a proper understanding of the present invention.

Adder 31 and MUX 35

Adder 31 is a 16 or 32-bit 2's complement binary adder having two inputs, namely DataIn from bus interface logic 11 which represents incoming data from the CPU and an input from MUX 35 which is a multiplexer which selects one of a set of inputs from raster offset registers 47, X/Y coordinate registers 37, or clip coordinate registers 39. The input from MUX 35 is selected by signals generated by loading control state machine 33 as described below.

The details of adder 31 and multiplexor 35 will now be described with reference to Figure 3. In Figure 3, adder 31 is shown as a 16 bit adder. In this connection, although a 32 bit adder could be used since DataIn in the preferred embodiment is 32 bits, in order to save space on the integrated circuit in which the invention is implemented and since timing requirements of the pipeline utilized by the present invention are satisfied by a two step add, the following description will be directed to a 16 bit adder. The differences for utilizing a 32 bit adder will be apparent to those skilled in the art and, therefore, will not be described.

Multiplexor 35 is actually a pair of multiplexors 35a and 35b and a third multiplexor 36 which is used to input the high order and low order 16 bits from DataIn. Multiplexor 35a and 35b receive the high order and low order 16 bits respectively from seven 32 bit inputs as follows: one 16 bit input (sign extended to 32-bits) from raster offset registers 41, four 32 bit inputs from X/Y coordinate registers 37 and two 16 bit inputs (sign extended to 32-bits) from clip coordinate registers 39. The outputs from

multiplexors 35a and 35b are combined to form the signal DataOut (for providing read access to these register values to the CPU) and are also input to a third multiplexor 40 which passes the output from multiplexor 35a whenever the high order bits from X₀-X₃ or Y₀-Y₃ are being accessed; otherwise multiplexor 40 selects the output from multiplexor 35b. The output from multiplexor 40 is one input to logic gate 42 which either passes the 16 bit output from multiplexor 40 or passes 16 bits of zeros. In this connection, zeros are forced by logic gate 42 whenever the bits of DataIn are passed by multiplexor 36 for directly loading (absolute loading) into a register within raster offset registers 41, X/Y coordinate registers 37, or clip coordinate registers 39. Also shown in Figure 3 are logic circuits 44 and 46 which perform the following function. When a low order 16-bit add is taking place, AND gate 44 has its output forced to a low providing a carry-In of a "0" to the adder 31. The carry out of this add is saved in flip flop 46. The output of flip flop 46 is gated by AND gate 44 to the carry in of adder 31 during the addition of the upper 16-bits. This combination provides a 2 cycle 32-bit add equivalent to a single cycle 32 bit add.

The operation of adder 31, raster offset registers 41, X/Y coordinate registers 37, clip coordinate registers 39, test window control 45 and comparison logic and result storage 47 are coordinated by loading control state machine 33 and comparison logic state machine 49 which causes the aforesaid functional blocks to operate so that the data is flowing in a pipeline. Thus, although not all control lines from loading control state machine 33 and comparison logic state machine 49 are shown, the details will be readily apparent to those skilled in the art from the description of

loading control state machine 33 and comparison logic state machine 49 below.

X/Y Coordinate Registers 37

X/Y coordinate registers 37 is, referring to Figure 4, a set of 16-bit registers which store the (X_0, Y_0) - (X_3, Y_3) vertices of an object to be drawn. One 16-bit register is used to store the upper 16 bits of each X coordinate and another 16-bit register is used to store the lower 16 bits of each X coordinate. Similarly, another 16-bit register holds the upper 16 bits of each Y coordinate and another 16-bit register holds the lower 16 bits of each Y coordinate. These registers are shown in Figure 4 as X0L representing the lower 16 bits of the X_0 coordinate and X0U representing upper 16 bits of the X_0 coordinate. Registers X1L-X3L and X1U-X3U represent the lower and upper 16 bits of the X_1 - X_3 coordinates respectfully. Similarly registers Y0L-Y3L and Y0U-Y3U store the lower and upper 16 bits of the Y_0 - Y_3 coordinates of the object. References to X_0, Y_0 etc. mean the 32 bit value stored in the corresponding register pair, i.e., X0U, X0L and Y0U, Y0L.

Each pair of registers, (X_{0L}, Y_{0L}) - (X_{3L}, Y_{3L}) are coupled to a multiplexer pair which are used to select either the corresponding X or Y register. For example, registers X0L and Y0L are coupled to multiplexers 61a and 61b. Loading control state machine 33 generates a signal which directs multiplexer 61a to select the input from register X0L or Y0L depending upon the whether the X coordinates are to be operated upon or the Y coordinates are to be operated upon. Each of multiplexers 62a and 62b - 64a and 64b operate in the same manner respectively for data from

register pairs (X1L,Y1L)-(X3L,Y3L). The outputs from multiplexers 61a-64a go to multiplexer 35b, while the outputs from multiplexers 61b-64b go to comparison logic and result storage 47.

Blocks 67, 69, 71, and 73 labeled All 0's All 1's are each logic circuitry which checks the upper 18-bits of its corresponding X,Y coordinate pair for all zeros or all ones. Sixteen of the bits come from the registers (X0U,Y0U)-(X3U,Y3U) with the seventeenth and eighteenth bits coming from the high order two bits of the corresponding register in the grouping (X0L,Y0L-X3L,Y3L). The seventeenth and eighteenth bit input is not shown in Figure 4 to avoid unnecessarily cluttering the figure. The register pairs (X0U,Y0U)-(X3U,Y3U) are input into multiplexers 75-78 respectively which select either the X coordinate or Y coordinate in the same manner as multiplexer pairs 61a,61b-64a,64b. The outputs from multiplexers 75-78 go to multiplexer 35a. One of the 4-bits output from each of logic blocks 67-73 are each a "1" if the upper 18-bits of its corresponding register are all zeros or all ones, otherwise each of the 4-bits is zero. The four 4-bit outputs from blocks 67-73 are input into status generation logic 51.

Clip Coordinate Registers 39

Clip coordinate registers, as shown in Figure 5 comprises four registers, XClipMin, XClipMax, YClipMin, YClipMax and multiplexors 81a, 81b, 83a and 83b. The values XClipMin, XClipMax, YClipMin, YClipMax, which are stored in the aforesaid registers with the same name, respectively define the left, right, top and bottom of the currently active window. These values are generated by the CPU and are input to adder 31

which adds 0 to these values for loading the registers XClipMin, XClipMax, YClipMin, and YClipMax as described above. Multiplexors 81a and 83a on the one hand, and multiplexors 81b and 83b on the other, select XClipMin and XClipMax or YClipMin and YClipMax, depending on control signals generated by loading control state machine 33 and comparison control state machine 49 respectively. The values from multiplexors 81a and 83a are sent to multiplexor 35, while the values from multiplexors 81b and 83b are sent to comparison logic and result storage 47 and test window control 45.

Raster Offset Registers 41

Raster offset registers 41, as shown in Figure 6 comprises two registers, XRasOff, YRasOff, and multiplexor 53. The values XRasOff and YRasOff, which are stored in the aforesaid registers with the same name, respectively define the X and Y offset to be added (when desired) to DataIn before storage into each of the four sets of X,Y coordinates in X/Y coordinate registers 37. These values are generated by the CPU for storage in XRasOff and YRasOff. Multiplexor 53 selects XRasOff or YRasOff depending on control signals generated by loading control state machine 33. The value selected by multiplexor 53 is sent to multiplexor 35.

Test Window Control 45

Test window control 45 will now be described with reference to Figure 7. The CPU generates the values testXVal and testYVal which offset a predetermined distance, i.e. number of pixels, above and below (for testYVal) and to the right and left (for testXVal) of the currently active clipping window. That is, for a given window on a display, there is a ΔX

and ΔY which define a test window surrounding the real clip window. The purpose of this test window is to eliminate, whenever it is beneficial to do so, the need for the hardware to calculate the location of objects or portions of the objects which are outside the clipping window.

The 4-bit values testXVal and testYVal are stored in the 4-bit registers testX and testY respectively. Multiplexer 91 selects one of the registers testX or testY depending upon whether the X coordinates or the Y coordinates are being operated upon as determined by the signal MUX Enable generated by the loading control state machine 33. The output of multiplexer 91 is input into decrementor 93 and incrementor 95. Decrementor 93 has as a second input the value XClipMin or YClipMin and incrementor 95 has as a second input the value XClipMax or YClipMax, again depending upon whether X or Y coordinates are being operated upon as determined by the signal MUX Enable generated by the loading control state machine 33. The outputs generated by decrementor 93 and incrementor 95 will be referred to as XTestMin, YTestMin and XTestMax, YTestMax respectively. Decrementor 93 creates the values XTestMin and YTestMin by subtracting from XClipMin and YClipMin a value equal to 2 raised to (testX-1) and (testY-1) power respectively. Similarly, incrementor 93 creates the values XTestMax and YTestMax by adding to XClipMax and YClipMax a value equal to 2 raised to the (testX-1) and (testY-1) power respectively. (i.e., $2^{(\text{testX}-1)}$ or $2^{(\text{testY}-1)}$).

Loading Control State Machine 33 and Index Logic 43

Loading control state machine 33 generates the control signals, MUX Enable, Index and Register Enable. MUX Enable is a set of control signals,

one of which causes the various multiplexors in raster offset registers 41, X/Y coordinate registers 37 and clip coordinate registers 39 to select their respective X inputs or Y inputs; a second of which causes multiplexor 35 to select one of the inputs from raster offset registers 41, X/Y coordinate registers 37 or clip coordinate registers 39. Index is a single control signal which causes an index register in index logic 43 to increment by 1 between for each of the values 0, 1 and 2, and if the value is 3, to reset to 0 (modulo 4). Register Enable is a set of control signals, one for each of the registers in raster offset registers 41, X/Y coordinate registers 37 and clip coordinate registers 39, enabling each such register to load the 16 bit value on the line from adder 31.

The operation of load control state machine 33 and index logic 43 will now be described by way of an example from which the implementation details should be apparent. As noted above, images to be drawn are defined as being made of one or more objects having four pairs of vertices, $(X_0, Y_0) - (X_3, Y_3)$. Objects may be points, lines, triangles, rectangles or quadrilaterals. For points, the four pairs of vertices are identical. For lines, there are only two pairs of unique vertices. Four sided quadrilaterals have four unique vertices. A rectangle represents a special case of quadrilateral wherein there are only two unique X coordinates and two unique Y coordinates (rectangles can be defined by a pair of vertices defining diagonally opposite corners). For triangles, there are only three pairs of unique vertices.

The index value specifies which registers to enable based upon the type of object being defined. For proper operation, Y values precede X values. Except for rectangles, the index register is incremented after the X

values have been loaded in the appropriate registers. For rectangles, the index register is incremented after both X and Y values. In this connection, the following table sets forth for each type of object, the X registers which are enabled for each index register value. Although not shown, the enabled Y registers would correspond to the enabled X registers.

TABLE I

Object Type	Index Value At Time Of Load			
	0	1	2	3
point	X0,X1,X2,X3	X1,X2,X3,X0	X2,X3,X0,X1	X3,X0,X1,X2
line	X0,X1,X2	X1,X2,X3	X2,X3,X0	X3,X0,X1
quadrilateral	X0	X1	X2	X3
rectangle	X0,X1	X1,X2	X2,X3	X3,X0

An important point that can be seen in Table I is that the coordinate pointed to by the index register is always written. The type of write (point, line, triangle, etc.) indicates how many subsequent registers (modulo 4) will also be written. For example, if the index is 2, at the time a line X write is received, then three registers will be written, namely X2, $(X2 + 1) \text{ modulo } 4$ and $(X2 + 2) \text{ modulo } 4$ or X2, X3 and X0. A quadrilateral write to Y would only affect Y2.

Examples 1-3 below will explain the role of the index register when defining an object. Each line of the example indicates the intended write operation, the index register value utilized by the loading control state machine to govern the loading of the coordinate registers, the values stored in the coordinate registers after the write, and the index value after the write cycle concludes. The mnemonics for the write commands are

PntX or PntY to indicate a point write, LineX or LineY for a line write, TriX and TriY for a triangle write, QuadX and QuadY for a quadrilateral write, and RectX and RectY for a rectangle write operation. The actual write operation identified by each write command is actually a multi-clock cycle operation as will be described later. For these examples though, the execution time of the command is of no relevance.

As a means of clarifying the interpretation of these examples, the first one will be described. From this description the interpretation of Examples 2 and 3 should be readily apparent.

At the time the PntY(6) command is received, all coordinate registers contain the value "0" and the index is equal to "1". The PntY(6) command says that a point of value 6 should be loaded into the Y coordinate registers. Since the index is a 1, Table I indicates that the incoming value (6) should be stored into Y1, Y2, Y3 and Y0. The next command received, PntX(3), then says to load the point 3 into X1, X2, X3 and X0. As is the case after all indexed X coordinate writes, the index is incremented (modulo 4) at the end of the write cycle. The next write command is a LineY(9). The index for this load is 2 and Table I indicates the loading of 9 into Y2, Y3 and Y0. The final write command for this example is LineX(7). Table I indicates the loading of 7 into X2, X3 and X0 after which the index register is again incremented. The final state of the coordinate registers identify two unique vertices (3 vertices at (7, 9) and one at (3, 6)). Geometrically, this is a line with endpoints at (7, 9) and (3, 6) as was intended.

Example 1 Specifying a line (3, 6) (7, 9)

Command	X0	X1	X2	X3	Y0	Y1	Y2	Y3	Index Before Write	Index After Write
-	0	0	0	0	0	0	0	0	01	01
write PntY(6)	0	0	0	0	6	6	6	6	01	01
write PntX(3)	3	3	3	3	6	6	6	6	01	02
write LineY(9)	3	3	3	3	9	6	9	9	02	02
write LineX(7)	7	3	7	7	9	6	9	9	02	03

Example 2 Specifying a triangle (1,5) (9,3) (4,6)

Command	X0	X1	X2	X3	Y0	Y1	Y2	Y3	Index Before Write	Index After Write
-	7	3	7	7	9	6	9	9	03	03
write TriY(5)	7	3	7	7	5	6	9	5	03	03
write TriX(1)	1	3	7	1	5	6	9	5	03	00
write TriY(3)	1	3	7	1	3	3	9	5	00	00
write TriX(9)	9	9	7	1	3	3	9	5	00	01
write TriY(6)	9	9	7	1	3	6	6	5	01	01
write TriX(4)	9	4	4	1	3	6	6	5	01	02

Example 3 Specifying a Rectangle (0,7) (8,7) (8,1) (0,1)

Command	X0	X1	X2	X3	Y0	Y1	Y2	Y3	Index Before Write	Index After Write
-	9	4	4	1	3	6	6	5	02	02
write RectY(1)	9	4	4	1	3	6	1	1	02	03
write RectX(0)	0	4	4	0	3	6	1	1	03	00
write RectY(7)	0	4	4	0	7	7	1	1	00	01
write RectX(8)	0	8	8	0	7	7	1	1	01	02

Although in example 1, the index register is arbitrarily 1 when the first coordinate is received, the index register in index logic 43 may be initialized based upon a value placed on DataIn if instructed by the CPU. (It is worth noting, however, that proper operation of this invention is totally independent of the initial value of the index register when a loading sequence is initiated.). It is also assumed in this example that XRasOff and YRasOff contain the value 0 so as not to obscure the operation of this circuitry.

Loading control state machine 33 in conjunction with comparison logic state machine 49 controls a pipelining scheme which in addition to loading the various registers described above, also controls the selection of registers and corresponding multiplexors necessary for the proper operation of comparison logic and result storage 47 and status generation logic 51. Additionally, when it is desired to not utilize the raster offset capability of the present invention, it is necessary to force the addition of 0's to the incoming data for storage into the X and Y coordinate registers prior to performing the comparisons performed by comparison logic and result storage 47.

In this connection, the MUX Enable, and Register Enable control signals generated by loading control state machine 33 and comparison logic state machine 49 may be ascertained from the timing sequence table set forth in Figure 9 and the following list showing the order of processing performed by coordinate staging section 15 for each entered Y coordinate.

1. Receive Y coordinate on DataIn

2. Add the low order 16 bits of the received Y coordinate to:
 - a) YRasOff (lower 16-bits)
 - or b) the low order 16 bits of Y0L-Y3L pointed to by (index-1)
 - or c) 0's

3. Add the high order 16 bits of the received Y coordinate to:
 - a) YRasOff (sign extended upper 16-bits)
 - or b) the high order 16 bits of Y0H-Y3H pointed to by (index-1)
 - or c) 0'sand compare the result of step 2 to the other Y coordinates

4. Compare the result of step 2 to YClipMin, YTestMin, YClipMax, and YTestMax and examine the upper 18 bits of the result of steps 2 and 3 for all 1's and all 0's.

In steps 2 and 3 above, the choices a), b) or c) are made as follows. For non-relative writes to an indexed register (PNT, LINE, TRI, QUAD, RECT) choice a) is selected. For a relative write to an indexed register (REL PNT, REL LINE, REL TRI, REL QUAD, REL RECT) choice b) is selected. All other writes select choice c). The loading of an X coordinate follows the same flow.

With the foregoing restrictions and definitions in mind, and assuming that the index register value in index logic 43 is '01' and registers (X0,Y0) - (X3,Y3) as described above with reference to Figure 4 are all 0, the following sequence of events takes place to load the registers so as to define a line having endpoints whose X,Y coordinates are (3,6) (7,9) as in Example 1.

At clock cycle 0, the command write PntY(6) places the value 6 on DataIn, and causes the register address input to loading control state

machine 33 to contain a value indicating that the incoming data is a Y point. At clock cycle 1 (and referring to Figure 3), multiplexor 36 is instructed to select the low order 16 bits on DataIn and multiplexors 35 (i.e., multiplexors 35a and 35b) and 40 and logic gate 42 are instructed to pass the lower 16 bits of YRasOff. Thus, during clock cycle 1, adder 31 adds the outputs from multiplexor 36 and logic gate 42 and places the result at its output. At the end of clock cycle 1, registers Y0L-Y3L are enabled and loaded with the value from adder 31, i.e., 6 representing the low order bits of the value 6 that was on DataIn. At clock cycle 2, multiplexor 36 is instructed to select the high order 16 bits on DataIn and multiplexors 35 and 40 and logic gate 42 are instructed to pass the sign extended upper 16 bits of YRasOff. Thus, during clock cycle 2, adder 31 adds the outputs from multiplexor 36 and logic gate 42 and places the result at its output. At the end of clock cycle 2, registers Y0H-Y3H are enabled and loaded with the value from the output of adder 31. At cycle 3, the command write PntX(3) places the value 3 on DataIn, and causes the register address input to loading control state machine 33 to contain a value indicating that the incoming data is an X point. Also at clock cycle 3, multiplexor 36 is instructed to select the low order 16 bits on DataIn and multiplexors 35 and 40 and logic gate 42 are instructed to pass the lower 16 bits of XRasOff. During clock cycle 3, adder 31 adds the outputs from multiplexor 36 and logic gate 42 and places the result at its output. At the end of clock cycle 3, registers X0L-X3L are enabled and loaded with the value from adder 31, i.e., 3 representing the low order bits of the value 3 that was on DataIn. At clock cycle 4, multiplexor 36 is instructed to select the high order 16 bits on DataIn and multiplexors 35 and 40 and logic gate 42 are instructed to pass the sign extended upper 16 bits of XRasOff. At

clock cycle 4, adder 31 adds the outputs from multiplexor 36 and logic gate 42 and places the result at its output. During clock cycle 4, registers X0H-X3H are enabled and loaded with the value from the output of adder 31, and the index register is incremented. At clock cycle 5, the command write LineY(9) places the value 9 on DataIn, and causes the register address input to loading control state machine 33 to contain a value indicating that the incoming data is a Y line. At clock cycle 5, multiplexor 36 is instructed to select the low order 16 bits on DataIn and multiplexors 35 and 40 and logic gate 42 are instructed to pass the lower 16 bits of YRasOff. During clock cycle 5, adder 31 adds the outputs from multiplexor 36 and logic gate 42 and places the result at its output. At the end of clock cycle 5, registers Y2L, Y3L and Y0L are enabled and loaded with the value from adder 31, i.e., 9 representing the low order bits of the value 9 that was on DataIn. At clock cycle 6, multiplexor 36 is instructed to select the high order 16 bits on DataIn and multiplexors 35 and 40 and logic gate 42 are instructed to pass the sign extended upper 16 bits of YRasOff. At clock cycle 6, adder 31 adds the outputs from multiplexor 36 and logic gate 42 and places the result at its output. During clock cycle 6, registers Y2H, Y3H and Y0H are enabled and loaded with the value from the output of adder 31. At clock cycle 7, the command write LineX(7) places the value 7 on DataIn, and causes the register address input to loading control state machine 33 to contain a value indicating that the incoming data is an X line. In a like manner registers X2L, X3L and X0L are eventually enabled to load the value 7 after which the index register is incremented from 2 to 3 as shown above. Loading X/Y coordinate registers for other objects follows the same pipeline scheme described above. Examples for triangles

and rectangles are given in examples 2 and 3 above. In a similar manner, quadrilateral objects are also loaded.

Raster offset registers 41 and clip coordinate registers 39 are loaded in a similar manner as X/Y coordinate registers 37 as described above, however, logic gate 42 is instructed to force 0's for each add cycle. (i.e., absolute loading)

The present invention, by use of the index register in index logic 43 also performs relative addressing which provides an efficient mechanism for displaying duplicates of objects. Relative addressing is best described by way of an example as follows. The three vertices of a triangle may be defined as (X_0, Y_0) , (X_1, Y_1) and (X_2, Y_2) . To duplicate this object 50 times at different locations on the display, it would be necessary to store 150 pairs of X,Y coordinates. Using relative addressing, one vertex is defined as the origin (X_0, Y_0) , and the second and third vertices are defined as offsets from the previous vertex, i.e., $\Delta X_{01}, \Delta Y_{01}$ and $\Delta X_{23}, \Delta Y_{23}$. To duplicate the object 50 times, all that needs to be stored are the two offset pairs and a new X_0, Y_0 for each duplicate (i.e. fifty object origins plus two offset pairs total).

This can be accomplished in the present invention by first storing the origin coordinate pair vertex in one of the register pairs within X/Y coordinate registers 37 using an indexed loading style (i.e., PntY, PntX). The two offset vertices are subsequently stored relative to the vertex pointed to by the current value of the index register. This is accomplished by selecting the vertex pointed to by (index -1) to be added to DataIn prior to register loading. The vertex referenced by (index -1) is

guaranteed to have been loaded on the previous indexed write irrespective of the type of write (PNT, LINE, etc.) and is, therefore, the vertex from which the relative offset applies.

Comparison logic and result storage logic 47

Comparison logic and result storage logic 47 will now be described with reference to Figures 7 and 8. Comparison logic and result storage logic 47 comprises multiplexors 101, 103, 105, 107 and 109 (see Figure 7), and, comparators 121-124, multiplexors 131-146 and registers R1-R44 (see Figure 8).

Registers R1-R44 store the results of the operation of comparators 121-124 as shown in Table II:

TABLE II

R1 X0:XClipMin	R23 Y0:YClipMin
R2 X0:XTestMin	R24 Y0:YTestMin
R3 X0:XClipMax	R25 Y0:YClipMax
R4 X0:XTestMax	R26 Y0:YTestMax
R5 X1:XClipMin	R27 Y1:YClipMin
R6 X1:XTestMin	R28 Y1:YTestMin
R7 X1:XClipMax	R29 Y1:YClipMax
R8 X1:XTestMax	R30 Y1:YTestMax
R9 X2:XClipMin	R31 Y2:YClipMin
R10 X2:XTestMin	R32 Y2:YTestMin
R11 X2:XClipMax	R33 Y2:YClipMax
R12 X2:XTestMax	R34 Y2:YTestMax
R13 X3:XClipMin	R35 Y3:YClipMin
R14 X3:XTestMin	R36 Y3:YTestMin
R15 X3:XClipMax	R37 Y3:YClipMax
R16 X3:XTestMax	R38 Y3:YTestMax
R17 X0:X1	R39 Y0:Y1
R18 X0:X2	R40 Y0:Y2
R19 X0:X3	R41 Y0:Y3
R20 X1:X2	R42 Y1:Y2

R21 X1:X3
R22 X2:X3

R43 Y1:Y3
R44 Y2:Y3

In Table II, excepting for the comparisons involving XClipMin/Max, YClipMin/Max, XTestMin/Max, and YTestMin/Max which store a one bit result, the indicated register stores a two bit result of a comparison between the two indicated values. If the value on the left of the colon is greater than the value to the right of the colon, the binary value stored in the corresponding register is '10'; if the value on the left of the colon is less than the value to the right of the colon, the binary value stored in the corresponding register is '01'; if the two values are equal, the binary value stored in the corresponding register is '00'. For XClipMin, YClipMin, XTestMin, and YTestMin, if the coordinate value compared is less, a '1' is stored, otherwise, a '0' is stored. For XClipMax and YClipMax, XTestMax, YTestMax, if the value compared is greater, a '1' is stored, otherwise, a '0' is stored.

The inputs to multiplexors 101, 103, 105, 107 and 109 are from X/Y coordinate registers 37, namely X0L,Y0L - X3L,Y3L, clip coordinate registers 39, namely XClipMin,YClipMin and XClipMax,YClipMax and test window control 45, namely XTestMin, YTestMin, XTestMax and YTestMax. Of course, at any one time, the inputs to multiplexors 101, 103, 105, 107 and 109 are either X values or Y values as described above, based upon a MUX Enable signal generated by comparison control state machine 49.

Comparator 121 compares multiplexor 101 output and multiplexor 109 output. Similarly, comparators 122-124 compare multiplexor 103, 105 and 107 outputs on the one hand and multiplexor 109 output on the other. The outputs from comparators 121-124 are input to multiplexors

131-146 which direct the appropriate data to registers R1-R44 to be loaded as follows.

The output from comparator 121 is connected to multiplexors 131-135, 139 and 143 which are used to load registers R1, R2, R3, R4, R5, R9, R13, R17, R18, and R19, for X values and registers R23, R24, R25, R26, R27, R31, R35, R39, R40, and R41 for Y values as shown in Figure 8 and Table II below. In Table III, A, B, C, and D refer to comparators 121, 122, 123 and 124 respectively.

The output from comparator 122 is connected to multiplexors 132, 135, 136, 137, 138, 140, and 144 which are used to load registers R2, R5, R6, R7, R8, R10, R14, R17, R20, and R21 for X values and registers R24, R27, R28, R29, R30, R32, R36, R39, R42 and R43 for Y values as shown in Figure 8 and Table III.

The output from comparator 123 is connected to multiplexors 133, 137, 139, 140, 142, and 145 which are used to load registers R3, R7, R9, R10, R12, R15, R18, R20 and R22 for X values and registers R25, R29, R31, R32, , R34, R37, R40, R42, and R44 for Y values as shown in Figure 8 and Table III.

The output from comparator 124 is connected to multiplexors 134, 138, 142, 143, 144, 145 and 146 which are used to load registers R4, R8, R12, R13, R14, R15, R16, R19, R21, and R22 for X values and registers R26, R30, R34, R35, R36, R37, R38, R41, R43 and R44 for Y values as shown in Figure 8 and Table III.

The comparisons done and stored are those required by coordinate sequencing block 17 and functional addressing block 19 in order to properly execute supported operations (DRAW, also known as quadrilateral rendering, or BLIT) and perform proper clipping.

Comparison Control State Machine 49

Comparison control state machine 49 is logic which enables the various comparators, multiplexors and registers in comparison logic and result storage 47. A truth table for absolute loading of the coordinate and clipping registers by the comparison control state machine 49 is shown in Table III for clock cycles 0 and 1, with comparators 121-124 referenced A, B, C and D respectively. Table III sets forth the output of each comparator 121-124 for each of the inputs X0L-X3L, XClipMin, XClipMax, XTestMin and XTestMax. In this connection, although Figure 8 shows that the outputs of multiplexors 101, 103, 105 and 107 are input into one side of comparators 121-124, with the output of comparator 109 being input into the other side. For consistency, it is necessary to store the comparisons of X0L to X1L, X1L to X2L and X2L to X3L etc., rather than the other way around (e.g., X1L to X0L). For this reason, when the column labeled reverse is "yes," the outputs from comparators 121-124 are reversed. This is handled by the right input of multiplexors 131-146. The output from the indicated comparators 121-124 are directly input to the left side of the indicated multiplexor 131-146. The right multiplexor input receive the 2 bit output from the indicated comparator in reverse bit order. Thus, the column labeled reverse becomes the truth table for the MUX select line lines for multiplexors 131-146 for absolute coordinate loads.

TABLE III

COMPARATOR	COMPARISON	REVERSE	CYCLE
WRITE TO X0			
B	X0L:X1L	YES	0
C	X0L:X2L	YES	0
D	X0L:X3L	YES	0
A	X0L:XClipMin	YES	1
B	X0L:XTestMin	YES	1
C	X0L:XClipMax	YES	1
D	X0L:XTestMax	YES	1
WRITE TO X1			
A	X1L:X0L	NO	0
C	X1L:X2L	YES	0
D	X1L:X3L	YES	0
A	X1L:XClipMin	YES	1
B	X1L:XTestMin	YES	1
C	X1L:XClipMax	YES	1
D	X1L:XTestMax	YES	1
WRITE TO X2			
A	X2L:X0L	NO	0
B	X2L:X1L	NO	0
D	X2L:X3L	YES	0
A	X2L:XClipMin	YES	1
B	X2L:XTestMin	YES	1
C	X2L:XClipMax	YES	1
D	X2L:XTestMax	YES	1
WRITE TO X3			
A	X3L:X0L	NO	0
B	X3L:X1L	NO	0
C	X3L:X2L	NO	0
A	X3L:XClipMin	YES	1
B	X3L:XTestMin	YES	1
C	X3L:XClipMax	YES	1
D	X3L:XTestMax	YES	1

COMPARATOR	COMPARISON	REVERSE	CYCLE
WRITE TO XClipMin			
A	XClipMin:X0L	NO	0
B	XClipMin:X1L	NO	0
C	XClipMin:X2L	NO	0
D	XClipMin:X3L	NO	0
A	XTestMin:X0L	NO	1
B	XTestMin:X1L	NO	1
C	XTestMin:X2L	NO	1
D	XTestMin:X3L	NO	1
WRITE TO XClipMax			
A	XClipMax:X0L	NO	0
B	XClipMax:X1L	NO	0
C	XClipMax:X2L	NO	0
D	XClipMax:X3L	NO	0
A	XTestMax:X0L	NO	1
B	XTestMax:X1L	NO	1
C	XTestMax:X2L	NO	1
D	XTestMax:X3L	NO	1

The results of Table III are repeated in a similar manner for Y0L-Y3L, YClipMin, YClipMax, YTestMin and YTestMax. Figure 9 shows the relative timings of the signals on DataIn, the register loading performed by raster offset registers 41, X/Y coordinate registers 37, clip coordinate registers 39 and comparison logic and result storage 47.

The comparison control state machine supports the indexed loading scheme as previously discussed utilizing both the index register value associated with a write cycle and Table IV. Since the register pointed to by the index register value is always written irrespective of the type of indexed write, the appropriate Mux Enables for MUXes 101, 103, 105 and 107 are selected by the comparison control state machine assuming a single register write to that coordinate. For example, if a rectangle write to

X with an index of 3 is received, the comparison logic will operate as if an explicit write to X3 was received and do comparisons X3L vs (X0L, X1L, X2L, XClipMin, XClipMax, XTestMin, XTestMax) as is required. The difference between an absolute loading of a register and an indexed (or relative indexed) load is that in the indexed case, more than one coordinate storage register in 47 may be enabled to receive the comparison results and the multiplexor selects for multiplexors 131-146 are generated according to Table IV instead of Table III.

In the previous example of a rectangle X write with an index of 3, comparison registers (refer to Table II or Figure 8) R1-R3, R13-R16, R17-R19, and R21-R22 are written. The following registers pairs will store the same individual comparison results: (R17, R21), (R18, R22), (R1, R13), (R2, R14), (R3, R15), and (R4, R16).

TABLE IV

COMPARATOR	COMPARISON	TYPE	REVERSE	INDEX
B	X0:X1	PNT	yes	-
C	X0:X2	PNT	yes	-
D	X0:X3	PNT	yes	-
C	X1:X2	PNT	yes	-
D	X1:X3	PNT	yes	-
D	X2:X3	PNT	yes	-
B	X0:X1	LINE	yes	0
C	X0:X2	LINE	yes	0
D	X0:X3	LINE	yes	0
C	X1:X2	LINE	yes	0
D	X1:X3	LINE	yes	0
D	X2:X3	LINE	yes	0

COMPARATOR	COMPARISON	TYPE	REVERSE	INDEX
A	X0:X1	LINE	no	1
A	X0:X2	LINE	no	1
A	X0:X3	LINE	no	1
C	X1:X2	LINE	yes	1
D	X1:X3	LINE	yes	1
D	X2:X3	LINE	yes	1
A	X0:X1	LINE	yes	2
C	X0:X2	LINE	yes	2
D	X0:X3	LINE	yes	2
B	X1:X2	LINE	no	2
B	X1:X3	LINE	no	2
C	X2:X3	LINE	yes	2
A	X0:X1	LINE	yes	3
C	X0:X2	LINE	yes	3
D	X0:X3	LINE	yes	3
C	X1:X2	LINE	yes	3
D	X1:X3	LINE	yes	3
C	X2:X3	LINE	no	3
B	X0:X1	TRI/RECT	yes	0
C	X0:X2	TRI/RECT	yes	0
D	X0:X3	TRI/RECT	yes	0
C	X1:X2	TRI/RECT	yes	0
D	X1:X3	TRI/RECT	yes	0
A	X0:X1	TRI/RECT	no	1
A	X0:X2	TRI/RECT	no	1
C	X1:X2	TRI/RECT	yes	1
D	X1:X3	TRI/RECT	yes	1
D	X2:X3	TRI/RECT	yes	1
A	X0:X2	TRI/RECT	no	2
A	X0:X3	TRI/RECT	no	2
B	X1:X2	TRI/RECT	no	2
B	X1:X3	TRI/RECT	no	2
D	X2:X3	TRI/RECT	yes	2

COMPARATOR	COMPARISON	TYPE	REVERSE	INDEX
B	X0:X1	TRI/RECT	yes	3
C	X0:X2	TRI/RECT	yes	3
D	X0:X3	TRI/RECT	yes	3
B	X1:X3	TRI/RECT	no	3
C	X2:X3	TRI/RECT	no	3
B	X0:X1	QUAD	yes	0
C	X0:X2	QUAD	yes	0
D	X0:X3	QUAD	yes	0
A	X0:X1	QUAD	no	1
C	X1:X2	QUAD	yes	1
D	X1:X3	QUAD	yes	1
A	X0:X2	QUAD	no	2
B	X1:X2	QUAD	no	2
D	X2:X3	QUAD	yes	2
A	X0:X3	QUAD	no	3
B	X1:X3	QUAD	no	3
C	X2:X3	QUAD	no	3

Status Generation Logic 51

Status generation logic 51 generates the control signals HW/SW, Up/R-to-L and HID/VIS. HW/SW is a 2 bit signal indicating whether the operation will be done by the hardware of the present invention or by software. Up/R-to-L is a 2 bit signal indicating whether operation should be processed top to bottom, bottom to top, right to left or left to right. HID/VIS is a two bit signal indicating whether the object to be drawn is hidden, i.e. behind the active clip window or visible. To generate these signals, status generation logic 51 receives as inputs the registers R1-R22 for X coordinates registers R23-R44 for Y coordinates and the four 4 bit signals indicating the upper 18 bits are all 1's and all 0's from X/Y

coordinate registers 37. The manner in which status generation logic generates the foregoing control signals will be explained with reference to Figures 10-14 which are truth tables for the logic performed by status generation logic 51. The logic circuitry necessary to implement the truth tables of Figures 10-14 is well within the capabilities of persons skilled in the relevant art.

Figure 10 is a truth table utilizing comparison results for the X0 coordinate (X0L and X0H). Truth tables utilizing comparison results for the X1-X3 and Y0-Y3 coordinates by substituting those coordinates and using YClipMin, YClipMax, YTestMin and YTestMax in place of XClipMin, XClipMax, XTestMin and XTestMax for the Y coordinates. The left side of the table are the inputs and the right side are the outputs. In the table, the symbol "-" is a don't care; O and !O means the bus bit values are all 1's or not all 1's respectively (from X/Y coordinate registers 37); and Z and !Z means the bus bit values are all 0's or not all 0's respectively (from X/Y coordinate registers 37). "X0 inside 2^{14} " means the 32 bit X0 coordinate is representable in 15 bits; "X0 inside clip" means X0 is on or inside the clip window X boundaries; "X0 inside test" means X0 is on or inside the test window X boundaries. The outputs "X0 < XClipMin", "X0 < XTestMin", "X0 > XClipMax", and "X0 > XTestMax" are feedback and used as inputs. To form the outputs, the inputs on a horizontal line are ANDed together and the outputs in a column are ORed together. Thus, for example, referring to the first two lines of Figure 10, if X0[31] (i.e., its sign bit) is 0 AND X0[30:14] (i.e., its high order bits 14-30) are all 0's, OR X0[31] is 1 AND X0[30:14] are all 1's, then X0 is inside 2^{14} . Similarly, referring to the last line of Figure

10, if $X0 < XTestMin$ is 0 (i.e. false) AND $X0 > XTestMax$ is 0, then $X0$ is inside the test window.

Figures 11a and 11b are a truth table utilizing comparisons between each of the four X vertices and each of the four Y vertices. As was the case with Figure 10, the values on a horizontal input line are ANDed together with the result being a logical 1 (true) or 0 (false) and the indicated outputs (except for top, bottom, right and left) are formed by ORing its corresponding column. The outputs top, bottom, right and left which are shown as 0, 1, 2 or 3 are interpreted as follows. The value 0, 1, 2 or 3 specifies which coordinate of $X0-X3$ or $Y0-Y3$ is the largest (top), smallest (bottom), rightmost (right) and leftmost (left). The symbols $<$, $>$, E , L and G on the input side indicate that the specified comparison result is less than, greater than, equal to, less than or equal to and greater than or equal to respectively.

Although the meaning of the outputs is defined by the table, the following sets forth in words what each indicated output means:

illegal - means that if a horizontal line is drawn through the object defined by the four pairs of vertices, it would cross two or more edges. An object which forms a bow tie is an example of an object that would cause illegal to be true.

horiz-means all four vertices have the same Y value.

vert-means all four vertices have the same X value.

rect-means the object defined by the four coordinates forms a rectangle.

line-means the object defined by the four coordinates forms a line.

EQ_01 means vertex 0 equals vertex 1. (defines the same point)

EQ_12 means vertex 1 equals vertex 2. (defines the same point)

EQ_23 means vertex 2 equals vertex 3. (defines the same point)

EQ_30 means vertex 3 equals vertex 0. (defines the same point)

Figures 12a-12d define a truth table utilizing comparisons between the four X and the four Y vertices and the clipping boundaries. The inputs top, bottom, right and left are from the truth table of Figures 11a-11b. When the outputs top visible, bottom visible, right visible and left visible are 1 (i.e. true), the object defined by the four coordinate pairs is inside the clip window. When surround clip is 1, the object is outside but surrounding the clip window. Hidden is applicable only for quadrilaterals and indicates that all four vertices are all right, left, top or bottom of the clip window. Hidden_01 (refers to BLIT SRC rectangle) and hidden_23 (refers to BLIT DEST rectangle) have a similar meaning for BLITs.

Figure 13 defines a truth table utilizing comparisons between the four X and the four Y vertices and the test window boundaries. The outputs "top within test" and "bottom within test", when true, mean that edge of the object is within the top or bottom boundaries of the test window, respectively.

Figure 14 defines a truth table showing the direction in which to draw objects or perform BLITs in order to minimize page crossings and processing of clipped pixels by generating the signals blit r-to-l, blit up,

draw r-to-l and draw up. These signals comprise the signal Drawing Direction shown in Figure 2.

Based upon the truth tables of Figures 10-14, status generation logic 51 generates the signals HW, SW, HID and VIS shown in Figure 2 as follows:

For quadrilateral objects-

HW = hidden OR

surround clip OR

(NOT hidden AND

NOT illegal AND

all vertices are inside 2^{14} AND

(all vertices are inside test OR

(line AND at least one endpoint is inside test) OR

(X0-X3 are inside test AND the top or bottom vertex is
inside test) OR

rect).

SW = NOT HW.

HID = hidden

VIS = NOT hidden

For BLITs-

HW = hid_23 OR

(hid_01 AND BLIT SRC_CHK=10) OR

(NOT hid_01 AND

BLIT SRC_CHK=10 AND

NOT hid_23 AND

the source rectangle is inside 2^{14} AND the destination rectangle
is inside 2^{14}) OR
(BLIT_SRC_CHK=01 AND
NOT hid_23 AND
the source rectangle is inside 2^{14} AND
the destination rectangle is inside 2^{14})

where BLIT_SRC_CHK is a two bit value from the CPU which is set to '10'
when it is desired to consider the relationship of the source rectangle to
the clipping window. This is necessary because the various graphics
software which may utilize the present invention are inconsistent as to
their treatment of the SRC rectangle and the clipping boundaries. For this
reason, the preferred embodiment has left BLIT SRC rectangle clip
checking as a software selectable option (BLIT-SRT-CHK=01 disables SRC
clip check, BLIT-SRC-CHK=10 enables SRC clip check).

SW = NOT HW.

HID = hid_23

VIS = NOT hid_23

As can be ascertained from the HW equation for quadrilateral
objects, certain optimizations are applied to increase the effectiveness of
the test window checks in the preferred embodiment of the graphics
subsystem described.

As the HW equation for quadrilateral objects reflects, the utilization
of the test window checks in the preferred embodiment of the graphics
subsystem described have been optimized to make maximum use of the
subsystem whenever it is advantageous.

Coordinate sequencing logic 17 and functional addressing logic 19 have the ability to handle certain classes of clipped objects such that no hidden (i.e., invisible or clipped) pixels need be processed. In these cases, the utilization of the test window optimization is not needed so it is inhibited from effecting the HW vs SW decision on these objects. In other cases, the object may have certain characteristics which may allow for the hardware to effectively handle the object despite some vertices being outside the test window.

Examples of objects which fall into these categories follow along with how the graphics subsystem handles them.

- 1) Objects that surround the clip window - the vertices of these objects can be directly substituted with the clip boundaries prior to processing. This occurs in coordinate sequencing logic 17.
- 2) Lines with one vertex within the test window and one vertex outside it - the processing of these lines is constrained to occur from the vertex that is within the test window and proceed toward the other vertex. When the visible portion of the line has been processed, the processing is terminated without ever having to process pixels outside of the test window. The processing direction constraint is determined by status generation logic 51. The termination of processing after the visible portion of the line had been handled is done by functional addressing logic 19.
- 3) Arbitrary quadrilaterals that have all vertices within the test window in the X direction and the top or bottom vertice(s) within the test window in the Y direction - the processing of these objects is constrained to occur from the top or bottom of the object depending on which side of

the object is within the test window. The processing of the object will then proceed toward the other side (top or bottom) in the direction toward the vertice(s) that are outside the test window. When the visible portion(s) of the object has been processed, the processing is terminated without ever having to process pixels outside of the test window. The processing direction constraint is determined by status generation logic 51. The termination of processing after the visible portion(s) of the object has been handled is done by functional addressing logic 19.



CLAIMS

1. An apparatus for performing comparisons between pairs of X and Y coordinates of an object to be displayed by a graphics subsystem, pairs of predetermined clip coordinates and pairs of predetermined offsets, and generating a plurality of signals representing the results of said comparisons, said object being one of a quadrilateral to be drawn and block image to be moved, said apparatus having a clip window with predetermined top, bottom, right and left clip coordinates, said apparatus comprising:

- a) a plurality of object coordinate registers;
- b) a plurality of clip coordinate registers;
- c) a plurality of offset registers;
- d) loading means comprising a first multiplexor coupled to the plurality of object coordinate registers, the plurality of clip coordinate registers and the plurality of offset registers, said loading means further comprising a loading control means for controlling the operation of the first multiplexor for loading:
 - i) the plurality of object coordinate registers with said X and Y coordinate pairs of said object,
 - ii) the plurality of clip coordinate registers with said predetermined clip coordinates, and
 - iii) the plurality of off set registers with predetermined X and Y offsets from said top and bottom clip coordinates, and from said right and left clip coordinates, said X and Y coordinate pairs of said object, said clip coordinates and said offset for use in calculations for performing clipping of the object prior to its display, wherein said predetermined X and Y offsets define a test window and wherein said test window is larger than, and encompasses, said clip window;
- e) comparison means coupled to said loading means for performing said comparisons between said X and



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Y coordinates of said object, said predetermined clip coordinates and said predetermined offsets;

f) calculation means for calculating the borders of said test window relative to the borders of said clip window;

g) a multiplexor coupled to said comparison means for selecting predetermined ones of said comparisons;

h) at least one comparison register coupled to said multiplexor for storing the selected predetermined ones of said comparisons;

i) comparison control means controlling the operation of said comparison means, said multiplexor and said comparison register; and

j) status generation means coupled to said comparison register for generating said plurality of signals based upon certain of said selected predetermined ones of said comparisons which specify whether the X coordinate of each said X and Y coordinate pair is less than said predetermined left clip coordinate, greater than said predetermined right clip coordinate, less than said predetermined left clip coordinate minus said X offset, greater than said predetermined right clip coordinate plus said X offset, is representable in 15 bits, within said left clip coordinate and right clip coordinate, within said left clip coordinate minus said X offset and said right clip coordinate plus said X offset, and which specify whether the Y coordinate of each said X and Y coordinate pair is less than said predetermined bottom clip coordinate, greater than said predetermined top clip coordinate, less than said predetermined bottom clip coordinate minus said Y offset, greater than said predetermined top clip coordinate plus said Y offset, is representable in 15 bits, within said bottom clip coordinate and top clip coordinate, and within said bottom clip coordinate minus said Y offset and said top



clip coordinate plus Y offset.

2. The apparatus defined by claim 1 wherein said loading control means comprises a load control state machine coupled to said multiplexor, said load control state machine for generating signals which cause said multiplexor to select one of said plurality of object coordinate registers, said plurality of clip coordinate registers and said plurality of offset register to be passed to said calculation means.

3. The apparatus defined by claim 2 wherein said calculation means comprises an adder coupled to said multiplexor.

4. The apparatus defined by claim 1 wherein said comparison means comprises a set of four comparators coupled to said plurality of object coordinate registers, said plurality of clip coordinate registers and said plurality of offset registers.

5. The apparatus defined by claim 3 wherein said multiplexor means comprises an array of multiplexors coupled to said comparators.

6. The apparatus defined by claim 5 wherein said at least one comparison register comprises an array of registers coupled to said array of multiplexors.

7. The apparatus defined by claim 6 wherein said comparison control means comprises a state machine coupled to said comparators, said array of multiplexors, said array of registers, and said loading means, said state machine generating control signals for controlling the operation of said comparators, said array of multiplexors, and said array of registers.



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8. A method for performing comparisons between pairs of X and Y coordinates of an object to be displayed by a graphics subsystem, pairs of predetermined clip coordinates and pairs of predetermined offsets, and generating a plurality of status signals representing the results of said comparisons, said object being one of a quadrilateral to be drawn and block image to be moved, said method employing a clip window with predetermined top, bottom, right and left clip coordinates, and a test window which is larger than, and encompasses, said clip window, said method comprising the steps of:

providing a plurality of object coordinate registers, a plurality of clip coordinate registers and a plurality of offset registers;

loading i) a plurality of object coordinate registers with said X and Y coordinate pairs of said object, ii) a plurality of clip coordinate registers with said predetermined clip coordinates, and iii) a plurality of offset registers with said predetermined offsets;

performing said comparisons between said X and Y coordinates of said object, said predetermined clip coordinate and said predetermined offsets with the coordinates and offsets respectively loaded into said plurality of object coordinate registers, plurality of clip coordinate registers and plurality of offset registers;

determining the borders of said test window relative to the borders of said clip window from the offsets loaded into the offset register and the clip coordinates loaded into the clip coordinate register;

selecting predetermined ones of said comparisons;

storing the selected predetermined ones of said comparisons in at least one comparison register;

generating a plurality of status values based upon certain of said selected predetermined ones of said comparisons stored in at least one comparison register



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which specify whether the X coordinate of each said X and Y coordinate pair is less than said predetermined left clip coordinate, greater than said predetermined right clip coordinate, less than said predetermined left clip coordinate minus said X offset; greater than said predetermined right clip coordinate plus said X offset, is representable in 15 bits, within said left clip coordinate and right clip coordinate, within said left clip coordinate minus said X offset and said right clip coordinate plus said X offset, and which specify whether the Y coordinate of each said X and Y coordinate pair is less than said predetermined bottom clip coordinate, greater than said predetermined top clip coordinate, less than said predetermined bottom clip coordinate minus said Y offset, greater than said predetermined top clip coordinate plus said Y offset, is representable in 15 bits, within said bottom clip coordinate and top clip coordinate, and within said bottom clip coordinate minus said Y offset and said top clip coordinate plus said Y offset, set status signals output for generation of the display of the object.
