IBM's copy!
960615-Q

BACKGROUND OF THE INVENTION

VIRTUAL INPUT/OUTPUT PROCESSOR

1. Field of the Invention:

The present invention relates to the field of computer systems. More specifically, the present invention relates to input/output (I/O) methods and apparatus of computer systems.

2. Background:

Programmed I/O (PIO) under the complete control of the central processing unit (CPU), as opposed to direct memory access (DMA) or dedicated I/O processor, is well known in the art. Under such technique, the CPU stalls for the completion of an access to an I/O device. Since I/O access tends to have a high latency compared to CPU cycle time, programmed I/O has the disadvantage of wasting CPU cycles. The disadvantage is especially aggravating for the modern processors running much faster than the average access time to the I/O devices. Each programmed I/O access to an I/O device could easily waste hundreds of CPU clock cycles. The situation becomes worse as the discrepancy between CPU cycle time and I/O access time becomes larger.

Hardware optimizations such as store buffers have been used to reduce the overhead of programmed I/O accesses. The CPU can continue its execution of other programs after a store operation is correctly issued. The store buffer approach typically improves programmed I/O write performance, but does not alleviate the latency problem for programmed I/O read operations. Another approach is the employment of an I/O processor dedicated to performing

programmed high level I/O operations. The I/O processor interprets and executes the high level commands received from the CPU, thereby freeing the CPU, allowing it to continue execution of other programs. The I/O processor can report the status through some pre-defined mechanisms upon the completion of command execution. Unfortunately, the dedicated I/O processor approach is inherently costly.

Thus, it is desirable to be able to support data transfers to and from I/O devices without wasting a lot of CPU cycles nor incurring expensive hardware costs. As will be disclosed, the present invention provides a virtual I/O processor which achieves the objects and desired results described earlier.

SUMMARY OF THE INVENTION

The desired results of supporting programmed I/O without wasting a lot of CPU cycles, nor incurring expensive hardware cost, are advantageously achieved by implementing a virtual I/O processor (VIOP), using a programmed I/O (PIO) unit. The PIO unit is complemented by a VIOP interrupt, a VIOP interrupt handler, and a number of VIOP data structures. Preferably, the PIO unit is further complemented with a set of dedicated I/O global registers, a number of VIOP library read/write routines for various I/O device types, and non-blocking read and write operations. During execution, these elements cooperate with each other to perform multiple sequences of programmed I/Os as if they were being performed by a dedicated I/O processor. In one embodiment, the VIOP handler automatically reinvokes the PIO unit if the sequence of programmed I/Os has not been completed.

The PIO unit performs actual non-blocking I/O read/write accesses against the target I/O devices. The VIOP interrupt and its handler facilitate returns from the PIO unit at the completion of I/O accesses by the PIO unit. Each VIOP data structure facilitates control and data management for a sequence of programmed I/Os. The VIOP handler maintains the VIOP data structures accordingly. In one embodiment, the VIOP handler automatically reinvokes the PIO unit if the sequence of programmed I/Os has not been completed.

The preferred set of dedicated I/O global registers facilitate the transfer of I/O data between system memory and the PIO unit, as well as the performance of the programmed I/O control and data management functions.

The preferred VIOP library read/write routines perform programmed I/Os against target I/O devices of various device types, using the PIO unit and its complimentary facilities. Application programs selectively invoke the appropriate VIOP library read/write routines to perform read/write accesses against the I/O devices. In one embodiment, the VIOP library read/write routines are responsible for repetitively invoking the PIO unit if the sequence of programmed I/Os has not been completed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is an exemplary computer system incorporating the teachings of the present invention.

FIGURE 2a illustrates the relevant portions of one embodiment of the execution unit of **Figure 1** in further detail, in particular, the preferred I/O global registers of the present invention. **FIGURE 2b** illustrates an exemplary VIOP interrupt entry in the interrupt receive buffer of **Figure 1**.

FIGURE 3 illustrates the relevant portions of one embodiment of the PIO unit of **Figure 1** in further detail.

FIGURE 4 illustrates the key software elements and their relationships to each other, in particular, the VIOP interrupt handler and the VIOP data structures. **Figure 4** also illustrates the VIOP library read/write routines, and the non-block read/write statements.

FIGURE 5 illustrates one embodiment of the VIOP data structures in further detail.

FIGURE 6 illustrates the method steps of the present invention for performing a sequence of programmed I/Os for a read operation.

FIGURE 7 illustrates the method steps of the present invention for performing a sequence of programmed I/Os for a write operation.

DETAILED DESCRIPTION

In the following description for purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well known systems are shown in diagrammatic or block diagram form in order not to obscure the present invention unnecessarily.

Referring now to **Figure 1**, a block diagram illustrating an exemplary computer system incorporating the teachings of the present invention is shown. The exemplary computer system **10** comprises a processor **11** including an instruction prefetch and dispatch unit (PDU) **12**, a load/store unit (LSU) **14**, and an execution unit (EU) **16** incorporated with the teachings of the present invention, coupled to each other as shown. The processor **11** further includes an instruction cache (i-cache) **18**, a data cache (d-cache) **22**, a memory management unit (MMU) **20**, and a bus interface **24**, coupled to each other, the PDU **12**, the LSU **14**, and the EU **16** as shown. Additionally, the computer system **10** comprises a system interconnect **13** and an I/O controller **15** including a bus interface **25**, a programmed I/O unit (PIO) **26** of the present invention, an interrupt generator **27** and DMA control **29**.

Cooperatively, instructions are fetched from the system memory (not shown), stored in the instruction cache **18**, and dispatched to the LSU **14** and EU **16** for execution. The execution results are stored back into the data cache **22**, and if applicable, to the system memory. I/O devices (not shown) are accessed through the I/O controller **15**. Some I/Os are performed by programmed I/Os

using the PIO unit 26 of the present invention. The PIO unit 26 performs the actual I/O accesses against the I/O devices (not shown) for programmed I/Os, and cooperates with a VIOP interrupt and a VIOP interrupt handler of the present invention, which will be described in more detail below. As will be obvious from the descriptions to follow, the PIO unit 26 can be built at a relatively low cost in terms of both circuitry and real estate required. Additionally, the present invention may be practiced with one or more PIO units 26.

Except for the teachings of the present invention incorporated in the EU 16 and the PIO unit 26 for supporting programmed I/Os, the elements illustrated in Figure 1 are intended to represent a broad category of these elements found in most computer systems. The constitutions and basic functions are well known and will not be otherwise described further. The teachings of the present invention incorporated in the EU 16 and the PIO unit 26 will be described in further detail below with additional references to the remaining figures. The elements of the present invention will be described individually first, and then followed by the manner they cooperate with each other.

Referring now to Figures 2a-2b, two block diagrams illustrating the relevant portions of one embodiment of the execution unit of Figure 1 in further detail is shown. The EU 16 comprises conventional elements such as a number of control and state registers 32 and 34, an integer and a floating point execution unit 28 and 30, an integer and a floating point register file 40 and 42, and an interrupt receive buffer 36. Additionally, in accordance to the present invention, the EU 16 preferably comprises a number of dedicated I/O global registers 38.

The interrupt receive buffer 36 stores received interrupts, including VIOP interrupts 37 of the present invention. VIOP interrupts are used by the PIO unit 26 to transfer execution to a VIOP interrupt handler. A VIOP interrupt 37 includes a PC 39 denoting the starting address of the VIOP interrupt handler, a pointer 41 to a VIOP descriptor and optionally, data just read from an I/O device, if the VIOP interrupt 37 was triggered as a part of a programmed read I/O. Alternatively, a pointer to be resolved indirectly, for example through a trap base register, may be used instead of PC 39. VIOP interrupt 37, VIOP interrupt handler, and VIOP descriptor will all be described in more detail below.

The preferred dedicated I/O global registers 38 facilitate I/O data transfers between the system memory and the PIO unit 26 as well as performance of control and data management functions for a sequence of programmed I/Os, which will be described in more detail below. As will be appreciated by those skilled in the art, the dedicated I/O global registers 38 are preferred for performance reasons. The provision of the dedicated I/O global registers 38 avoids having to spill a portion of the current content of the register files 40 and 42 to facilitate the above described I/O data transfers and performance of management functions.

The functions and the constitutions of the remaining control and state registers 32 and 34, the integer and floating point units 28 and 30, the integer and floating point register files 40 and 42, and the interrupt assertion and detection mechanism are all well known, and will not be further described. However, it should be noted that while the present invention is being described with the preferred dedicated I/O global registers 38 disposed as part of the EU

16, the present invention may be practiced with the preferred dedicated I/O global registers 38 disposed in other parts of the processor 11.

Referring now to Figure 3, a block diagram illustrating the relevant portions of one embodiment of the PIO unit of Figure 1 in further detail is shown. The PIO unit 26 comprises a sequencer 50, a number of data buffers 48, and a number of control and status registers 46, and non-blocking read/write control circuitry 44 coupled to each other as shown. The sequencer 50 executes a pre-defined sequence of operations for performing actual I/O accesses against an I/O device, after the PIO unit 26 has been allocated and properly initialized. The non-blocking read/write control circuitry 44 controls the actual non-blocking read/write from/to an I/O device. Additionally, the sequencer 50 asserts the VIOP interrupt at the completion of each I/O access. The data buffers 48 buffer the I/O data being transferred by the programmed I/Os to and from the I/O device. The control and status registers 46 store current control and status information of the PIO unit 26. Allocation and initialization of the PIO unit 26, transfer of data between the data buffers 48 and the dedicated I/O global registers 38, as well as assertion and servicing of the VIOP interrupt will also be described in more detail below.

Referring now to Figure 4, a block diagram illustrating key software elements of the present invention are shown. As illustrated, the key software elements include a VIOP interrupt handler 116 and a number of VIOP data structures 118.

The VIOP interrupt handler **116** in cooperation with the VIOP interrupt facilitate returns from the PIO unit **26** at the completion of actual I/O accesses performed by the PIO unit **26**. The VIOP interrupt handler **116** is invoked and given execution control through the VIOP interrupt, as described earlier. The VIOP interrupt handler **116** performs control and data management functions for programmed I/Os utilizing the VIOP data structures **118**. As will be described in more detail below, in one embodiment, the VIOP interrupt handler **116** also automatically reinvokes the PIO unit **26** if a series of programmed I/Os has not been completed.

The VIOP data structures **118** facilitates the control and data management functions performed by the VIOP handler **116**. One VIOP data structure **118** is used for each sequence of programmed I/Os. Each VIOP data structure **118** comprises a VIOP descriptor **122** and a VIOP data buffer **124**. The VIOP descriptor **122** holds the control information for a sequence of programmed I/Os, whereas, the VIOP data buffer **124** holds the actual I/O data being transferred by the sequence of programmed I/Os between the system memory and the I/O devices.

Referring now to **Figure 5**, a block diagram illustrating the VIOP descriptor **122** and the VIOP data buffer **124** of **Figure 4** in further detail is shown. As illustrated, a VIOP descriptor **122** comprises a VIOP data buffer pointer **126**, an I/O word count **128**, an I/O device address **130**, and a VIOP address **132**. The VIOP data buffer area pointer **126** points to a location in the VIOP data buffer area **124** where the next group of programmed I/O data are to be read or written. The I/O word count **128** keeps track of the amount of I/O data

remains to be transferred by the programmed I/Os between the system memory and the target I/O device. The device address **130** points to the target I/O device against which the programmed I/Os are performed. The VIOP address **132** denotes the address of a PIO unit **26**.

Referring back to **Figure 4**, preferably, the software elements further include a number of VIOP library read/write routines **112** and **114**. The VIOP library read and write routines **112** and **114** perform programmed I/Os against I/O devices of various device types, using the above described PIO unit **26** and its complementary facilities. Application programs **102** invoke VIOP library read/write routines **112** and **114** to access I/O devices. As will be described in more detail below, in one embodiment, the VIOP read/write routine **112** or **114** automatically reinvokes the PIO unit **26** if a series of programmed read/write I/Os has not been completed. The VIOP read and write routines **112** and **114** may be statically linkedited as integral parts of an application program **102**, or they may be dynamically loaded during execution.

Having now described the individual elements of the present invention, the manner in which these elements cooperate to perform the programmed I/Os as if the programmed I/Os are executed by a dedicated I/O processor on the exemplary computer system **10** will now be described in detail with references to **Figures 6 - 7**.

As illustrated in **Figure 6**, invoking the VIOP library read routine **112** in an application program **102**, at step **202**, the VIOP library read routine **112** allocates a VIOP descriptor **122** and a VIOP data buffer area **124** in the system memory. In other words, the VIOP library read routine **112** initializes the

VIOP descriptor 122 with a VIOP data buffer pointer 126 pointing to the VIOP data buffer area 124, and an I/O word count 128 denoting the amount of I/O data to be read from the target I/O device. Additionally, the VIOP library read routine 112 initializes the VIOP descriptor 122 with an I/O device address 130 locating the target I/O device where the I/O data are to be read, and an VIOP address 132 locating the PIO unit 26 for performing the programmed read I/Os. Next, at step 204, the VIOP library read routine 112 allocates the PIO unit 26 and initializes the PIO unit 26 with the proper control information, such as the device address of the target I/O device. At step 206, the VIOP library read routine 112 starts VIOP by issuing a non-blocking PIO read 206. For the purpose of this application, a non-blocking read/write instruction is a read/write instruction where the processor does not wait for the completion of the read/write operation initiated on behalf of the read/write instruction, before proceeding to execute other instructions.

Then, at step 208, the PIO unit 26 makes an actual I/O access against the target I/O device and reads a predetermined quantity of data from the target I/O device. The PIO unit 26 repeats the access against the target I/O device until the PIO data buffer 48 is full or the PIO unit 26 has read all the data as instructed by the VIOP library read routine 112, step 210. If the PIO unit 26 detects either one of these conditions, at step 212, the PIO unit 26 stops accessing the target I/O device, and generates a VIOP interrupt 37 instead. The VIOP interrupt 37 is delivered to the processor 11 through the system interconnect 15. The processor 11 stores the VIOP interrupt 37 in its Interrupt Receive Buffer 36.

Upon detecting the VIOP interrupt, the processor 11 transfers execution control to the VIOP interrupt handler 116. The VIOP interrupt handler 116 upon given execution control, obtains the VIOP descriptor address from the Interrupt Receive Buffer 36, step 214. Next, at step 216, the VIOP interrupt handler 116 loads the VIOP descriptor 122 into the dedicated I/O global registers 38. The VIOP interrupt handler 116 then moves the read data from the Interrupt Receive Buffer 36 to the dedicated I/O global registers 38, step 218, and then into the VIOP buffer 124, step 220. Upon moving the read data from the dedicated I/O global registers 38, the VIOP interrupt handler 116 updates and saves the VIOP descriptor 122, in particular, the VIOP data buffer pointer 126, and the I/O word count 128 denoting the amount of I/O data remaining to be read 128, step 222.

Next, for the illustrated embodiment, the VIOP interrupt handler 116 determines if the I/O word count 128 has reached zero denoting completion of the sequence of programmed read I/Os, step 224. If I/O word count 128 is non-zero, VIOP interrupt handler 116 automatically reinvokes the PIO unit 26 again by issuing a non-blocking PIO read 228, which in turn repeats steps 208 through 212 as described earlier. Eventually, the VIOP interrupt handler 116 will determine at step 224 that the I/O word count has reached zero. Then, the VIOP interrupt handler 116 transfers execution control to the VIOP library read routine 112, which in turn performs a block move, moving the read data from the VIOP data buffer 124 to the application program's data transfer area 108, step 226.

Alternatively, as will be appreciated by those skilled in the art, the present invention may be practiced with the VIOP interrupt handler 116 returning

to the VIOP library read routine 112 after step 222, and have the VIOP library read routine 112 be responsible for reinvoking the PIO unit 26 if the sequence of programmed read I/Os has not been completed.

As illustrated in Figure 7, upon execution of a non-blocking write instruction 103 in an application program 102, at step 242, the VIOP library write routine 114 allocates a VIOP descriptor 122 and a VIOP data buffer 124 in the system memory. In other words, the VIOP library write routine 112 initializes the VIOP descriptor 122 with a VIOP data buffer pointer 126 pointing to the VIOP data staging area 124, and an I/O word count 128 denoting the amount of I/O data to be written into the target I/O device. Additionally, the VIOP library write routine 112 initializes the VIOP descriptor 122 with an I/O device address 130 locating the target I/O device where the I/O data are to be written, and an VIOP address 132 locating the PIO unit 26 for performing the programmed write I/O.

Next, at step 244, the VIOP library write routine 114 block moves the I/O data from the application program's data transfer area 108 to the VIOP data buffer area 124. The VIOP library write routine 114 further loads portions of the write data from the VIOP data buffer area 124 into the dedicated I/O global registers 38, step 250. Then, the VIOP library write routine 114 allocates the PIO unit 26 and initializes the PIO unit 26 with the proper control information, such as the device address of the target I/O device, step 252. Upon allocating and initializing the PIO unit 26, the VIOP library write routine 114 moves the write data from the I/O global registers 38 to the PIO data buffers 48 by issuing a non-blocking PIO write, step 254.

Then, at step 256, the PIO unit 26 makes an actual I/O access against the target I/O device and writes a predetermined quantity of data to the target I/O device. The PIO unit 26 repeats the access against the target I/O device until the PIO data buffer 48 is empty or the PIO unit 26 has written all the data as instructed by the VIOP library write routine 114, step 258. If the PIO unit 26 detects either one of these conditions, at step 260, the PIO unit 26 stops accessing the target I/O device, and generates a VIOP interrupt 37 instead, step 260. The VIOP interrupt 37 is delivered to the processor 11 through the system interconnect 15. Upon receiving the interrupt, the processor 11 stores the VIOP interrupt 37 in its Interrupt Receive Buffer 36.

Upon detecting the VIOP interrupt 37, the processor 11 transfers execution control to the VIOP interrupt handler 116. The VIOP interrupt handler 116 upon given execution control, obtains the VIOP descriptor address from the Interrupt Receive Buffer 36, step 262. Next, at step 264, the VIOP interrupt handler 116 loads the VIOP descriptor 122 into the dedicated I/O global registers 38. The VIOP interrupt handler 116 then updates and saves the VIOP descriptor 122, in particular, the VIOP data staging area pointer 126, and the I/O word count 128 denoting the amount of I/O data remaining to be written, step 266.

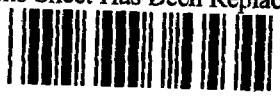
Next, for the illustrated embodiment, the VIOP interrupt handler 116 determines if the I/O word count 128 has reached zero, denoting the programmed write I/O has been completed, step 268. If the I/O word count 128 has not reached zero, the VIOP interrupt handler 116 loads additional portions of write data into the I/O global registers 38, step 270, and then to the PIO data buffers 48 by issuing a non-blocking PIO write, step 272. Upon moving the write

data to the PIO data buffers 48, VIOP interrupt handler 116 automatically reinvokes the PIO unit 26, which repeats steps 256 - 260 as described earlier. Eventually, the VIOP interrupt handler 116 will determine at step 268 that the I/O word count 128 has reached zero.

Alternatively, as will be appreciated by those skilled in the art, the present invention may be practiced with the VIOP interrupt handler 116 returning to the VIOP library write routine 114 after step 266, and have the VIOP library write routine 114 be responsible for reinvoking the PIO unit 26 if the sequence of programmed write I/Os has not been completed.

While the present invention has been described in terms of presently preferred and alternate embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The method and apparatus of the present invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting on the present invention.

This Sheet Has Been Replaced



WHAT IS CLAIMED IS

1. An apparatus comprising:

(a) a programmable input/output (I/O) unit for accessing an I/O device;

(b) an interrupt triggering mechanism for triggering an interrupt to interrupt execution of a processor, said interrupt being asserted by said programmable I/O unit at the end of an access of an I/O device; and

(c) an interrupt handler executed by said processor and responsive to the assertion of said interrupt for performing control and data management functions for a sequence of programmed I/Os being performed by repetitively using said programmable I/O unit, said interrupt, and said interrupt handler.

2. The apparatus as set forth in Claim 1, wherein said programmable I/O unit comprises:

(a.1) a sequencer coupled to the interrupt triggering mechanism for executing predefined sequence of operations for accessing an I/O device, and asserting said interrupt at the end of an access of an I/O device;

(a.2) a data buffer coupled to the sequencer, the I/O device and the interrupt triggering mechanism for buffering I/O data being transferred from and to an I/O device;

(a.3) a plurality of registers coupled to a bus interface and said sequencer for storing control and status information for said programmable I/O unit; and

(a.4) non-blocking read/write control circuitry coupled to the sequencer and the I/O device for controlling data transfers between the data buffer and the I/O device.



THIS SHEET HAS BEEN REPLACED

This Sheet Has Been Replaced



3. The apparatus as set forth in Claim 1, wherein,

said interrupt handler performs said control and data management function for a sequence of programmed I/Os using a data structure comprising a descriptor block and a data buffer; and

said descriptor block comprises (c.1) a pointer pointing into said data buffer denoting where I/O data are to be read or written next.

4. The apparatus as set forth in Claim 3, wherein said descriptor block further comprises:

(c.2) an I/O data word count denoting an amount of I/O data still to be read or written for a sequence of programmed I/Os.

5. The apparatus as set forth in Claim 4, wherein said descriptor block further comprises:

(c.3) a first address locating the I/O device; and

(c.4) a second address for locating the programmed I/O unit.

6. The apparatus as set forth in Claim 1, wherein said apparatus further comprises:

(d) a plurality of dedicated registers coupled to said programmable I/O unit for storing I/O data being transferred from or to an I/O device by said programmable I/O unit, and for storing control management data being operated on by said interrupt handler for a sequence of programmed I/Os.

THIS SHEET HAS BEEN REPLACED



This Sheet Has Been Replaced

7. The apparatus as set forth in Claim 1, wherein said apparatus further comprises:

(d) a read routine for performing a sequence of programmed I/Os for a read operation against an I/O device using said programmable I/O unit, interrupt, and interrupt handler; and

(e) a write routine for performing a sequence of programmed I/Os for a write operation against an I/O device using said programmable I/O unit, interrupt, and interrupt handler.

8. The apparatus as set forth in Claim 7, wherein said apparatus further comprises:

(f) a non-blocking read operation for reading from an I/O device; and

(g) a non-blocking write operation for writing into an I/O device;

wherein, said read and write routines, when invoked by an application program, use said non-blocking read and write operations to read from and write into an I/O device.

9. The apparatus as set forth in Claim 1, wherein,

said programmable I/O unit is disposed in an I/O controller; and

said processor further comprises an integer execution unit for executing integer instructions, an integer register file coupled to said integer execution unit for storing integer execution results, and a plurality of control and state registers for storing control and state information of said processor.

10. The apparatus as set forth in Claim 9, wherein,

said processor is disposed in a computer system; and

* C L M S *

THIS SHEET HAS BEEN REPLACED

This Sheet Has Been Replaced

said computer system further comprises a system interconnect coupled to said processor for transferring instructions and data, a system memory coupled to said system interconnect for storing instructions and data, and an I/O device coupled to said system interconnect for providing I/O data to said processor.

11. A computer implemented method comprising the steps of:

(a) accessing an I/O device by a programmable I/O unit for reading from or writing into said I/O device;

(b) interrupting execution of said processor by said programmable I/O unit at the end of an access against said I/O device using an interrupt triggering mechanism; and

(c) responding to said interrupt by an interrupt handler executed by said processor to perform control and data management functions for a sequence of programmed I/Os being performed by repetitively using said programmable I/O unit, said interrupt, and said interrupt handler.

12. The method as set forth in Claim 11, wherein said performance of control and data management functions by said interrupt handler in said step (c) comprises maintaining control data information in a data structure having a descriptor block and a data buffer, including maintaining a pointer in said descriptor block pointing into said data buffer denoting where I/O data are to be read or written next.

13. The method as set forth in Claim 12, wherein said maintenance of control data information in said data structure further includes

maintaining an I/O data word count in said descriptor block denoting an amount of I/O data still to be read or written for a sequence of programmed I/Os,

* C L M S *

THIS SHEET HAS BEEN REPLACED

This Sheet Has Been Replaced

maintaining a first address locating the I/O device, and

maintaining a second address locating the programmed I/O unit.

14. The method as set forth in Claim 11, wherein said step (a) further comprises invoking a read routine from an application program for performing a sequence of programmed I/Os against an I/O device using said programmable I/O unit, interrupt, and interrupt handler.

15. The method as set forth in Claim 11, wherein said step (a) further comprises invoking a write routine from an application program for performing a sequence of programmed I/Os against an I/O device using said programmable I/O unit, interrupt, and interrupt handler.

16. A method for providing programmed input/output (I/O) capability to a computer system comprising the steps of:

(a) providing a programmable input/output (I/O) unit to said computer system for accessing an I/O device of said computer system;

(b) providing an interrupt triggering mechanism for triggering an interrupt to interrupt a processor of said computer system, said interrupt being asserted by said programmable I/O unit at the end of an access of the I/O device; and

(c) providing an interrupt handler to be executed by said processor and responsive to the assertion of said interrupt for performing control and data management functions for a sequence of programmed I/Os being performed by repetitively using said programmable I/O unit, said interrupt, and said interrupt handler.

* C L M S *

THIS SHEET HAS BEEN REPLACED

This Sheet Has Been Replaced

17. The method as set forth in Claim 16, wherein said step (a) comprises the steps of:

(a.1) providing a sequencer coupled to an interrupt triggering mechanism for executing predefined sequence of operations for accessing an I/O device, and asserting an interrupt at the end of an access of the I/O device;

(a.2) providing a data buffer coupled to the sequencer and the interrupt triggering mechanism for buffering I/O data being transferred from and to the I/O device;

(a.3) providing a plurality of registers coupled to a bus interface and said sequencer for storing control and status information for said programmable I/O unit; and

(a.4) providing non-blocking read/write circuitry coupled to the sequencer and the I/O device for controlling data transfers between the data buffer and the I/O device.

18. The method as set forth in Claim 16, wherein said method further comprises the steps of:

(d) providing a plurality of dedicated registers coupled to said programmable I/O unit for storing I/O data being transferred from or to an I/O device by said programmable I/O unit, and for storing control management data being operated on by said interrupt handler for a sequence of programmed I/Os.

19. The method as set forth in Claim 16, wherein said method further comprises the steps of:

(d) providing a read routine for performing a sequence of programmed read I/Os against an I/O device using said programmable I/O unit, interrupt, and interrupt handler; and

THIS SHEET HAS BEEN REPLACED

* C L M S *

This Sheet Has Been Replaced

(e) providing a write routine for performing a sequence of programmed write I/Os against an I/O device using said programmable I/O unit, interrupt, and interrupt handler.

20. The method as set forth in Claim 19, wherein said method further comprises the steps of:

(f) providing a non-blocking read operation for reading from an I/O device; and

(g) providing a non-blocking write operation for writing into an I/O device;

wherein, said read and write routines, when invoked by an application program, use said non-blocking read and write operations to read from and write into an I/O device.

* C L M S *

THIS SHEET HAS BEEN REPLACED

ABSTRACT

VIRTUAL INPUT/OUTPUT PROCESSOR

A virtual I/O processor (VIOP) is implemented using a programmed I/O (PIO) unit. The PIO unit is complemented by a VIOP interrupt, a VIOP interrupt handler, and a number of VIOP data structures. Preferably, the PIO unit is further complemented with a set of dedicated I/O global registers, a number of VIOP library read/write routines for various I/O device types, and non-blocking read and write operations. During execution, these elements cooperate with each other to perform multiple sequences of programmed I/Os as if they were being performed by a dedicated I/O processor.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

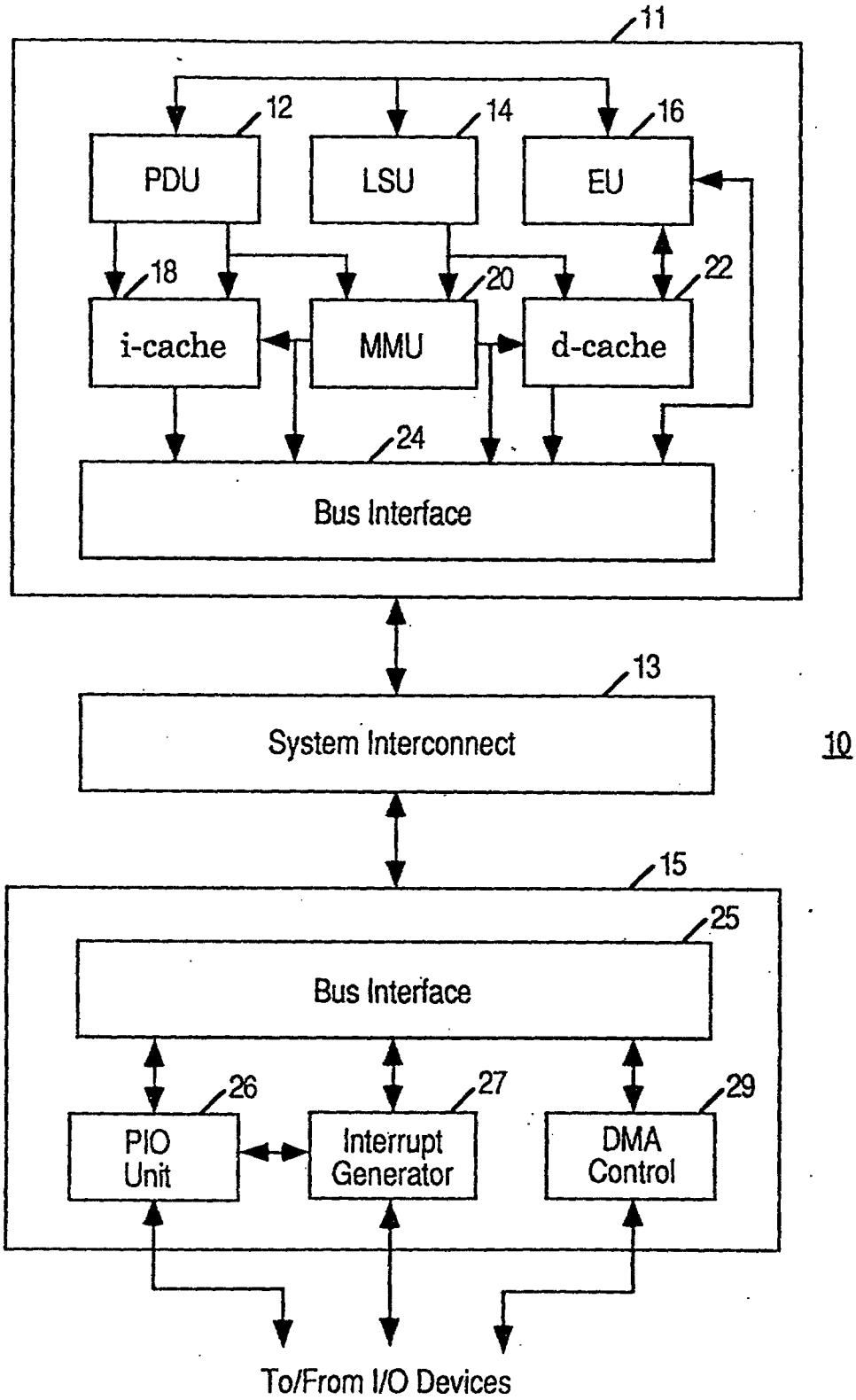

11
12
14
16
PDU
LSU
EU
18
20
22
i-cache
MMU
d-cache
24
Bus Interface
13
System Interconnect
10
15
25
Bus Interface
26
27
29
PIO Unit
Interrupt Generator
DMA Control
To/From I/O Devices

Figure 1

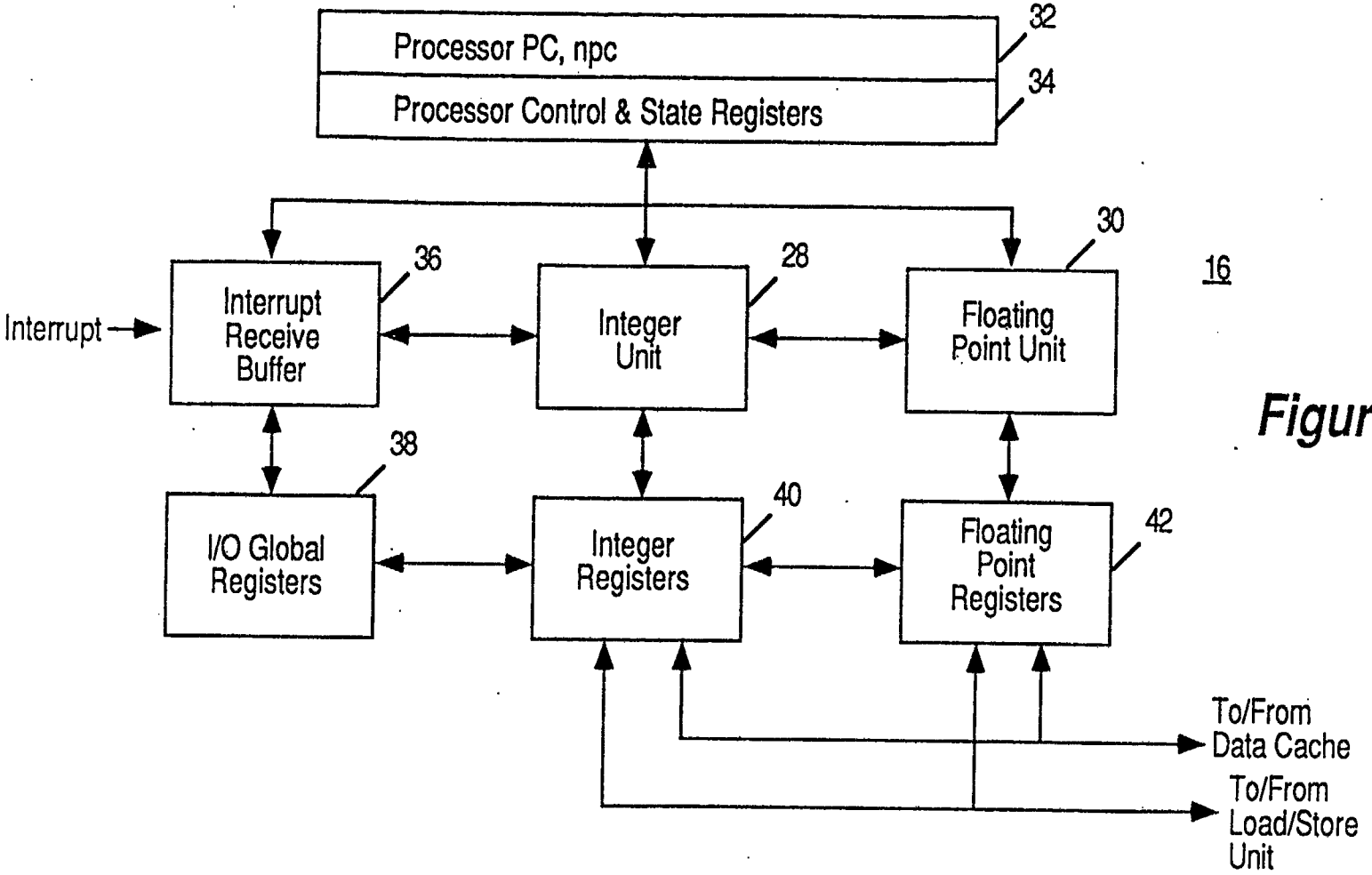


Figure 2a

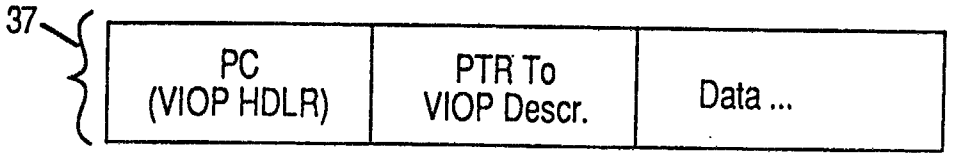


Figure 2b

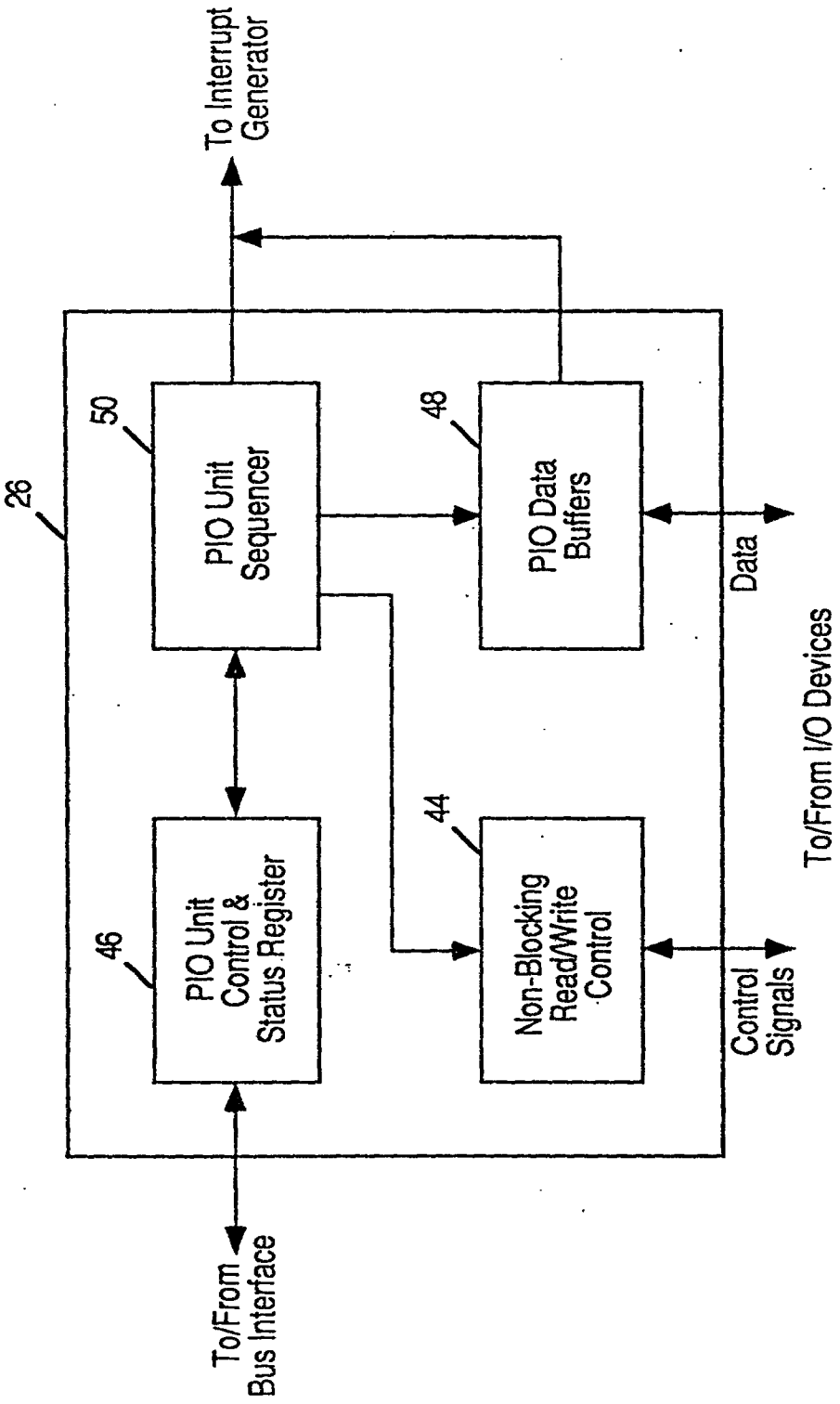

To Interrupt Generator
26
50
PIO Unit Sequencer
48
PIO Data Buffers
Data
To/From I/O Devices
46
PIO Unit Control & Status Register
44
Non-Blocking Read/Write Control
Control Signals
To/From Bus Interface

Figure 3

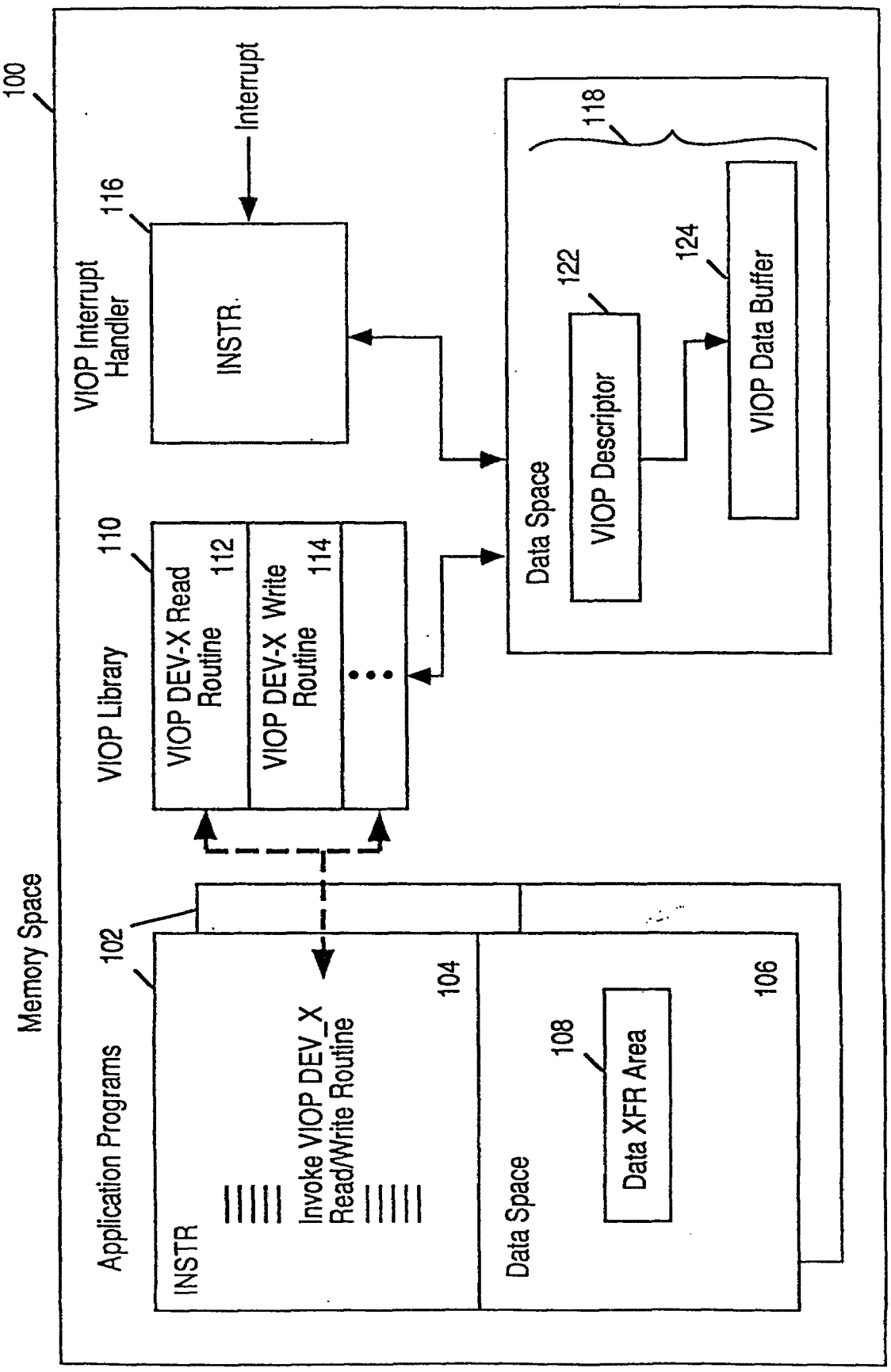

100
Memory Space
Application Programs
102
INSTR
Invoke VIOP DEV_X Read/Write Routine
104
Data Space
108
Data XFR Area
106
VIOP Library
110
VIOP DEV-X Read Routine
112
VIOP DEV-X Write Routine
114
VIOP Interrupt Handler
116
INSTR.
Interrupt
Data Space
118
VIOP Descriptor
122
VIOP Data Buffer
124

Figure 4

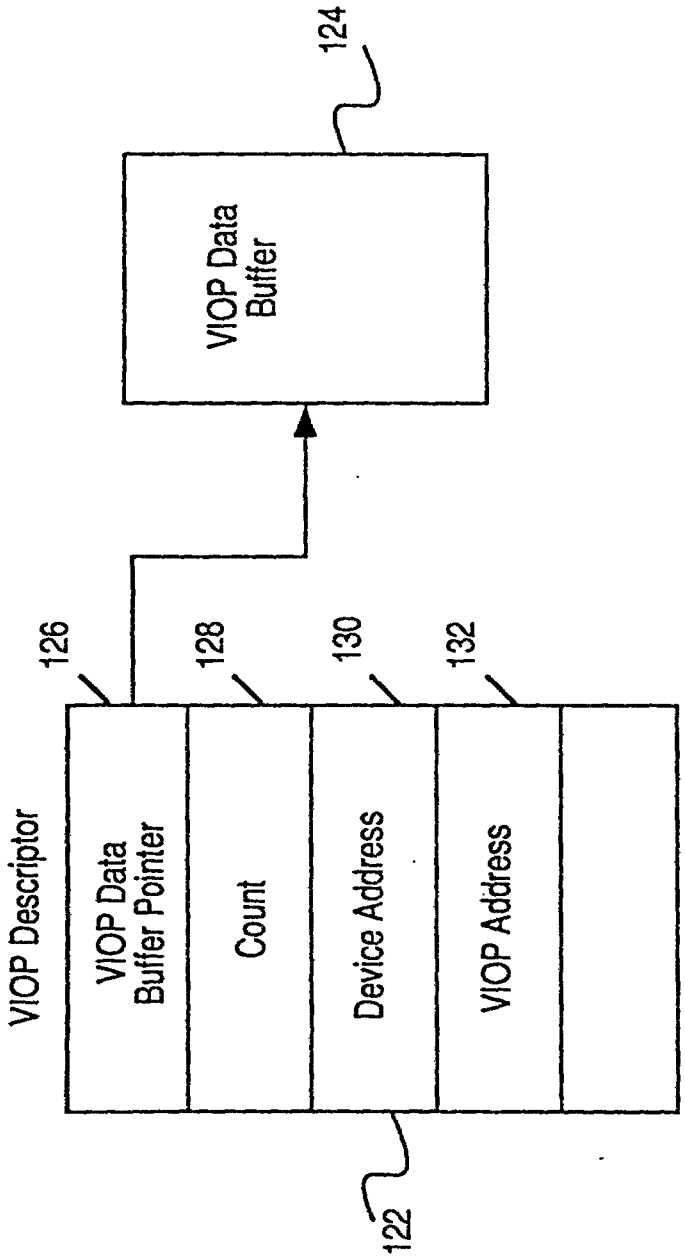

VIOP Descriptor
VIOP Data Buffer Pointer
Count
Device Address
VIOP Address
126
128
130
132
122
124
VIOP Data Buffer

Figure 5

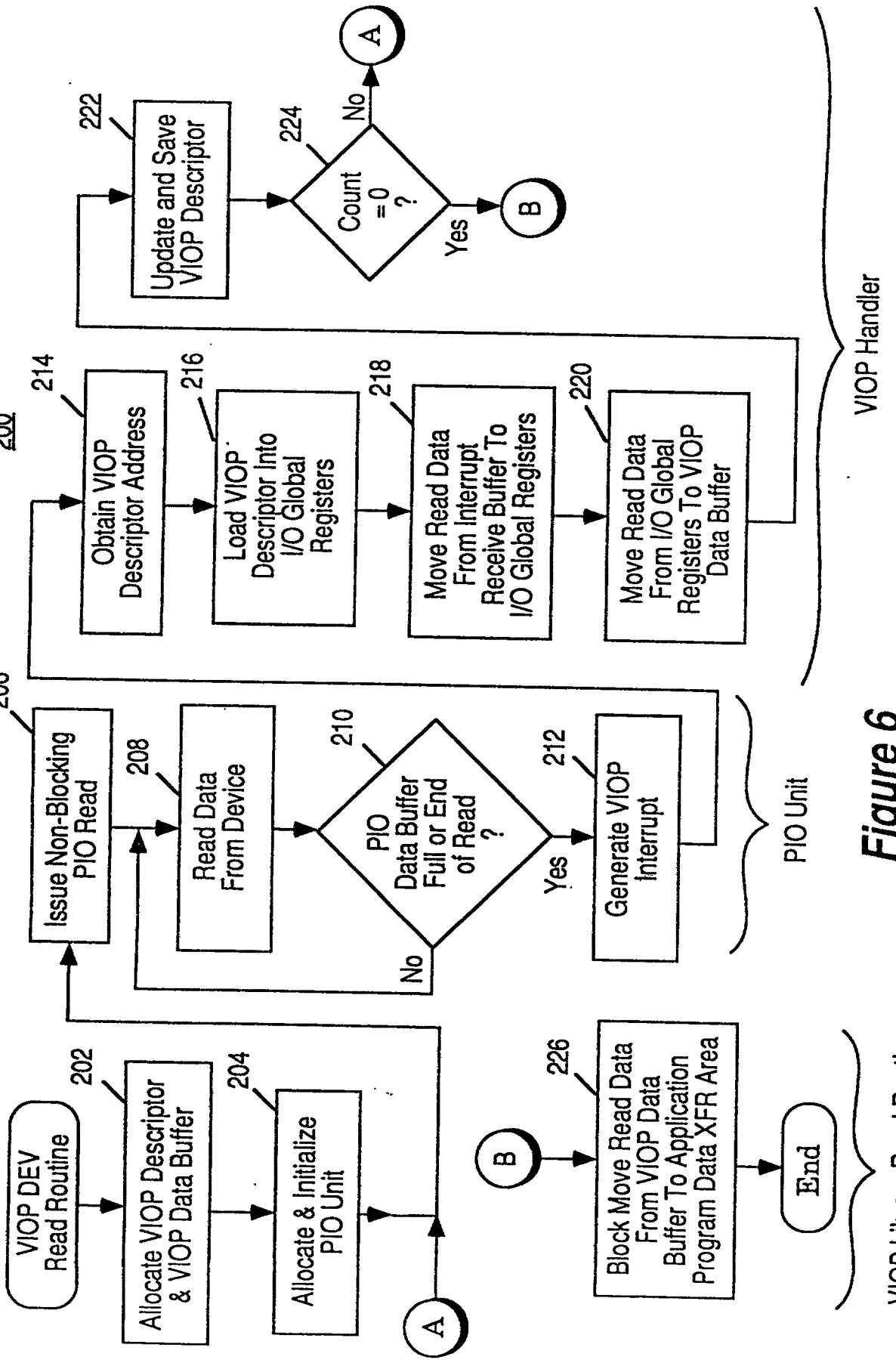

VIOP DEV Read Routine
202
Allocate VIOP Descriptor & VIOP Data Buffer
204
Allocate & Initialize PIO Unit
A
206
Issue Non-Blocking PIO Read
208
Read Data From Device
210
PIO Data Buffer Full or End of Read ?
No
Yes
212
Generate VIOP Interrupt
PIO Unit
200
214
Obtain VIOP Descriptor Address
216
Load VIOP Descriptor Into I/O Global Registers
218
Move Read Data From Interrupt Receive Buffer To I/O Global Registers
220
Move Read Data From I/O Global Registers To VIOP Data Buffer
VIOP Handler
222
Update and Save VIOP Descriptor
224
Count = 0 ?
No
Yes
A
B
B
226
Block Move Read Data From VIOP Data Buffer To Application Program Data XFR Area
End
VIOP Library Read Routine

Figure 6

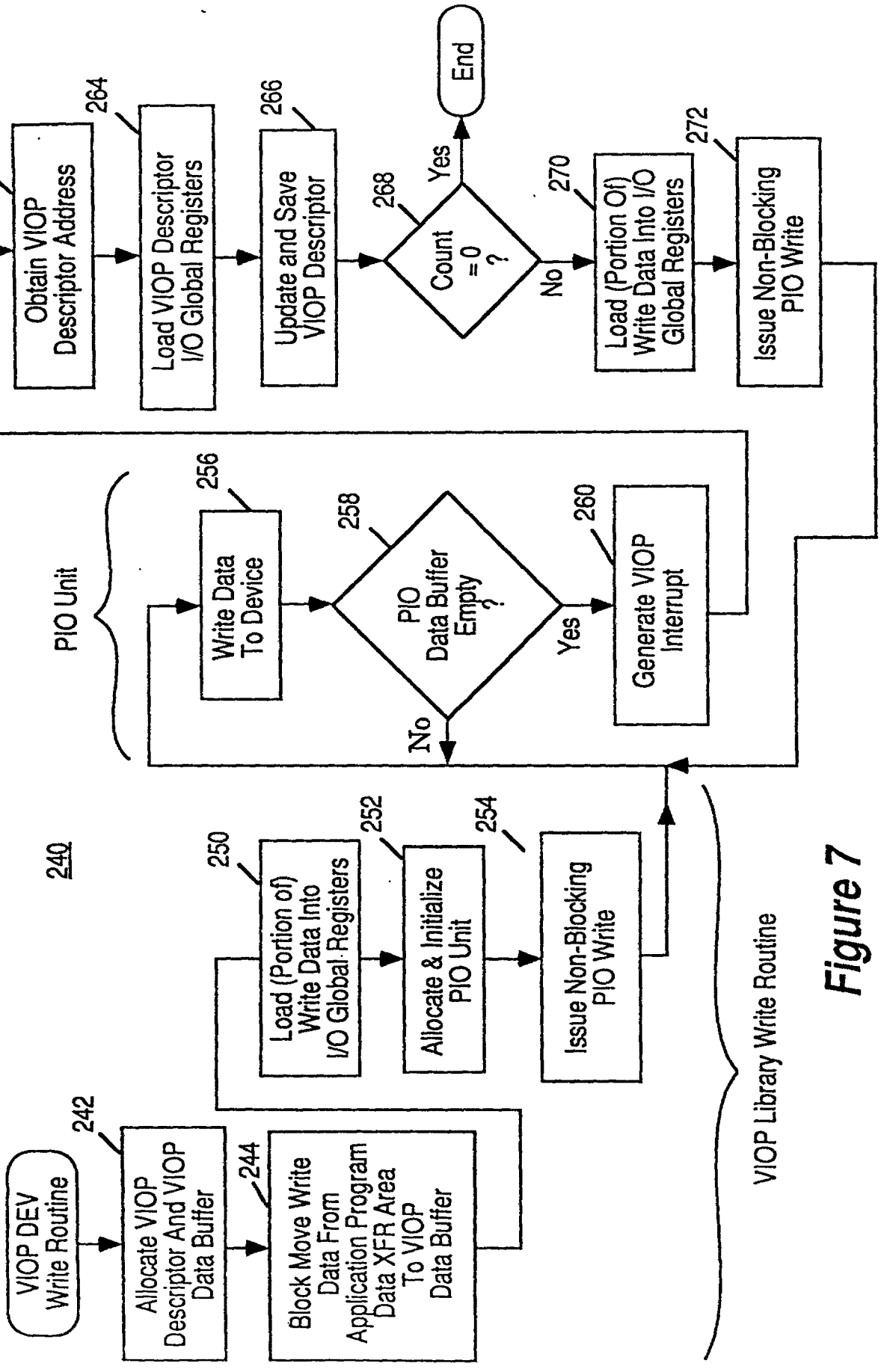

VIOP DEV Write Routine
240
Allocate VIOP Descriptor And VIOP Data Buffer
242
Block Move Write Data From Application Program Data XFR Area To VIOP Data Buffer
244
Load (Portion of) Write Data Into I/O Global Registers
250
Allocate & Initialize PIO Unit
252
Issue Non-Blocking PIO Write
254
VIOP Library Write Routine
PIO Unit
Write Data To Device
256
PIO Data Buffer Empty ?
258
No
Yes
Generate VIOP Interrupt
260
Issue Non-Blocking PIO Write
Obtain VIOP Descriptor Address
262
Load VIOP Descriptor I/O Global Registers
264
Update and Save VIOP Descriptor
266
Count = 0 ?
268
Yes
End
No
Load (Portion Of) Write Data Into I/O Global Registers
270
272

Figure 7

ABSTRACT

VIRTUAL INPUT/OUTPUT PROCESSOR

A virtual I/O processor (VIOP) is implemented using a programmed I/O (PIO) unit. The PIO unit is complemented by a VIOP interrupt, a VIOP interrupt handler, and a number of VIOP data structures. Preferably, the PIO unit is further complemented with a set of dedicated I/O global registers, a number of VIOP library read/write routines for various I/O device types, and non-blocking read and write operations. During execution, these elements cooperate with each other to perform multiple sequences of programmed I/Os as if they were being performed by a dedicated I/O processor.

(Fig. 2A)

REPLACEMENT SHEET
27 SEP 1996

REPLACEMENT SHEET
04 NOV 2000

CLAIMS

1. An apparatus comprising:

(a) a programmable input/output (I/O) unit (26) for transferring data to and from an I/O device;

(b) an interrupt triggering mechanism for triggering an interrupt to (37) interrupt execution of a processor (11), said interrupt being asserted by said programmable I/O unit at the end of a data transfer operation performed in association with an I/O device; and

(c) an interrupt handler (116), executed by said processor and responsive to the assertion of said interrupt , including a plurality of data structures (118), for performing control and data management functions for a sequence of programmed I/Os being performed by a program executed by the processor, by repetitively invoking said programmable I/O unit, based on said data structures, said interrupt handler being given back control when said programmable I/O unit asserts an interrupt using said interrupt triggering mechanism at the end of each data transfer operation.

2. The apparatus as set forth in claim 1, wherein said programmable I/O unit (26) comprises:

(a.1) a sequencer (50) coupled to the interrupt triggering mechanism for executing predefined sequence of operations for transferring data to and from an I/O device, and asserting said interrupt at the end of a data transfer operation of an I/O device;

(a.2) a data buffer (48) coupled to the sequencer, the I/O device and the interrupt triggering mechanism for buffering I/O data being transferred from and to an I/O device;

(a.3) a plurality of registers (46) coupled to a bus interface and said sequencer for storing control and status information for said programmable I/O unit; and

9606615-4
4/11/00
AMENDED SHEET

REPLACEMENT SHEET
04 NOV 2009

(a.4) non-blocking read/write control circuitry (44) coupled to the sequencer and the I/O device for controlling data transfers between the data buffer and the I/O device.

3. The apparatus as set forth in claim 1, wherein,

said data structures comprising a descriptor block (122) and a data buffer (124) ; and

said descriptor block comprises (c.1) a pointer pointing into said data buffer denoting where I/O data are to be read or written next.

4. The apparatus as set forth in claim 3, wherein said descriptor block further comprises:

(c.2) an I/O data word count (128) denoting an amount of I/O data still to be read or written for a sequence of programmed I/Os.

5. The apparatus as set forth in claim 4, wherein said descriptor block further comprises:

(c.3) a first address (130) locating the I/O device; and

(c.4) a second address (132) for locating the programmed I/O unit.

6. The apparatus as set forth in claim 1, wherein said apparatus further comprises:

(d) a plurality of dedicated registers (38) coupled to said programmable I/O unit for storing I/O data being transferred from or to an I/O device by said programmable I/O unit, and for storing control management data being operated on by said interrupt handler for a sequence of programmed I/Os.

7. The apparatus as set forth in claim 1, wherein said apparatus further comprises:

(d) a read routine (112) for performing a sequence of programmed I/Os for a read operation performed in association with an I/O device using said programmable I/O unit, interrupt, and interrupt handler; and

AMENDED SHEET

REPLACEMENT SHEET
04 NOV 2000

(e) a write routine for performing a sequence of programmed I/Os for a write operation performed in association with an I/O device using said programmable I/O unit (26), interrupt (37), and interrupt handler (116).

8. The apparatus as set forth in claim 7, wherein said apparatus further comprises:

(f) a non-blocking read operation for reading from an I/O device; and

(g) a non-blocking write operation for writing into an I/O device;

wherein, said read and write routines, when invoked by an application program, use said non-blocking read and write operations to read from and write into an I/O device.

9. The apparatus as set forth in claim 1, wherein,

said programmable I/O unit (26) is disposed in an I/O controller (15); and

said processor (11) further comprises an integer execution unit for executing integer instructions, an integer register file (40) coupled to said integer execution unit for storing integer execution results, and a plurality of control and state registers for storing control and state information of said processor.

10. The apparatus as set forth in claim 9, wherein,

said processor is disposed in a computer system; and

said computer system further comprises a system interconnect (13) coupled to said processor for transferring instructions and data, a system memory coupled to said system interconnect for storing instructions and data, and an I/O device coupled to said system interconnect for providing I/O data to said processor.

11. A computer implemented method comprising the steps of:

(a) transferring data from and to an I/O device by a programmable I/O unit for reading from or writing into said I/O device;

AMENDED SHEET

REPLACEMENT SHEET
04 NOV 2000

(b) interrupting execution of a processor (11) by said programmable I/O unit at the end of a data transfer operation performed in association with said I/O device using an interrupt triggering mechanism; and

(c) responding to said interrupt (37) by an interrupt handler (116) executed by said processor, said interrupt handler having a plurality of data structures to perform control and data management functions for a sequence of programmed I/Os being performed by a program executed by the processor by repetitively invoking said programmable I/O unit based on said data structures, said interrupt handler being given back control when said programmable I/O unit asserts an interrupt using said interrupt triggering mechanism at the end of each data transfer operation.

12. The method as set forth in claim 11, wherein said performance of control and data management functions by said interrupt handler in said step (c) further comprises maintaining control data information in a descriptor block (122) and a data buffer (124) of the data structure (118), including maintaining a pointer in said descriptor block pointing into said data buffer denoting where I/O data are to be read from or written to next.

13. The method as set forth in claim 12, wherein said maintenance of control data information in said data structure further includes

maintaining an I/O data word count (128) in said descriptor block denoting an amount of I/O data still to be read or written for a sequence of programmed I/Os,

maintaining a first address locating the I/O device, and

maintaining a second address locating the programmed I/O unit.

14. The method as set forth in claim 11, wherein said step (a) further comprises invoking a read routine (112) from an application program (102) for performing a sequence of programmed I/Os in association with an I/O device invoking said programmable I/O unit, interrupt, and said interrupt handler.

AMENDED SHEET

REPLACEMENT SHEET
04 NOV 2000

15. The method as set forth in claim 11, wherein said step (a) further comprises invoking a write routine (114) from an application program for performing a sequence of programmed I/Os in association with an I/O device invoking said programmable I/O unit, interrupt, and interrupt handler.

16. A method for providing programmed input/output (I/O) capability to a computer system comprising the steps of:

(a) providing a programmable input/output (26) unit to said computer system for transferring data to and from an I/O device of said computer system;

(b) providing an interrupt triggering mechanism for triggering an interrupt to interrupt a processor of said computer system, said interrupt being asserted by said programmable I/O unit at the end of a data transfer operation performed in association with an I/O device; and

(c) providing an interrupt handler (116) having a plurality of data structures to be executed by said processor and responsive to the assertion of said interrupt for performing control and data management functions for a sequence of programmed I/Os being performed by a program executed by the processor by repetitively invoking said programmable I/O unit based on said data structures, returning control to said interrupt handler when said programmable I/O unit asserts an interrupt using said interrupt triggering mechanism at the end of each data transfer operation.

17. The method as set forth in claim 16, wherein said step (a) comprises the steps of:

(a.1) providing a sequencer (50) coupled to an interrupt triggering mechanism for executing predefined sequence of operations for transferring data from and to an I/O device, and asserting an interrupt at the end of a data transfer operation performed in association with the I/O device;

(a.2) providing a data buffer (48) coupled to the sequencer and the interrupt triggering mechanism for buffering I/O data being transferred from and to the I/O device;

AMENDED SHEET

REPLACEMENT SHEET
04 NOV 2000

(a.3) providing a plurality of registers (46) coupled to a bus interface and said sequencer for storing control and status information for said programmable I/O unit; and

(a.4) providing non-blocking read/write circuitry (44) coupled to the sequencer and the I/O device for controlling data transfers between the data buffer and the I/O device.

18. The method as set forth in claim 16, wherein said method further comprises the steps of:

(d) providing a plurality of dedicated registers (38) coupled to said programmable I/O unit for storing I/O data being transferred from or to an I/O device by said programmable I/O unit, and for storing control management data being operated on by said interrupt handler for a sequence of programmed I/Os.

19. The method as set forth in claim 16, wherein said method further comprises the steps of:

(d) providing a read routine (112) for performing a sequence of programmed read I/Os performed in association with an I/O device invoking said programmable I/O unit, interrupt, and interrupt handler; and

(e) providing a write routine (114) for performing a sequence of programmed write I/Os performed in association with an I/O device using said programmable I/O unit, interrupt, and interrupt handler.

20. The method as set forth in claim 19, wherein said method further comprises the steps of:

(f) providing a non-blocking read operation for reading from an I/O device; and

(g) providing a non-blocking write operation for writing into an I/O device;

wherein, said read and write routines, when invoked by an application program, use said non-blocking read and write operations to read from and write into an I/O device.

* C L M S *

AMENDED SHEET