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(54) **RECONFIGURABLE LOGIC FOR A COMPUTER**

REKONFIGURIERBARE LOGIK FÜR EINEN RECHNER

LOGIQUE RECONFIGURABLE POUR ORDINATEUR

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(73) Proprietor: **INTEL CORPORATION**
Santa Clara, CA 95054 (US)

(72) Inventors:
• **MORELLI, John**
Milpitas, CA 95035 (US)

• **KENDALL, H., Richard**
Santa Clara, CA 95051 (US)

(74) Representative: **Molyneaux, Martyn William et al**
Harrison Goddard Foote
40-43 Chancery Lane
London WC2A 1JA (GB)

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Description

BACKGROUND

[0001] The present application relates to computing systems, and more particularly, but not exclusively, is directed to reconfigurable-logic for accelerating performance of a computer. Additionally or alternatively, it is envisioned that the present invention may be directed to other applications and technologies.

[0002] Programmable Logic Devices (PLDs) have been developed to facilitate testing and modification of a digital logic design before committing it to mass production. Because these devices fill a unique gap between software data processing and dedicated hardware data processing, some have attempted to augment existing computer systems by installing an input/output (I/O) module with a software accessible programmable logic device. Typically, these modules support only one software application. Moreover, these I/O modules tend to communicate too slowly with the system processor to be of practical benefit for many implementations that would otherwise be desirable. Reference is made to U.S. Patent Nos. 5,978,862 to Kou. et al.; 5,857,109 to Taylor. 5,692,159 to Shand; 5,535,342 to Taylor; and 5,036,473 to Butts et al. for more background information on these arrangements.

[0003] On another front, Field Programmable Gate Array (FPGA) integrated circuit development has begun to focus on single-chip, multiple context arrangements. U.S. Patent Nos. 6,011,740 to Trimberger; 5,978,260 to Trimberger et al.; 5,956,518 to DeHon et al.; 5,915,123 to Mirsky et al.; 5,838,954 to Trimberger; 5,838,165 to Chatter; 5,646,545 to Trimberger et al.; and 5,600,263 to Trimberger et al. provide further information regarding these types of chips. Despite these efforts, challenges remain concerning how to implement these more complicated designs. These challenges are especially acute in relation to interfacing these complex devices with standard computing systems and management of the devices with such systems.

[0004] Jean J.S.N. et al. "Dynamic Reconfiguration to Support Concurrent Applications", IEEE Transactions on Computers, IEEE Inc. New York, US, vol. 48, No. 6, June 1999 (1999-06), pages 591-602, XP000832606 ISSN: 0018-9340 discloses a dynamically reconfigurable system that is able to support multiple applications running concurrently. The dynamically reconfigurable system allows hardware reconfiguration while part of the reconfigurable hardware is computing. A field programmable gate array (FPGA) resource manager is developed to allocate and de-allocate FPGA resources and to pre-load FPGA configuration files. For each individual application, different tasks that require FPGA resources are represented as a flow graph which is made available to the resource manager so as to enable efficient resource management and pre-loading. This reference, therefore, discloses a system having a computer cou-

pled to a reconfigurable logic circuit which includes programmable logic.

[0005] However, there is a need for further contributions in this area of technology.

SUMMARY

[0006] According to this invention there is provided a system as claimed in claim 1 herein.

[0007] Preferred features of the invention are defined by the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

FIG. 1 is a diagrammatic view of a computing system with reconfigurable logic.

FIG. 2 is a diagrammatic view depicting further details of a portion of the system of FIG. 1.

FIG. 3 is a flow chart of a process for utilizing the reconfigurable logic of the system shown in FIG. 1. FIG. 4 is a flow chart showing further details of a "Create" routine for the process of FIG. 3.

FIG. 5 is a flow chart showing further details of an "Open" routine for the process shown in FIG. 3.

FIG. 6 is a memory allocation diagram for the interface memory shown in FIGS. 1 and 2.

FIG. 7 is a flow chart showing further details of a "Write" routine for the process shown in FIG. 3.

FIG. 8 is a flow chart showing further details of a "Read" routine for the process shown in FIG. 3.

FIG. 9 is a flow chart showing further details of a "Close" routine for the process shown in FIG. 3.

FIG. 10 is a flow chart showing further details of a "Release" routine for the process shown in FIG. 3.

FIG. 11 is a diagrammatic view of another arrangement of reconfigurable logic.

FIG. 12 is a diagrammatic view of another computing system with yet another reconfigurable logic arrangement.

FIG. 13 is a diagrammatic view depicting further details of a portion of the system of FIG. 12.

DETAILED DESCRIPTION OF SELECTED EMBODIMENTS

[0009] For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiment illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described device, and any further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the invention relates.

[0010] FIG. 1 is a diagrammatic view of computing system 20 of one embodiment of the present invention. System 20 includes computer 22. Computer 22 includes processor bus 24 arranged to operatively couple together a cluster 25 of Central Processing Units (CPUs) 26a, 26b, 26c, 26d, four (4) of which are depicted (collectively designated processors 26). For one embodiment, cluster 25 includes up to four (4) PENTIUM II microprocessors supplied by Intel Corporation, and processor bus 24 is of a type suitable to interconnect a PENTIUM II microprocessor cluster. Reference is made to: Tom Shanley, Pentium Pro and Pentium II System Architecture, (2d ed., Addison-Wesley Books, 1998) as a source of more information for this type of processor cluster and bus arrangement, and is hereby incorporated by reference. In another embodiment, one or more PENTIUM III microprocessors from Intel Corporation are utilized with a correspondingly arranged processor bus 24. In still other embodiments, more processors or as few as one processor may be utilized. Also, one or more processors of other types and from other manufacturers can be used. In one alternative, computer 22 has only a single processor and processor bus 24 is of a noncluster type. Furthermore, it should be understood that processors or CPUs of the present invention may include one or more components and that processor bus 24 may include one or more components to manage its operation.

[0011] Computer 22 also includes memory controller 27 coupled to processor bus 24. Memory controller 27 operatively couples main memory 28 to processor bus 24 via memory bus 29. Memory controller 27 manages access to main memory 28 over processor bus 24, and may be in the form of one or more dedicated components or part of one or more other components of system 20. Main memory 28 may be comprised of one or more components of the volatile or nonvolatile type and may vary in size. For a typical PENTIUM II arrangement of cluster 25, main memory 28 is typically of the Dynamically Random Access Memory (RAM) type; however, other arrangements of main memory 28 may be utilized with or without a PENTIUM II arrangement for cluster 25.

[0012] Computer 22 also includes Input/Output (I/O) subsystem 32. Subsystem 32 includes I/O bridge 30 operatively coupled to processor bus 24. I/O bridge 30 is also operatively coupled to I/O bus 34. I/O bridge 30 serves as a communication link between processor bus 24 and I/O bus 34, providing buffering, reformatting, arbitration, and/or other operations to facilitate desired communications between the buses. I/O bus 34 operatively connects one or more I/O devices to processor bus 24 via I/O bridge 30. Two I/O modules 36a, 36b are depicted in FIG. 1 (collectively designated modules 36). It should be appreciated that more or fewer I/O modules 36 may be coupled to I/O bus 34. In one implementation, I/O bridge 30 and memory controller 27 are provided in a combined form as a single component or dedicated set of components to manage I/O and main memory transactions with processor bus 24. Computer 22 can

alternatively or additionally include one or more other I/O bridges coupled to I/O bus 34 and/or processor bus 24 to correspondingly provide further I/O buses of the same or different types. In other embodiments, distinct I/O bridges and/or I/O buses are absent.

[0013] For one embodiment with a PENTIUM II arrangement of cluster 25, I/O bus 34 is of a standard Peripheral Component Interconnect (PCI) local bus type. In this embodiment, the bandwidth of I/O bus 34 is less than the bandwidth of processor bus 24; where bandwidth is the product of the data width of the given bus and the bus speed (usually in terms of frequency). Also, latency time for a data transfer between different agents on processor bus 24 is typically less than the latency time for a data transfer between one of the devices on processor bus 24 and one of the devices on I/O bus 34 for this embodiment. As used herein, "latency time" means a measure of time from a request by a first device to receive data from a second device to the start of receipt of that data by the first device from the second device in response to the request (usually in terms of bus cycles). Accordingly, the "total transfer time" for a data block is a function of latency time, and the product of the bandwidth and data block size, which is typically less for transfers between devices on processor bus 24 than transfers between a device on processor bus 24 and a device on I/O bus 34.

[0014] This embodiment can also include one or more additional I/O bridges to other I/O buses coupled to processor bus 24. Alternatively or additionally, an I/O bridge can be provided to couple an I/O bus of the PCI type to other varieties, such as the Industry Standard Architecture (ISA) and/or the Extended Industry Standard Architecture (EISA) type. In one particular instance of a PENTIUM II-based embodiment, an additional EISA-type I/O bridge is coupled to a PCI form of I/O bus 34 to provide an EISA extension of I/O bus 34, and an Advanced Programmable Interrupt Controller (APIC) bus is connected to processors 26 and an I/O APIC module that is connected to the additional EISA bridge. Furthermore, in other embodiments, different I/O bridges and/or I/O bus types may be utilized for I/O subsystem 32 either with or without a PENTIUM II processor cluster as would occur to those skilled in the art.

[0015] I/O module 36b is further designated as a non-volatile mass memory interface. This interface is for a permanently installed and/or a portable computer-readable device 37, as schematically depicted in FIG. 1. Device 37 can be of the electromagnetic, optical, semiconductor, and/or other variety as would occur to those skilled in the art. For example, device 37 can be an optically encoded Compact Disk (CD) or Digital Video Disk (DVD) of the read only or read/write type; an electromagnetic hard drive disk, portable floppy drive disk, tape, or bubble memory cartridge; and/or a nonvolatile semiconductor cartridge or card of the Programmable Read Only Memory (PROM), Erasable Programmable Read Only Memory (EPROM), Electrically Erasable

Read Only Memory (EEROM), flash, and/or Static Random Access Memory (SRAM) type with portable back up power, just to name a few. In one embodiment, I/O module 36a and device 37 collectively designate a PCI/ISA/IDE accelerator component and Integrated Drive Electronics (IDE) hard drive unit.

[0016] Computer 22 is coupled to reconfigurable logic circuit 40 by processor bus 24. Reconfigurable logic circuit 40 includes programmable logic 50. As used herein, "programmable logic" refers broadly to any form of hardware logic that may be programmed more than once, including, but not limited to, one or more Programmable Logic Devices (PLDs), Field Programmable Gate Arrays (FPGAs), and/or Dynamically Programmable Gate Arrays (DPGAs), to name only a few. Programmable logic 50 is coupled to interface memory 60 by memory bus 64 and design loading logic 70 by bus 74. Design loading logic 70 is coupled to logic design memory 80 by bus 84. Interface memory 60 and logic design memory 80 are collectively designated local memory 90. In one embodiment, reconfigurable logic circuit 40 is provided as a unit with a connector to removably interface to processor bus 24 of computer 22. For this embodiment, the one or more components comprising reconfigurable logic circuit 40 may be mounted to a common printed wiring board with a plugable card edge connector. For multiple component embodiments of reconfigurable logic circuit 40, such components may be mounted on more than one printed wiring board or card, or otherwise be distributed throughout system 20. Indeed, reconfigurable logic circuit 40 may be provided as a permanently installed subsystem on a mother board shared with various components of computer 22. Accordingly, reconfigurable logic circuit 40 alternatively may be considered an integral part of computer 22.

[0017] Referring additionally to FIG. 2, further details of reconfigurable logic circuit 40 are described. Programmable logic 50 is provided with computer interface logic portion 54, memory interface logic portion 56, and user-defined programmable logic portion 58. Preferably, programmable logic 50 is comprised of one or more FPGA devices of the volatile type, such as those manufactured by Xilinx or Altera; however, one or more other device types or a combination of different device types may comprise programmable logic 50. For volatile configurations of programmable logic 50, computer interface logic portion 54 and/or memory interface logic portion 56 can be programmed as part of an initialization operation when power or a reset signal is applied to reconfigurable logic circuit 40 as more fully described hereinafter in connection with FIG. 3.

[0018] Computer interface logic portion 54 of programmable logic 50 is operatively coupled to processor bus 24 to provide a direct, two-way communication pathway with one or more of processors 26 of computer 22. Computer interface logic portion 54 is also operatively coupled to design loading logic 70 by bus 74. Because of the bus 84 connection of design loading logic 70 to

logic design memory 80, information can be communicated between computer 22 and logic design memory 80 via computer interface logic portion 54 and design loading logic 70. Logic design memory 80 is arranged to store a number of core logic designs 86 in memory 80, a few of which are individually designated in FIG. 2 as Core 0, Core 1, Core 2, ..., and Core n; where "n" is the total number of core logic designs stored. Designs 86 can be initially provided to logic design memory 80 from computer 22. Designs 86 each provide a different configuration of user-defined logic portion 58. Design loading logic 70 is responsive to appropriate signals or commands to load a selected one of the stored logic designs 86 into programmable logic 50 via bus 84 and 74. One or more designs 86 in memory 80 can be scheduled for application to programmable logic 50.

[0019] Memory interface logic portion 56 of programmable logic 50 provides a communication pathway from interface memory 60 to computer 22 and user-defined logic portion 58. Interface memory 60 is dynamically allocated to include one or more control structures 66, scratch memory space 67, and one or more interface buffers 68. For each scheduled or active design 86, one of control structures 66 and one or more corresponding interface buffers 68 are allocated to store information pertinent to interfacing between the given design 86 and computer 22. Scratch memory space 67 is available for access by user-defined logic 58.

[0020] Referring additionally to FIG. 3, one technique for managing and scheduling the configuration of programmable logic 50 with logic designs 86 is described in connection with process 210 illustrated by the flow chart of FIG. 3. Process 210 starts from a reset or power-on condition 212 of system 20. From condition 212, computer 22 maps reconfigurable logic circuit 40 into a designated memory space "RL" in operation 214. In operation 216, loading logic 70 is configured to load Core 0 into programmable logic 50 from memory 80. Once loaded, Core 0 sets-up reconfigurable logic circuit 40 to interface with computer 22 via processor bus 24 by defining computer interface logic portion 54 and memory interface logic portion 56 of programmable logic 50. Typically, Core 0 is a special initialization design that need not specify a user-defined logic portion 58 of programmable logic 50. It should be appreciated that for process 210, it is desirable that at least a portion of design loading logic 70 and core logic design memory 80 be of a nonvolatile type to provide for loading of computer interface logic portion 54 and memory interface logic portion 56 upon power-up. In one embodiment, loading logic 70 is provided by a nonvolatile Complex Programmable Logic Device (CPLD), a hard-wired state machine of multiple devices, or the like; and memory 80 includes one or more nonvolatile flash-type devices. It should be understood that each core logic design 86 may be arranged to configure computer interface logic portion 54 and/or memory interface logic portion 56 along with user-defined logic portion 58. Alternatively, once interface

logic portions 54 and/or 56 are configured upon power-up or reset condition 212, subsequent reconfigurations of programmable logic 50 with different core logic designs 86 only alter user-defined logic portion 58. In still other embodiments, interface logic portions 54, 56 are nonvolatile, so that initial loading is not required upon power-up.

[0021] After computer interface logic portion 54 and memory interface logic portion 56 are established in operation 216, communication between computer 22 and reconfigurable logic 50 may take place over processor bus 24. For example, by accessing memory addresses in memory space RL, one or more processors 26 of computer 22 can write interface information to reconfigurable logic circuit 40, such as input data to be processed by programmable logic 50 or commands to reconfigurable logic circuit 40; and read interface information, such as processing results from programmable logic 50 or status of reconfigurable logic circuit 40. Computer 22 executes a number of application programs 112 and logic interface program 122 (see FIG. 2). Logic interface program 122 provides an upper-level interface programming layer responsive to requests by application programs 112 to utilize reconfigurable logic circuit 40. Logic interface program 122 communicates with reconfigurable logic circuit 40 through a second, lower-level programming layer in the form of device driver routine 124. Device driver routine 124 is customized to the particulars of the design for reconfigurable logic circuit 40 to convert communications from logic interface program 122 into a format recognized by reconfigurable logic circuit 40. Accordingly, for this embodiment a number of different device driver routines 124 can be alternatively utilized to interface with correspondingly different reconfigurable logic designs. These different device driver routines 124 each communicate with logic interface program 122 through a common protocol, but generally have different communication protocols peculiar to the associated reconfigurable logic design. In other embodiments, different interface program arrangements may be utilized that include the same, more, or fewer programming layers. Indeed, in one alternative embodiment, logic interface program 122 is integrally combined with device driver routine 124 to provide a single layer of logic interface programming. In other alternatives, logic interface program 122 can include multiple device drivers in the form of selectable subroutines, and/or include three or more programming layers.

[0022] In FIG. 2, application programs 112 are designated as APP 1, APP 2, ..., and APP m; where "m" is the total number of application programs 112 undergoing concurrent execution by computer 22. As used herein, "concurrent execution" of two or more programs refers to starting and managing execution of the two or more programs by the computer at the same time, even though the computer may only perform instructions for one of the programs at a time. Concurrent execution includes, but is not limited to multitasking of two or more

programs through context switching, time slicing, or another mode, and/or multiprocessing of two or more programs by simultaneously executing each program on a different CPU.

[0023] Typically, an application program 112 provides input data for processing by the programmable logic 50 with the requested core logic design 86, and programmable logic 50 processes the input data to generate corresponding output data. Management of this input and output data for each requesting application program 112 are among the tasks performed by logic interface program 122, computer interface logic portion 54, and/or memory interface logic portion 56.

[0024] For many applications, reconfigurable logic circuit 40 is utilized to accelerate a computationally intense algorithm. Such algorithms are commonly included in encryption/decryption, image processing, voice recognition or synthesis, video conferencing, and the like. By making a variety of core logic designs 86 and/or logic design instances available to application programs 112, acceleration of these and other commonly executed processes is made possible. In one embodiment, computer 22 operates with a WINDOWS-based operating system from MICROSOFT, and logic interface program 122 is arranged to provide a WINDOWS-compatible interface protocol for application programs 112. For this embodiment, logic interface program 122 provides a standard Application Program Interface (API) to communicate with application programs 112 executed under the WINDOWS operating system. Nonetheless, in other embodiments, different operating systems and/or operation system relationships to logic interface program 122 can be utilized.

[0025] After operation 216, process 210 continues with processing/monitoring loop 220. In loop 220, operation 230 includes the performance of tasks by logic program interface 122 in operations block 232 and reconfigurable logic circuit 40 in operations block 234. In operations block 232, logic interface program 122 generates various read/write accesses to memory space RL of reconfigurable logic circuit 40. Reconfigurable logic circuit 40 interprets and responds to these memory accesses in operations block 234 via computer logic interface portion 54.

[0026] As part of operation 230, logic interface program 122, computer interface logic portion 54, or a combination of these is configured to periodically switch between core logic designs 86 of logic design memory 80 that have been scheduled to service requests from application programs 112. In one embodiment, context switching is performed by changing the configuration of programmable logic 50 from one requested core logic design 86 to next, based on the passage of a uniform time interval between each change. In another embodiment, the timing of context switching may vary depending on the core logic design and/or inputs from logic interface program 122. For example, these inputs may relate to the need for additional time to process a given

core logic design that handles larger amounts of data relative to another of the core logic designs. In still another embodiment, logic interface program 122 is arranged to recognize when requests by application programs 112 can be addressed more efficiently by processing with no or limited context switching. Nonetheless, alternative embodiments may include context switching regardless of priority or other inputs. Yet other embodiments provide for multiple context switching modes and an option of no context switching as part of logic interface program 122. Indeed, in a further embodiment, logic interface program 122 is arranged to handle simultaneous processing of different core logic designs by multiple programmable logic devices 50 included in reconfigurable logic circuit 40 (not shown). Logic interface program 122 includes a scheduler routine to schedule and manage configuration of programmable logic 50 with different logic designs 86.

[0027] Even if different application program requests are for the same core logic design, logic interface program 122 instantiates a different logical or virtual program interface for each application program request because the input and/or output data for a given request typically differs. Accordingly, whether for the same or different core logic designs, each of these instantiations or "instances" is separately established and maintained by logic interface program 122. Logic interface program 122 is further arranged to determine if a given instantiation or "instance" of a logic design requires activation/loading of a new logic design or if it is already scheduled. In correspondence with this capability, instances and/or virtual program interfaces established for active instances may be modeled as "clients" and logic interface program 122/reconfigurable logic circuit 40 may be modeled as a "server" for these clients.

[0028] In one example directed to multiple instances of a common core logic design, an encryption core logic design is requested by a number of the application programs 112 that is embodied in user-defined logic portion 58 of programmable logic 50. This design partially or completely encrypts data provided to the reconfigurable logic circuit 40 and returns encrypted results to computer 22 via processor bus 24. It should be appreciated that such a core logic design might be requested a number of times by different application programs or the same application program multiple times with different input data for each request. Accordingly, logic interface program 122 tracks a separate designator for each instance; however, once the corresponding user-defined logic portion 58 is configured with the encryption logic, it need not change. Furthermore, when multiple instances of a common design are indicated along with scheduling of other designs, logic interface program 122 can be arranged to provide the option of processing each of these instances consecutively to reduce overhead that might otherwise occur due to swapping different core logic designs in and out of programmable logic 50. Nonetheless, in other embodiments, it may be more ad-

vantageous to provide context switching without adjustment for multiple instances of the same design, or to otherwise adjust allocation as would occur to those skilled in the art.

[0029] Logic interface program 122/reconfigurable logic circuit 40 provides for the allocation of overflow memory space in main memory 28 as needed to address fluctuating demands on local memory 90. Fig. 2 depicts an overflow memory space 128 with a few representative overflow segments designated by reference numerals 128a, 128b, 128c, 128d. Segments 128a, 128c represent overflow segments for core logic design programs that are further described in connection with routine 310 of Fig. 4. Segments 128b, 128d represent interface information overflows 2 and 5 that correspond to logic design instances 2 and 5 scheduled for execution by programmable logic 50. During context switching between core logic designs or logic design instances, the size of memory 60 may not be sufficient to store desired input, output, and/or state information of a context while it is deactivated. Accordingly, overflow segments 128b and 128d may be used until programmable logic 50 is again allocated to process that particular context. Nonetheless, in other embodiments, such overflow space may not be necessary or may not be allocated, instead limiting operations to available space in local memory 90 of reconfigurable logic circuit 40.

[0030] It should be understood that application programs 112 requests to utilize reconfigurable logic circuit 40 may result in a number of coexisting virtual program interfaces. Each of these virtual program interfaces communicates with reconfigurable logic circuit 40 through a set of standard routines or functions of logic interface program 122 that treat each logic design instance in a manner comparable to a logical file. These routines are listed as part of operations block 232 in FIG. 3. Logic interface program 122 manages the virtual program interfaces in a file-like manner. Logic interface program 122 communicates these standard commands/functions through device driver routine 124. Device driver routine 124 generates each read or write access to which reconfigurable logic circuit 40 responds. Computer interface logic portion 54 of programmable logic 50 monitors processor bus 24 for an appropriate read or write access to memory space RL by device driver routine 124. If a valid access is detected, reconfigurable logic circuit 40 responds in accordance with the command, request, or data communicated by computer 22.

[0031] Operations 232, 234 are further described in terms of the tasks performed for various routines of logic interface program 122 as follows. A new core logic design is loaded into reconfigurable logic circuit 40 from computer 22 with the Create(Core Design) routine 310 as further described in connection with the flow chart of FIG. 4. Routine 310 starts with designation stage 312. From stage 312, routine 310 continues with conditional 314 that determines whether memory space is available in logic design memory 80. In one embodiment, this test

is performed by logic interface program 122, which maintains a record of the amount of memory space available in logic design memory 80 since the reset or power-on condition 212. In alternative embodiments, this test may be partially or completely performed by computer interface logic portion 54 and/or design loading logic 70. If memory space is available in logic design memory 80, routine 310 continues with stage 322 to push the new logic core design into logic design memory 80 in stage 322. The execution of stage 322 includes transferring the new core logic design under the control of logic interface program 122 from main memory 128 and/or an I/O device such as computer readable device 37 to logic design memory 80 via computer interface logic portion 54, bus 74, loading logic 70, and bus 84.

[0032] Routine 310 continues with stage 324. In stage 324, logic interface program 122 assigns a unique identification (ID) for the new core logic design stored in logic design memory 80 that may be used in other routines of logic interface program 122. Routine 310 then halts, returning to operation 230 of process 210 of FIG. 3. From operation 230, process 210 continues with conditional 236. Conditional 236 tests if a power-down or reset has occurred. If a power-down or reset condition has not occurred, then loop 220 is engaged to return to operation 230 to process the next task of logic interface program 122 in operations block 232 and reconfigurable logic circuit 40 in operations block 234. If a power-down or reset condition has occurred, process 210 halts.

[0033] Returning to conditional 314 of FIG. 4, if space is not available in logic memory 80, routine 310 continues with conditional 316. Conditional 316 test whether overflow memory space 128 is available in main memory 28. As depicted in FIG. 2, overflow memory space 128 includes overflow segments 128a and 128b for Core X and Core Y logic designs, respectively. If overflow space is not available, routine 310 continues with stage 318 which indicates a failure of the Create function and returns a corresponding indication. From stage 318, routine 310 halts and control returns to operation 230 of process 210.

[0034] If it is determined that overflow memory space is available in main memory 28, as tested by conditional 316, routine 310 continues at stage 320. In stage 320, logic interface program 122 directs the transfer of the least recently used core logic design to main memory 28. For the FIG. 2 depiction, Core X or Core Y may be such a design. The determination of which logic design was least recently used includes a reference by logic interface program 122 to interface memory 60 through memory interface logic portion 56 of programmable logic 50, as will be explained in greater detail hereinafter in connection with the flow chart of routine 410 shown in FIG. 5 and the memory diagram of FIG. 6. After stage 320, routine 310 resumes with stages 322 and 324 as described previously. Routine 310 then halts and control returns to operation 230 of process 210 as shown in FIG. 3.

[0035] Routine 310 may be repeated a number of times to provide for an appropriate loading of a number of desired core logic designs 86 in memory 80. Once a desired logic design 86 is stored in memory 80, a virtual program interface to that design is established by activating (instantiating) an instance of the logic design with the Open(ID, PL) routine 410 further described in connection with the flow chart of FIG. 5 and the memory diagram of FIG. 6. Routine 410 begins with stage 412; where 'ID' is the ID of a core logic design previously created with Create(Core Design) routine 310, and 'PL' is a selected priority level. From stage 412, routine 410 continues with stage 413 that establishes a logical/virtual program interface for an instance of core logic design ID with logic interface program 122. Stage 413 also assigns a unique instance identifier IID for that instance. After opening a program interface in stage 413, routine 410 continues with conditional 414 to test whether programmable logic 50 is available to execute the core logic design ID corresponding to the newly opened instance IID. If it is available, the core logic design specified by ID is loaded into programmable logic 50 in stage 416. If it is not available, the scheduler routine of logic interface program 122 is executed to schedule an active instance of the core logic design specified by ID according to its assigned priority level PL in stage 418. Once either stage 416 or 418 is completed, routine 410 halts and control returns to operation 230 of process 210.

[0036] Regardless of which stage 416 or 418 is executed by routine 410, core logic design ID stored in memory 80 is activated either to be immediately loaded into programmable logic 50 via loading logic 70 or scheduled for such loading. This loading process includes sending appropriate direction from logic interface program 122 via device driver routine 124 to design loading logic 70 through computer interface logic portion 54. Design loading logic 70 then transfers the appropriate core logic design 86 designated by ID via bus 84 and 74 either immediately for stage 416 or in accordance with the schedule established in stage 418. As in the case of the Create(Core Design) routine, the Open (ID) routine may be repeated a number of times to establish a number of coexisting program interfaces for different logic design instances. It should be appreciated that in other embodiments, the Create(Core Design) and Open(ID) operations may be combined into a single routine or function with or without other operations. In one form of this combined approach, a new core logic design is loaded into reconfigurable logic circuit 40, and a logic design instance instantiated in response to the routine. Subsequent attempts to load the same program instantiate a new instance, but do not reload the design.

[0037] Referring additionally to FIG. 6, with each establishment of an instance IID of one of core logic designs 86, logic interface program 122 also directs the establishment of a corresponding control structure 66 and interface buffer(s) 68 via computer interface logic portion 54 and memory interface logic portion 56 of pro-

grammable logic 50. Going from top to bottom, memory 60 is diagrammed from its lowest address to its highest address. For each instance IID that has been opened in accordance with routine 410, a control structure for the corresponding core logic design is added from low to high memory; where the ellipsis between structures 66 represent like structures that are not shown to preserve clarity. From the highest address towards lower addresses of memory 60, interface control buffers 68 are allocated in sets for each instance IID of a core memory design. Again, an ellipsis is shown between interface buffers 68 to represent like buffers that are not specifically illustrated to preserve clarity. Between control structures 66 and interface buffers 68, scratch memory space 67 is illustrated that dynamically changes in size depending on the number of allocated control structures 66 and interface buffers 68.

[0038] FIG. 6 illustrates in greater detail a representative control structure entry set 69a for one of the control structures 66. The entries of set 69a are arranged to store interface information for a designated Core 1 logic design (ID=Core 1). Entry 66a specifies a unique identifier to designate Core 1 as the corresponding logic design for the particular instance. Entry 66b includes data specifying the time of last use of the instance IID. The information in entry 66b can be referenced to determine which logic design is the least recently used in stage 320 of routine 310.

[0039] FIG. 6 also illustrates in greater detail a representative interface buffer set 69b. Interface buffer set 69b includes the interface buffers 68 allocated to the logic design instance IID of the Core 1 logic design with the control structure entry set 69a. Entry 66c of control structure entry set 69a is a pointer that specifies the starting address in interface memory 60 of input buffer 68a of set 69b. Entry 66d of set 69a specifies the size of the input buffer 68c. Accordingly, input buffer 68a is allocated through entries 66c, 66d of the corresponding control structure 66. Data is stored in input buffer 68a by computer 22 for processing by the requested instance IID of the Core 1 logic design via the Write(IID) function to be further described hereinafter.

[0040] Entry 66e of control structure entry set 69a is a pointer to the starting address of output buffer 68b of interface buffer set 69b. Entry 66f specifies the size of output buffer 68b. Accordingly, output buffer 68b is allocated through entries 66e, 66f of the corresponding control structure 66. Data is read from output buffer 68a by computer 22 with the Read(IID) function to be further described hereinafter. This output data includes the results obtained by processing the data in input buffer 68a with the Core 1 logic design for instance IID.

[0041] Entry 66g of control structure entry set 69a specifies the starting address of a state buffer 68c of interface buffer set 69b. Entry 66h of control structure 66a specifies the size of state buffer 68c. The state buffer may be used for the storage of intermediate results during context switching, to provide overflow for input

buffer 68a and/or output buffer 68b, or as would otherwise occur to those skilled in the art.

[0042] Other control structures 66 and interface buffers 68 of memory 60 are configured like sets 69a, 69b, respectively, for each instance IID. In other embodiments, the number and type of entries for control structures 66 may vary. Likewise, the number and type of interface control buffers 68 may be different in number and type, and indeed may vary from one to the next for different core logic designs or logic design instances. In one variation, a common buffer is used by an instance IID for storing both input and output data. The allocation and storage of values in control structures 66 for each different instance IID may be performed and managed by logic interface program 22 via device driver routine 124, computer interface logic portion 54, memory interface logic portion 56, or a combination of these. Accordingly, the allocation of scratch space 67 follows from the size, location, and number of buffers defined by each of control structures 66.

[0043] Referring again to operation 230 of process 210 shown in FIG. 3, a Write(IID) function of operations block 232 is further described in connection with routine 510a detailed in the flow chart of FIG. 7. Write(IID) routine 510a is performed to provide input data from a requesting application program 112 for processing by reconfigurable logic circuit 40 via logic interface program 122 and device driver routine 124. The Write(IID) function is only performed after the corresponding instance IID has been instantiated. From the designation in stage 512a, routine 510a continues with conditional 514a. In conditional 514a, routine 510a tests whether the particular core logic design IID has priority for execution by the hardware of reconfigurable logic circuit 40. Such priority may be dynamic or static and may be based on one or more factors. Such factors can include, the relative priority level PL of the various active instances IID, the amount of time since a given instance IID has been given hardware priority, the degree of utilization of reconfigurable logic circuit 40, and/or the availability of a software routine alternative to name a just a few. In one form, priority is determined based on a status flag that is updated from time-to-time based one or more of these factors.

[0044] If the core logic design instance IID does have priority as tested by conditional 514a, routine 510a continues with conditional 516a, which tests whether the corresponding core logic design ID is loaded in programmable logic 50. If the core logic design specified by ID is not loaded, stage 518a is engaged which waits until the appropriate core logic design specified by ID is switched into the programmable logic 50 in accordance with the scheduler routine of logic interface program 122. Typically this wait is for the next context switch. Stage 519a is next encountered in which data to be processed for the Write(IID) operation is pushed into the corresponding input buffer of interface buffers 68. If the test of conditional 516a is affirmative, that is the desired

core logic design ID is already loaded in programmable logic 50, then routine 510a proceeds directly to stage 519a from the affirmative branch of conditional 516a.

[0045] Routine 510a then resumes with a protocol test in conditional 520a. Conditional 520a determines whether the particular core logic design is to be applied immediately as a part of routine 510a - an "eager protocol." If the protocol for the given instance IID is of the eager type, as tested by conditional 520a, then routine 510a continues with stage 522a to apply the corresponding core logic design. Routine 510a then returns to process 210 to await the next operation. Likewise, if the test of conditional 520a is negative--that is the protocol is not of the eager type, then the routine 510a returns directly to process 210 from the negative branch of conditional 520a.

[0046] Returning to conditional 514a, if the instance IID does not have priority for hardware execution, then routine 510a continues with stage 530a. In stage 530a, the input data that would have been processed by reconfigurable logic circuit 40 if instance IID did have priority, is instead provided to a software routine that emulates the corresponding core logic design ID. This input data may be stored in a corresponding software input buffer for the emulation routine. Next, conditional 532a is encountered which performs the same protocol test as conditional 520a. If the protocol is of the eager type as tested by conditional 532a, then the software emulation routine is applied in stage 534a. The Write(IID) routine 510 then returns. Likewise, if the protocol type is not of the eager type, then routine 510 returns directly from the negative branch of conditional 532a.

[0047] A Read(IID) function of operations block 232 is further described in connection with routine 510b detailed in the flow chart of FIG. 8. Read(IID) routine 510b is performed to obtain output data relating to the processing of data previously input through the performance of one or more Write(IID) functions in accordance with routine 510a. Likewise, a Read(IID) function is only performed after the corresponding instance IID has been instantiated. From the designation in stage 512b, routine 510b continues with conditional 514b. Conditional 514b performs the same test as conditional 514a of routine 510a, regarding whether the particular core logic design IID has priority for execution by the hardware of reconfigurable logic circuit 40. If the core logic design instance IID does have priority as tested by conditional 514b, routine 510b continues with conditional 516b, which tests whether the corresponding core logic design ID is loaded in programmable logic 50. If the core logic design specified by ID is not loaded, operation 518b is engaged which waits until the appropriate core logic design specified by ID is switched into the programmable logic 50 in accordance with the scheduler routine of logic interface program 122. Typically this wait is for the next context switch. Routine 510b then resumes with conditional 520b. If the test of conditional 516a is affirmative, that is the desired core logic design

ID is already loaded in programmable logic 50, then routine 510a proceeds directly to conditional 520b from the affirmative branch of conditional 516b.

[0048] Conditional 520b provides the same protocol test as conditionals 520a, 532a of routine 510a to determine if the instance IID is of the eager type. If the given instance IID is not of the eager type, then stage 522b is encountered which applies the corresponding core logic design. Routine 510b continues at stage 540b. If instance IID is of the eager type as tested by conditional 520b, then routine 510b proceeds directly from the affirmative branch of conditional 520b to stage 540b. In stage 540b, the processed output data is pulled from the corresponding output buffer of interface buffers 68 by interface program 122 via device driver routine 124 to be returned to the corresponding application program 112.

[0049] Returning to conditional 514b, if the instance IID does not have priority for hardware execution, then routine 510b continues with conditional 532b, which performs the same protocol test as conditional 520b. If the test of conditional 532b is negative, that is a noneager instance IID, then routine 510b continues with stage 534b to apply the emulation software. Routine proceeds from stage 534b to stage 542b to provide the output data to the requesting application program 112 produced by the software routine emulating the core logic design. If the test of conditional 532b is affirmative, that is the instance IID is eager, then routine 510b proceeds directly from the affirmative branch of routine 532b to stage 542b. Routine 510b returns to process 210 after performance of stage 542b.

[0050] Referring to both FIGs. 7 and 8, it should be understood that an instance IID of the eager type favors processing in stage 522a or 534a of the associated data input in stage 519a or 530a, respectively, as part of the performance of the Write(IID) routine 510a. Accordingly, because the data has already been processed, it need only be retrieved in the corresponding stages 540b, 542b of the Read(IID) routine 510b. In contrast, for a noneager type of instance IID, Write(IID) routine 510a inputs the data in the respective stage 519a or 530a without application. Instead, the Read(IID) routine 510b processes the input data in stage 522b or 534b, respectively.

[0051] The Close(IID) routine 610 is detailed in the flow chart of FIG. 9. It is performed to selectively close an open instance IID of logic design ID as established with the Open(ID) routine. From the identifier 612, routine 610 continues with stage 613. In stage 613, the core logic design instance IID is closed. Routine 610 resumes with conditional 614. In conditional 614, logic interface program 122 tests whether IID was the only instance of the corresponding core logic design ID. If it was the only instance, routine 610 continues with stage 615. In stage 615, a flag is set to indicate configurable logic 40 is free to accept another design. This flag can be read for conditional 314 and/or 316 of routine 310 to

determine if a new logic design can be loaded. Routine 610 then proceeds from stage 625 or a negative result for conditional 614 to conditional 616 to determine whether there is a request pending to utilize programmable logic 50. Such requests are maintained as part of the scheduler routine for logic interface program 122. If there is not a pending request, stage 618 is engaged to set a flag indicating availability of programmable logic 50. This flag can be read when executing conditional 414 of routine 410 to determine if a logic design can be executed. If there is a request pending, stage 620 is engaged. In stage 620 logic interface program 122 executes its scheduler routine to load another core logic design into programmable logic 50 or serve another instance IID. From the execution of either stage 618 or 620 as determined by conditional 616, routine 610 halts and returns to operation 230 of process 210 as depicted in FIG. 3.

[0052] The Release(ID) routine 710 of operations 232 is further detailed by the flow chart depicted in FIG. 10. Routine 710 is performed to release resources set aside for core logic design ID established with the Create (Core Design) routine 310, and requires that all instances IID for core logic design ID be closed first with the Close(IID) routine 610. From the identifier 712, routine 710 proceeds to stage 714 to free the core logic design identifier ID for use by a different core logic design. Routine 710 then proceeds to stage 716 to purge the released core logic design from storage in logic design memory 80 and any overflow space contained in main memory 28. This purge may be accomplished by marking the associated memory space to be overwritten by subsequent designs and/or to take action to erase logic design information. After stage 716, routine 710 halts, returning control to operation 230 of process 210. It should be appreciated that in other embodiments, the Close(IID) and Release(ID) operations may be combined into a single routine or function with or without other operations. In one form, all instances IID of the core logic design ID are closed and the core logic design memory space released in response to execution of this combined routine.

[0053] FIG. 11 illustrates reconfigurable logic circuit 140 of another embodiment of the present invention; where like reference numerals represent like features of previously described embodiments. Reconfigurable logic circuit 140 is interchangeable with reconfigurable logic circuit 40 of system 20. Reconfigurable logic circuit 140 includes programmable logic 150 interfaced with computer 22; where such interface may be, for example, by coupling to processor bus 24 as in the case of system 20. Programmable logic 150 includes computer interface logic 154, memory interface logic 156, and user-defined logic portion 58. Computer interface logic 154 is coupled to computer 22 by processor bus 24 and loading logic 170 by bus 174 in a manner analogous to that described for computer interface logic portion 54, bus 74, and design loading logic 70 of reconfigurable logic

circuit 40.

[0054] Memory interface 156 is coupled to interface memory 160 by memory buses 164a and 164b. Interface memory 160 is comprised of two devices, memory device 160a and memory device 160b. Each of memory devices 160a and 160b includes one or more corresponding control structures 166a, 166b, scratch spaces 167a, 167b, and interface buffers 168a, 168b, respectively. For the depicted example, memory device 160a stores control structure 166a and interface buffers 168a for a Core 1 logic design and memory device 160b stores control structure 166b and interface buffers 168b for a Core 2 logic design. Memory interface 156 is partitioned so that user-defined logic portion 58 can access one of the devices 160a, 160b on one of buses 164a, 164b (a local access mode), while computer 22 can access the other of the devices 160a, 160b on the other bus 164a, 164b (a remote access mode). For instance, during operation of programmable logic 50 while configured with the Core 1 design, user-defined logic portion 58 can locally access scratch space 167a, and/or interface buffers 168a; and computer 22 can remotely access device 160b simultaneously. Likewise during operation of programmable logic 150 configured with the Core 2 logic design, user-defined logic portion 58 can locally access scratch space 167b and/or interface buffers 168b; and computer 22 can remotely access device 160a simultaneously.

[0055] This parallel access capability permits logic interface program 122 to send/receive interface information with respect to a first one of devices 160a, 160b while the executing user-defined logic portion 58 of programmable logic 50 utilizes the interface information and/or scratch space 167a, 167b of a second one of the devices 160a, 160b. Accordingly, greater efficiencies can be realized in comparison to a technique where access to the interface memory 60 by only computer 22 or user-defined logic portion 58 is permitted at a given time. Typically, remote access by computer 22 is given priority when both computer 22 and user-defined logic portion 58 are seeking access to one of devices 160a or 160b.

[0056] It should be understood, that multiple control structures and corresponding interface buffers for multiple instances may be stored in either or memory devices 160a and 160b. For such arrangements, context switching may be arranged to alternate between local and remote access modes for each device 160a and 160b. By way of nonlimiting example, for context switching between four different logic designs with the sequence Core 1 logic design, Core 2 logic design, Core 3 logic design, and Core 4 logic design; interface information for the Core 1 and Core 3 logic designs could be stored in memory device 160a and the interface information for the Core 2 and Core 4 logic designs could be stored in memory device 160b to provide the local/remote access alternation. Alternatively or additionally, more than two memory devices each having a separate access bus may be operated with local and remote ac-

cess modes in correspondence with the particular core logic design being executed.

[0057] Computer interface logic 154 is also coupled to loading logic 170 via bus 174. Loading logic 170 is coupled to logic design memory 180 via bus 184. Logic design memory 180 includes one or more volatile memory devices 180a and one or more nonvolatile memory devices 180b. In one embodiment, the one or more nonvolatile memory devices 180b include at least one flash memory device for initial storage of core logic designs. The one or more volatile memory devices 180a can include Static Random Access Memory (SRAM), Dynamic Random Access Memory (DRAM), a combination of these, and/or such other type of memory as would occur to those skilled in the art. Because a limit typically exists regarding the number of times a flash memory of devices 180b may be rewritten, the one or more volatile devices 180a can serve as another means to store core logic designs; and thereby can be utilized to reduce the likelihood of reaching such a limit. In one embodiment, volatile devices 180a are arranged to provide storage for core logic designs that are expected to change more frequently relative to core logic designs stored in nonvolatile devices 180b. Accordingly, logic interface program 122 and/or device driver routine 124 can be arranged to provide an option regarding the form of core logic design storage desired. Furthermore, it should be appreciated that SRAM and DRAM type devices 180a can often provide greater storage density than flash memory type devices 180b, facilitating the local storage of more core logic design information.

[0058] FIG. 12 illustrates computer system 200 of another embodiment of the present invention; where like reference numerals refer to like features of previously described embodiments. System 200 includes computer 22 as described in connection with FIG. 1. System 200 also includes reconfigurable logic circuit 240 operatively coupled to memory bus 29 along with main memory 28. Memory controller 27 interfaces with both memory bus 29 and processor bus 24 to manage access to main memory 28 or reconfigurable logic circuit 240 by one or more processors 26.

[0059] Referring additionally to FIG. 13, reconfigurable logic circuit 240 includes programmable logic 250, interface memory 260, core loading logic 270, and core storage 280. Interface memory 260 includes two separately accessible interface storage memories 260a and 260b. As previously described for memory 60 and 160, interface storage memories 260a and 260b can each be configured of one of more memory types and/or comprised of one or more components. Each interface storage memory 260a and 260b is selectively coupled to memory bus 29 by a different isolating bus switch 230a and 230b, respectively. Each bus switch 230a and 230b is coupled to bus 29 by one or more pathways 29a as needed to transmit data to and from the respective interface storage memory 260a or 260b via memory bus 29. Bus switches 230a and 230b can be controlled in-

dependent of one another by corresponding control pathways 231a and 231b.

[0060] Programmable logic 250 includes control interface 254, memory interface 256, and user-defined logic 258. Programmable logic 250 may be comprised of one or more devices of the type described in connection with reconfigurable logic circuit 40 or 140, or otherwise configured as would occur to those skilled in the art. Control interface 254 is directly coupled to memory bus 29 by one or more pathways 29b and is also coupled to an isolating bus switch 230c. Bus switch 230c is coupled to memory bus 29 by one or more pathways 29c. Control interface 254 also includes a control pathway 231c to bus switch 230c.

[0061] Control interface 254 is coupled to core loading logic 270 via bus 274 which is in turn coupled to core storage 280 by bus 284. Core loading logic 270 can be configured the same as design loading logic 70 or 170; and core storage 280 can be configured the same as logic design memory 80 or 180. Alternatively, core loading logic 270 and/or core storage 280 can be configured with such other arrangement as would occur to those skilled in the art. Control interface 254 of programmable logic 250 is likewise configured to be compatible with the particular core loading logic 270 and core storage 280 arrangement.

[0062] Memory interface 256 is coupled to interface storage memory 260a and 260b by local memory buses 264a and 264b, respectively. Memory interface 256 is also coupled to control pathways 231a and 231b to direct operation of bus switches 230a and 230b, respectively. Memory interface 256 can be arranged to manage access to interface storage memories 260a and 260b in the manner described in connection with memory devices 160a and 160b of reconfigurable logic circuit 140, such that one can be locally accessed while the other can be remotely accessed. Also, interface storage memories 260a and 260b can each be organized to include a control structure, scratch space, and/or interface buffer structures for one or more core logic designs, as described in connection with memory devices 160a and 160b.

[0063] User-defined logic 258 can be arranged the same as user-defined logic 58. Correspondingly, user-defined logic 258 can be configured with one or more core logic designs under the control of computer 22 according to any of the routines or processes described in connection with FIGs. 3-10, or as would otherwise occur to those skilled in the art.

[0064] Referring generally to FIGs. 12 and 13, operation of system 200 is next described. As previously described, one or more processors 26 can utilize reconfigurable logic circuit 240 to perform auxiliary processing as directed by one or more applications being executed by computer 22. Processor(s) 26 access reconfigurable logic circuit 240 via processor bus 24, memory controller 27, and memory bus 29. Typically, reconfigurable logic circuit 240 is mapped to a designated memory space or

spaces that do not overlap main memory 28. A reconfigurable logic interface program executed by one or more of processors 26 can be configured to transmit information to/from reconfigurable logic circuit 240 and/or direct operation of reconfigurable logic circuit 240 by accessing the designated memory space(s). Control interface 254 of programmable logic 250 determines when such access is occurring by monitoring selected signal(s) of memory bus 29 via pathway(s) 29b. These signals could be, for example, addresses in the designated memory space(s).

[0065] Some of these signals can correspond to commands to reconfigurable logic circuit 240 to perform various operations. Such commands can be configured to facilitate performance of previously described processes, routines, and/or operations, using reconfigurable logic circuit 240 in place of reconfigurable logic circuit 40 or 140. One set of commands can direct the reading and writing core logic designs to and from core storage 80 via loading logic 270, and the management of core logic design execution by user-defined logic 258. One command in this set could cause control interface 254 to direct the loading of a given core logic design into user-defined logic 258 from core storage 80 for instance. Other commands could cause control interface 254 to direct the loading of one or more core logic designs from memory bus 29 through the selective activation of bus switch 230c via control pathway 231c. When not activated, bus switch 230c isolates bus 29 from control interface 254 with the exception of the direct coupling of pathway(s) 29b. Such commands could be used in the execution of the previously described Create (Core Design), Open (ID, PL), Close(IID), and/or Release(ID) routines with reconfigurable logic circuit 240.

[0066] Another set of commands could be directed to the management of interface memory 260. For these commands, control interface 254 interprets input signals and correspondingly directs operation of memory interface 256. In response to various commands of this set, memory interface 256 could control access between memory bus 29 and interface memory 260 through selective activation of bus switches 230a and 230b via the respective control pathways 231a and 231b. Such commands could be used, for example, in the execution of the previously described Read(IID) and Write(IID) routines with reconfigurable logic circuit 240. When not active, bus switches 230a and 230b isolate the respective interface storage memories 260a and 260b from memory bus 29.

[0067] Still other commands of this set could cause memory interface 256 to direct the transmission of data between interface storage memory 260a or 260b and programmable logic 250 over the respective local memory bus 264a or 264b. As described in connection with reconfigurable logic circuit 140, each interface storage memory 260a or 260b can be switched between local access via the respective local memory bus 264a or 264b, and remote access over memory bus 29 via bus

switch 230a or 230b. The capability to alternate between local and remote access facilitates multitasking between several different logic designs with user-defined logic 258. Accordingly, when a logic design is being executed by user-defined logic 258, the corresponding memory interface information in one of interface storage memories 260a or 260b can be locally accessed while the other interface storage memory can be remotely accessed via memory bus 29 and the corresponding bus switch 230a or 230b. The isolation provided by bus switches 230a, 230b, and 230c makes it unnecessary to buffer data through programmable logic 250. Likewise, programmable logic 250 interfaces need not be configured with dedicated data isolation logic. Furthermore, this arrangement facilitates implementation of some or all of interface memory 260 in the form of digital Dynamic Random Access Memory (DRAM) devices.

[0068] Referring generally to FIGS. 1-13, in other embodiments, memory 60, 160 and 260 and/or memory 80, 180 and 280 may be partially or completely provided by main memory 28 of computer 22. In still other embodiments, main memory 28 may not be utilized at all for overflow of reconfigurable logic circuit 40, 140, 240. Alternatively or additionally, reconfigurable logic circuit 40, 140, 240 may include programmable logic arranged to be simultaneously configured with two or more core logic designs and with one or more logic interface programs executed by computer 22 to control and interface with instances of such designs.

[0069] Because computer interface logic 54, 154, and 254, and memory interface logic 56, 156, and 256 are not likely to change frequently, it can completely or partially be stored in one or more flash memory devices and/or other nonvolatile type of memory devices that are separate from devices for storing core logic designs. In one alternative embodiment, some or all of computer interface logic 54, 154, or 254, and/or memory interface logic 56, 156, or 256 can be downloaded from computer 22 upon power-up. In another alternative embodiment, computer interface logic 54, 154, or 254 and/or memory interface logic 56, 156, or 256 is partially or completely provided in an Application Specific Integrated Circuit (ASIC), or other hardwired logic form instead of being configured in programmable logic 50, 150 or 250, respectively.

[0070] It should be understood that in an alternative embodiment, one or more reconfigurable logic circuits according to the present invention can be connected to processor bus 24 as described in connection with FIG. 1 and one or more other reconfigurable logic circuits according to the present invention can be connected to memory bus 29 as described in connection with FIG. 12. In yet other embodiments, one or more reconfigurable logic circuits according to the present invention can be configured as an I/O module either with or without other reconfigurable logic circuits that are connected to processor bus 24 and/or memory bus 29. Furthermore, a reconfigurable logic circuit of the present invention can

be configured as an active bus agent-even emulating a processor in one or more respects-as opposed to a passive memory-mapped agent.

[0071] In other embodiments, one or more features of reconfigurable logic circuit 40, 140, or 240 can be combined, added, or interchanged with one or more features of another of reconfigurable logic circuits 40, 140, or 240 as would occur to those skilled in the art. Reconfigurable logic circuit 40, 140, and/or 240 can be comprised of one or more components mounted on a common printed wiring board with a connector suitable to interface with a computer. Alternative or additionally, one or more components can be in the form of a multichip module. In still other embodiments, some or all components of reconfigurable logic 40, 140, or 240 can be provided on a substrate common to computer 22, or otherwise configured as would occur to those skilled in the art.

[0072] Many other embodiments of the present invention are envisioned. For example, in another embodiment, a system includes a digital processor bus operable to interconnect a process cluster, a reconfigurable logic device, a main memory, and one or more processors coupled together by the processor bus. At least one of the processors is operable to access the reconfigurable logic device. An input/output bridge is coupled to the processor bus and is also coupled to an input/output bus, that has a slower transmission clock speed than the processor bus.

[0073] In yet a further embodiment, an apparatus comprises a reconfigurable logic circuit configured with a computer interface. This circuit includes programmable logic, a first memory to dynamically store a number of logic designs each selected to configure the programmable logic, and a second memory to dynamically store interface control information for each of the logic designs. This information relates to one or more buffers allocated in the second memory for each of the logic designs. These buffers are provided to transmit data through the computer interface.

[0074] In still a further embodiment, a reconfigurable logic circuit includes programmable logic, design loading logic connected to the programmable logic, and one or more memory devices. These memory devices include a first memory space operable to store a number of logic designs for the programmable logic. The first memory space is accessible by the loading logic to selectively load one or more of the logic designs into the programmable logic. The memory devices also include a second memory space operable to store a number of interface control structures each corresponding to a different instance of one of the logic designs. The second memory space is accessible by the programmable logic.

[0075] Another embodiment includes operating a computer coupled to a reconfigurable logic circuit that has programmable logic, a first memory device, and a second memory device. This embodiment also includes storing first interface information in the first memory device for a first logic design and second interface infor-

mation in the second memory for a second logic design. Furthermore, it includes performing an operation with the programmable logic during configuration by the first logic design and accessing the first memory device with the programmable logic and the second memory device with the computer during performance.

[0076] For still another embodiment, a system includes a reconfigurable logic circuit and a computer. The reconfigurable logic circuit comprises programmable logic and a local memory that is operable to store interface information relating to a number of logic designs for the programmable logic. The computer is operatively coupled to the reconfigurable logic circuit and includes one or more processors and a main memory. The computer is operable to execute one or more application programs and a logic interface program. The one or more application programs are operable to generate a number of requests to utilize the reconfigurable logic circuit. The logic interface program is responsive to these requests to control application of the logic designs to the programmable logic. The logic interface program is operable to selectively allocate a memory space in the main memory for overflow of the local memory.

[0077] In yet another embodiment, a method comprises: executing at least one application program and a logic interface program on a computer coupled to a reconfigurable logic circuit that includes programmable logic and a local memory; storing several logic designs in the local memory with the logic interface program that are each operable to configure the programmable logic; operating two or more coexisting program interfaces between one or more of the application programs and the reconfigurable logic circuit with the interface program, where the program interfaces each correspond to a selected one of the logic designs; writing input data to the reconfigurable logic circuit for a selected one of the program interfaces; configuring the programmable logic with the selected one of the logic designs; processing the input data with the programmable logic after this configuration; reading output data from the reconfigurable logic circuit for the selected program interface after this processing; closing the selected program interface after reading with the interface program, where other of the program interfaces remain open; and replacing a first one of the logic designs with a different logic design.

[0078] Another method of the present invention includes operating a computer coupled to programmable logic; concurrently executing two or more application programs with the computer that each generate at least one of a plurality of requests to utilize the programmable logic during execution; processing the requests with an interface program executed by the computer; and controlling the programmable logic with the interface program to reconfigure it a number of times during execution of the application programs in accordance with the requests.

[0079] An additional embodiment of the present invention includes a computer-readable device storing a

number of instructions for execution by a computer coupled to a reconfigurable logic circuit that has programmable logic and a local memory to store a number of logic designs each operable to configure the programmable logic. The instructions are arranged to provide logic interface programs responsive to requests to utilize the reconfigurable logic circuit from a number of application programs being executed by the computer. The logic interface program includes a first routine executable a number of times to open a corresponding number of coexisting program interfaces between the application programs and the reconfigurable logic circuit. The program interfaces each provide for configuration of the programmable logic with a corresponding one of the logic designs stored with the first routine. Also included in this program is a second routine to provide input data to the reconfigurable logic circuit for a selected one of the program interfaces opened by the first routine for processing by the programmable logic. A third routine is also included to request output data from the reconfigurable logic circuit. The logic interface program also has a fourth routine to selectively close a specified one of the program interfaces established with the first routine.

[0080] A further embodiment of the present invention includes an apparatus that comprises a reconfigurable logic circuit configured to communicate through a memory bus of a computer. This circuit includes programmable logic, a first interface memory circuit, a second interface memory circuit and memory interface logic. The first interface memory circuit includes a first memory device and a first bus switch that is controlled by the programmable logic. The first bus switch couples the first interface memory circuit to the memory bus and the first memory device is coupled to the programmable logic to store interface information for a first logic design. The second interface memory circuit includes a second memory device and a second bus switch that is controlled by the programmable logic. The second bus switch couples the second interface memory circuit to the memory bus and the second memory device is coupled to the programmable logic to store interface information for a second logic design. The memory interface logic simultaneously provides local access to the interface information in the first memory device by the programmable logic and remote access to the interface information in the second memory device through the second bus switch during configuration of the programmable logic with the first logic design. Furthermore, the memory interface logic is configured to change access modes to simultaneously provide local access to the interface information in the second memory device with the programmable logic and remote access to the interface information in the first memory device through the first bus switch in response to configuring the programmable logic with the second logic design.

[0081] In a still further embodiment, a system includes a processor bus operable to interconnect a processor

cluster, a memory controller coupled to the processor bus, a memory bus connected to the memory controller, a system memory connected to the memory bus, and a reconfigurable logic device including programmable logic and a first interface memory. The programmable logic is connected to the memory bus by a first bus switch and the first interface memory is connected to the memory bus by a second bus switch controlled by the programmable logic. In addition, one or more processors are included that are coupled to the reconfigurable logic device by the processor bus, memory controller, and memory bus. Furthermore, the system includes an input/output bus coupled to the processor by an input/output bridge and an input/output module coupled to the one or more processors by the input/output bridge and the input/output bus. At least one of the processors transfers data to the reconfigurable logic device with a first latency time and to the input/output module with a second latency time that is greater than the first latency time.

Claims

1. A system comprising:

a reconfigurable logic circuit (40) including programmable logic (50), a first memory (80) and a second memory (60), said first memory being arranged to store a number of logic designs each operable to configure said programmable logic;
a computer (22) coupled to said reconfigurable logic circuit, said computer being operable to concurrently execute one or more application programs (112) and an interface program (122), the one or more application programs generating a number of requests to utilize said reconfigurable logic circuit, the interface program being responsive to the requests to open a number of coexisting program interfaces (54, 56) between the one or more application programs and said reconfigurable logic circuit, the program interfaces each corresponding to one of the logic designs stored in said first memory;

wherein the reconfigurable logic circuit, in response to the interface program, provides a number of interface buffers (68) in the second memory, each interface buffer corresponding to one of the program interfaces; and

wherein each provided interface buffer is operable to store data passing between the computer and the reconfigurable logic circuit.

2. The system of claim 1, wherein said reconfigurable logic circuit includes design loading logic coupled between said programmable logic and said first

memory to control loading of said programmable logic with any of the logic designs in accordance with the interface program.

3. The system of claim 1, wherein said programmable logic device is a field programmable gate array configured to include a first portion with logic to interface with said computer, a second portion with logic to interface with said second memory, and a third portion to be variably configured in accordance with one of the logic designs. 5 10
4. The system of claim 1, wherein the second memory includes a first memory device with a first one of the interface buffers for a first one of the logic designs and a second memory device with a second one of the interface buffers for a second one of the logic designs, and said reconfigurable logic circuit provides for simultaneous access to said first memory device by said programmable logic and said second memory device by said computer during operation of said programmable logic in accordance with the first one of the logic designs. 15 20

Patentansprüche

1. System, das folgendes umfasst:

eine rekonfigurierbare Logikschaltung (40), die eine programmierbare Logik (50), einen ersten Speicher (80) und einen zweiten Speicher (60) aufweist, wobei der genannte erste Speicher so angeordnet ist, dass er eine Mehrzahl von Logikstrukturen speichert, die jeweils so betrieben werden können, dass sie die genannte programmierbare Logik konfigurieren; 30 35

einen Computer (22), der mit der genannten rekonfigurierbaren Logikschaltung gekoppelt ist, wobei der genannte Computer so betrieben werden kann, dass er gleichzeitig eines oder mehrere Anwendungsprogramme (112) und ein Schnittstellenprogramm (122) ausführt, wobei das eine oder die mehreren Anwendungsprogramme eine Reihe von Anforderungen zur Nutzung der genannten rekonfigurierbaren Logikschaltung erzeugt, wobei das Schnittstellenprogramm auf die Anforderungen anspricht, so dass eine Reihe von nebeneinander existierenden Programmschnittstellen (54, 56) zwischen dem einen oder den mehreren Anwendungsprogrammen und der genannten rekonfigurierbaren Logikschaltung geöffnet wird, wobei die Programmschnittstellen jeweils einer der Logikstrukturen entsprechen, die in dem genannten ersten Speicher gespeichert sind; 40 45 50

wobei die rekonfigurierbare Logikschaltung

als Reaktion auf das Schnittstellenprogramm eine Reihe von Schnittstellenpuffern (68) in dem zweiten Speicher bereitstellt, wobei jeder Schnittstellenpuffer einer der Programmschnittstellen entspricht; und

wobei jeder bereitgestellte Schnittstellenpuffer so betrieben werden kann, dass er Daten speichert, die zwischen dem Computer und der rekonfigurierbaren Logikschaltung verläuft.

2. System nach Anspruch 1, wobei die genannte rekonfigurierbare Logikschaltung eine Strukturlade-schaltung aufweist, die zwischen die genannte programmierbare Logik und den genannten ersten Speicher gekoppelt ist, um das Laden der genannten programmierbaren Logik mit einer beliebigen der Logikstrukturen gemäß dem Schnittstellenprogramm steuert.
3. System nach Anspruch 1, wobei es sich bei der genannten programmierbaren Logikvorrichtung um ein Field Programmable Logic Array handelt, das so konfiguriert ist, dass es einen ersten Abschnitt mit einer Logik zum Schnittstellenbetrieb mit dem genannten Computer, einen zweiten Abschnitt mit einer Logik zum Schnittstellenbetrieb mit dem genannten zweiten Speicher und einen dritten Abschnitt aufweist, der gemäß einer der Logikstrukturen variabel konfiguriert werden kann. 25 30
4. System nach Anspruch 1, wobei der zweite Speicher einen ersten Speicherbaustein aufweist, mit einem ersten der Schnittstellenpuffer für eine erste der Logikstrukturen, und einen zweiten Speicherbaustein mit einem zweiten der Schnittstellenpuffer für eine zweite der Logikstrukturen, und wobei die genannte rekonfigurierbare Logikschaltung den gleichzeitigen Zugriff auf den genannten ersten Speicherbaustein durch die genannte programmierbare Logik bereitstellt sowie auf den zweiten Speicherbaustein durch den genannten Computer während dem Betrieb der genannten programmierbaren Logik gemäß der ersten der Logikstrukturen. 35 40 45 50

Revendications

1. Système comprenant :

un circuit logique reconfigurable (40) comprenant une logique programmable (50), une première mémoire (80) et une seconde mémoire (60), ladite première mémoire étant agencée pour stocker plusieurs conceptions logiques chacune pouvant fonctionner pour configurer ladite logique programmable ;
un ordinateur (22) couplé audit circuit logique reconfigurable, ledit ordinateur pouvant fonc-

tionner pour exécuter en même temps un ou plusieurs programmes d'application (112) et un programme d'interface (122), le ou les programmes d'application générant plusieurs requêtes pour utiliser ledit circuit logique reconfigurable, le programme d'interface répondant aux requêtes pour ouvrir plusieurs interfaces de programme coexistantes (54, 56) entre le ou les programmes d'application et ledit circuit logique reconfigurable, les interfaces de programme correspondant chacune à l'une des conceptions logiques stockées dans ladite première mémoire ;

dans lequel le circuit logique reconfigurable, en réponse au programme d'interface, fournit plusieurs tampons d'interface (68) dans la seconde mémoire, chaque tampon d'interface correspondant à l'une des interfaces de programme ; et

dans lequel chaque tampon d'interface fourni peut fonctionner pour stocker des données passant entre l'ordinateur et le circuit logique reconfigurable.

2. Système selon la revendication 1, dans lequel ledit circuit logique reconfigurable comprend une logique de chargement de conception couplée entre ladite logique programmable et ladite première mémoire pour commander le chargement de ladite logique programmable avec l'une quelconque des conceptions logiques selon le programme d'interface.
3. Système selon la revendication 1, dans lequel ledit circuit logique reconfigurable est un prédiffusé programmable par l'utilisateur configuré pour inclure une première partie avec une logique pour assurer l'interface avec ledit ordinateur, une deuxième partie avec une logique pour assurer l'interface avec ladite seconde mémoire, et une troisième) partie devant être configurée de façon variable selon l'une des conceptions logiques.
4. Système selon la revendication 1, dans lequel la seconde mémoire comprend un premier dispositif mémoire avec un premier tampon d'interface pour une première conception logique et un second dispositif mémoire avec un second tampon d'interface pour une second conception logique, et ledit circuit logique reconfigurable permet l'accès simultané audit premier dispositif mémoire par ladite logique programmable et audit second dispositif mémoire par ledit ordinateur pendant le fonctionnement de ladite logique programmable selon la première des conceptions logiques.

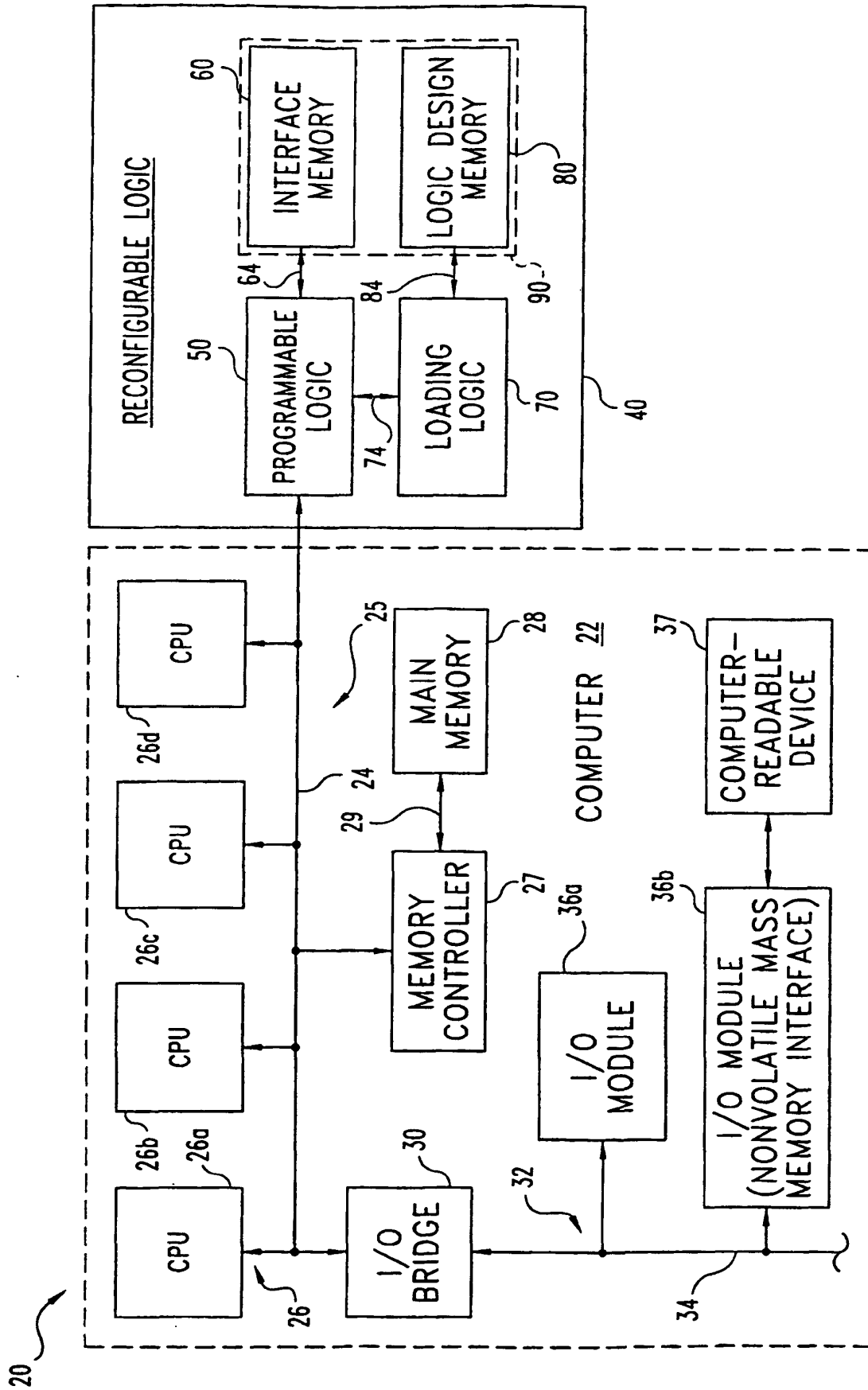


Fig. 1

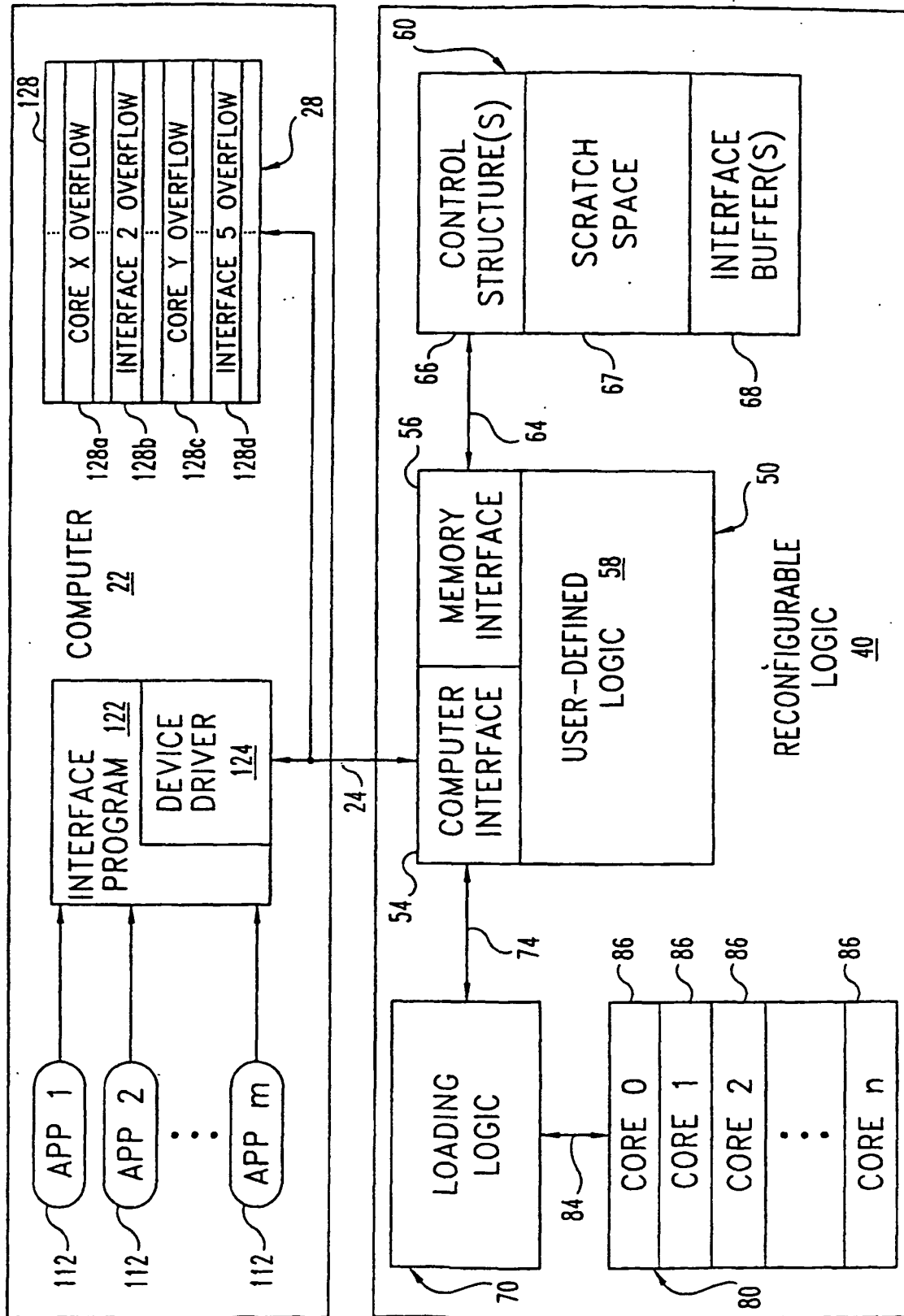
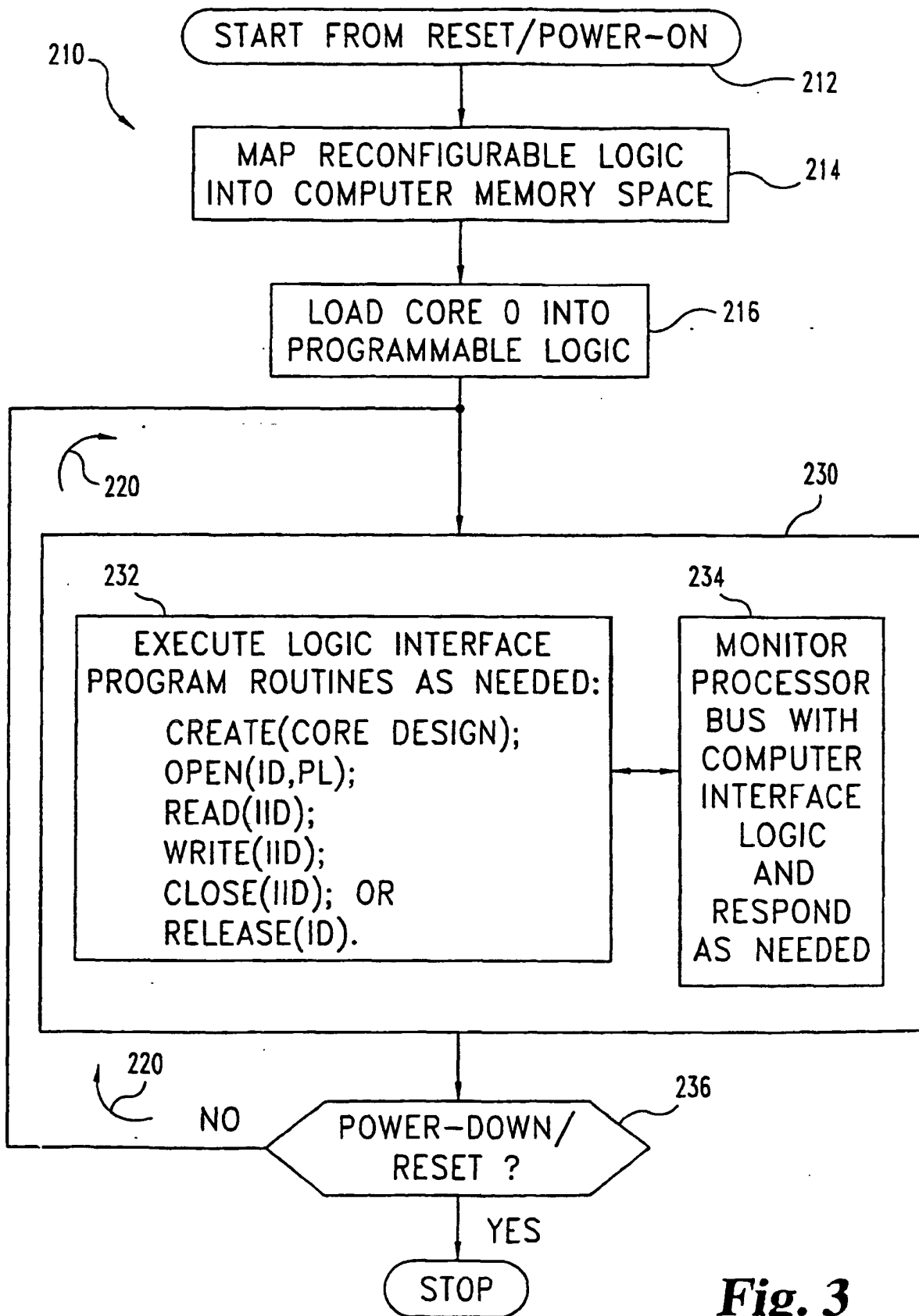
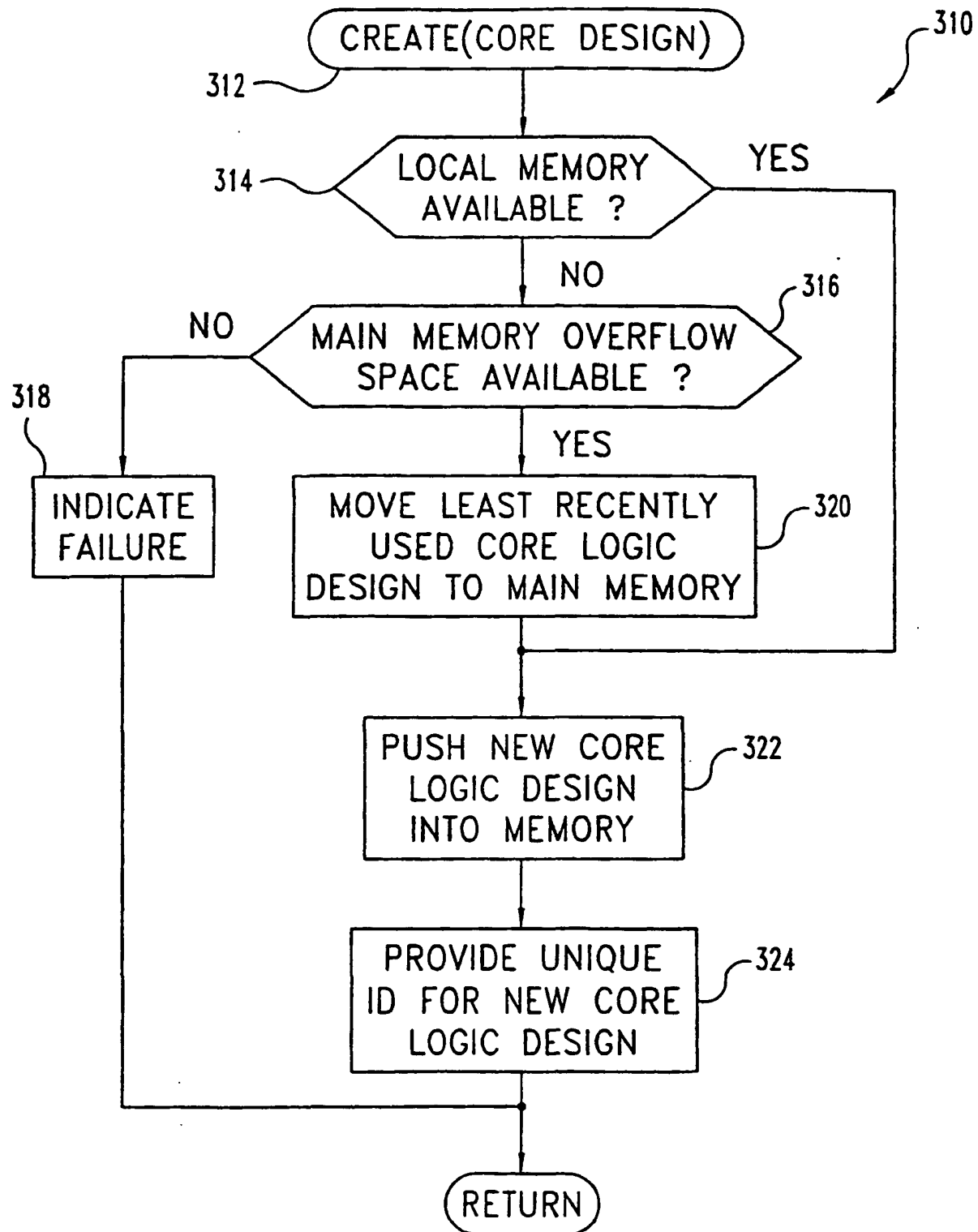
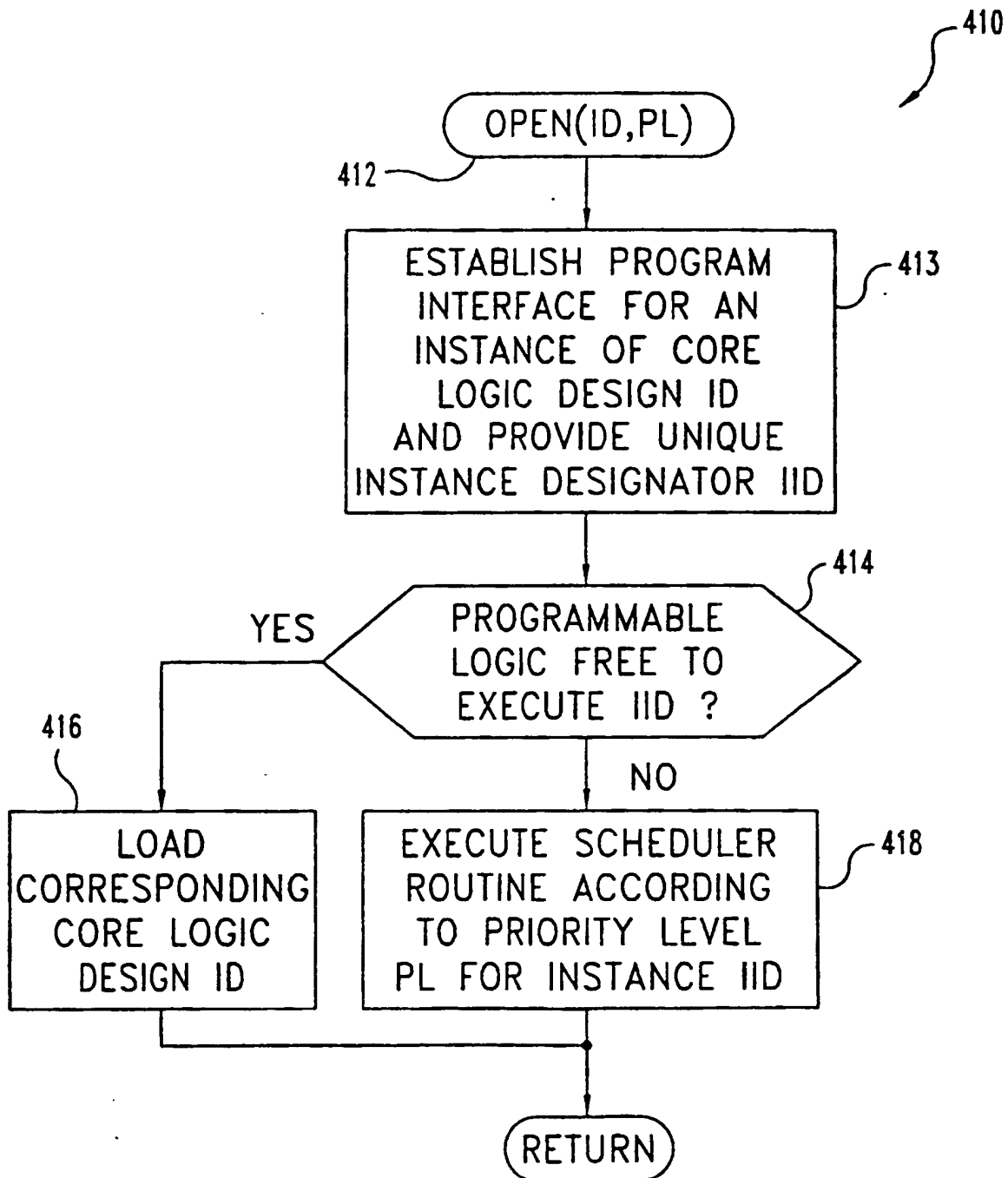


Fig. 2

**Fig. 3**

**Fig. 4**

**Fig. 5**

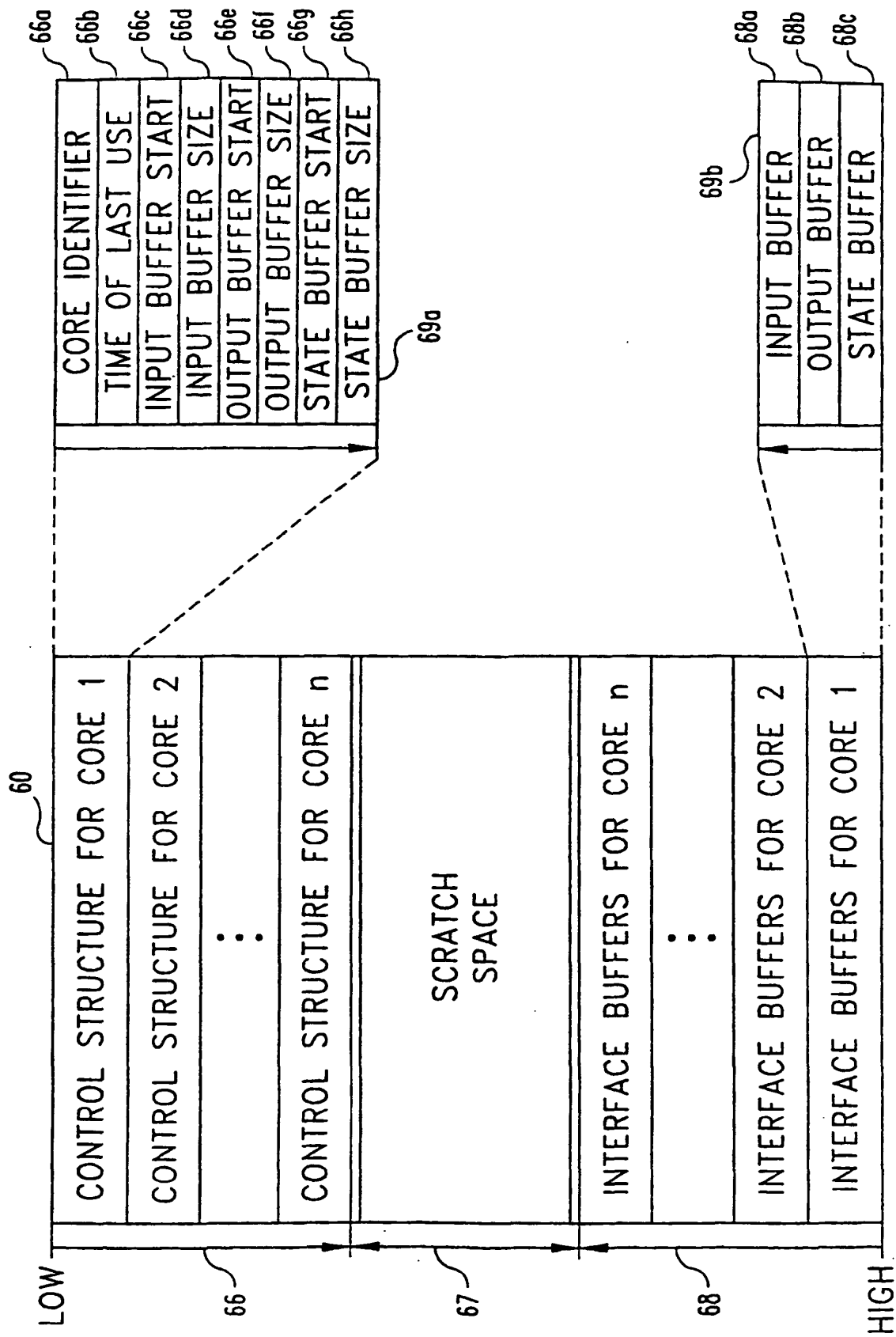
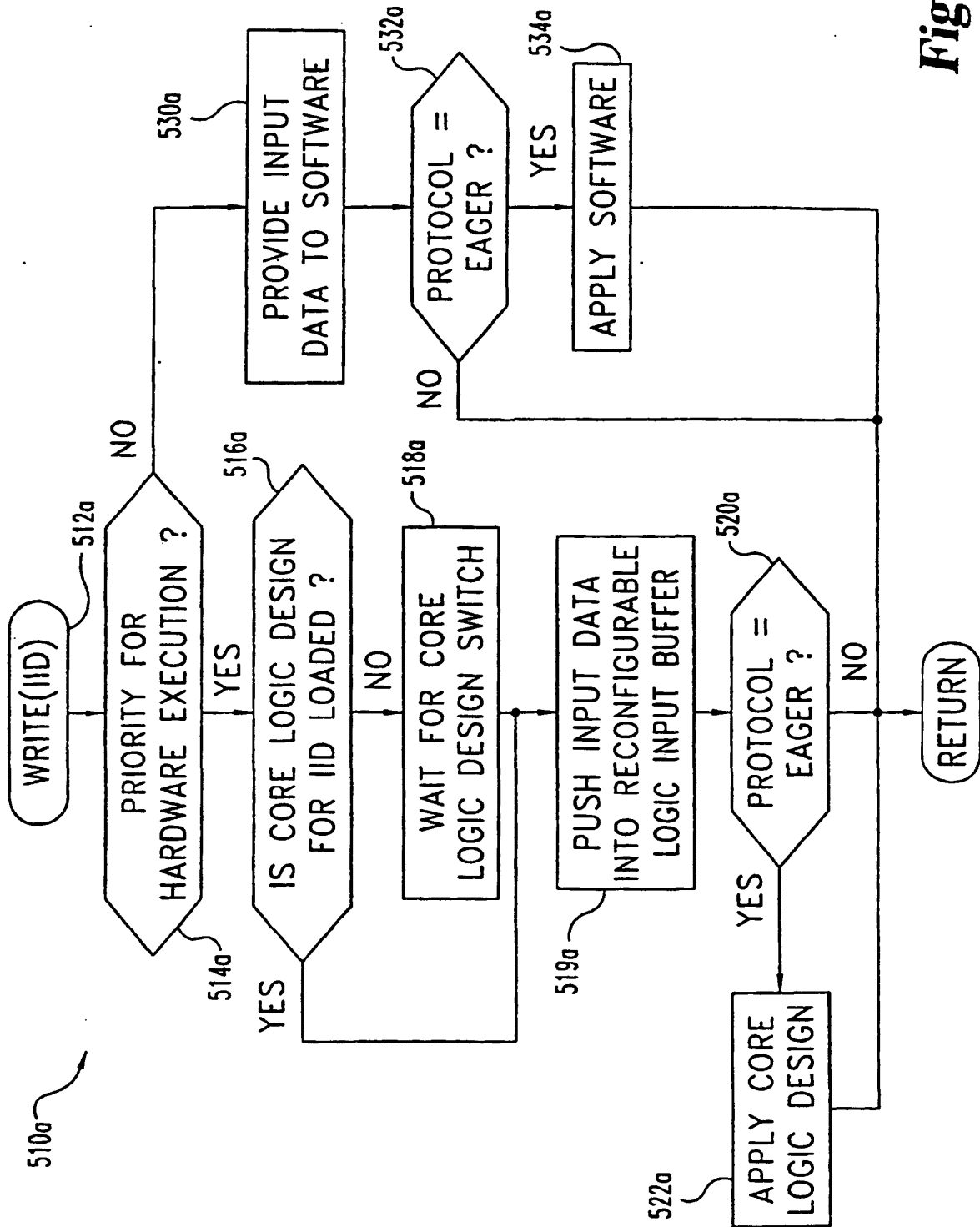


Fig. 6

**Fig. 7**

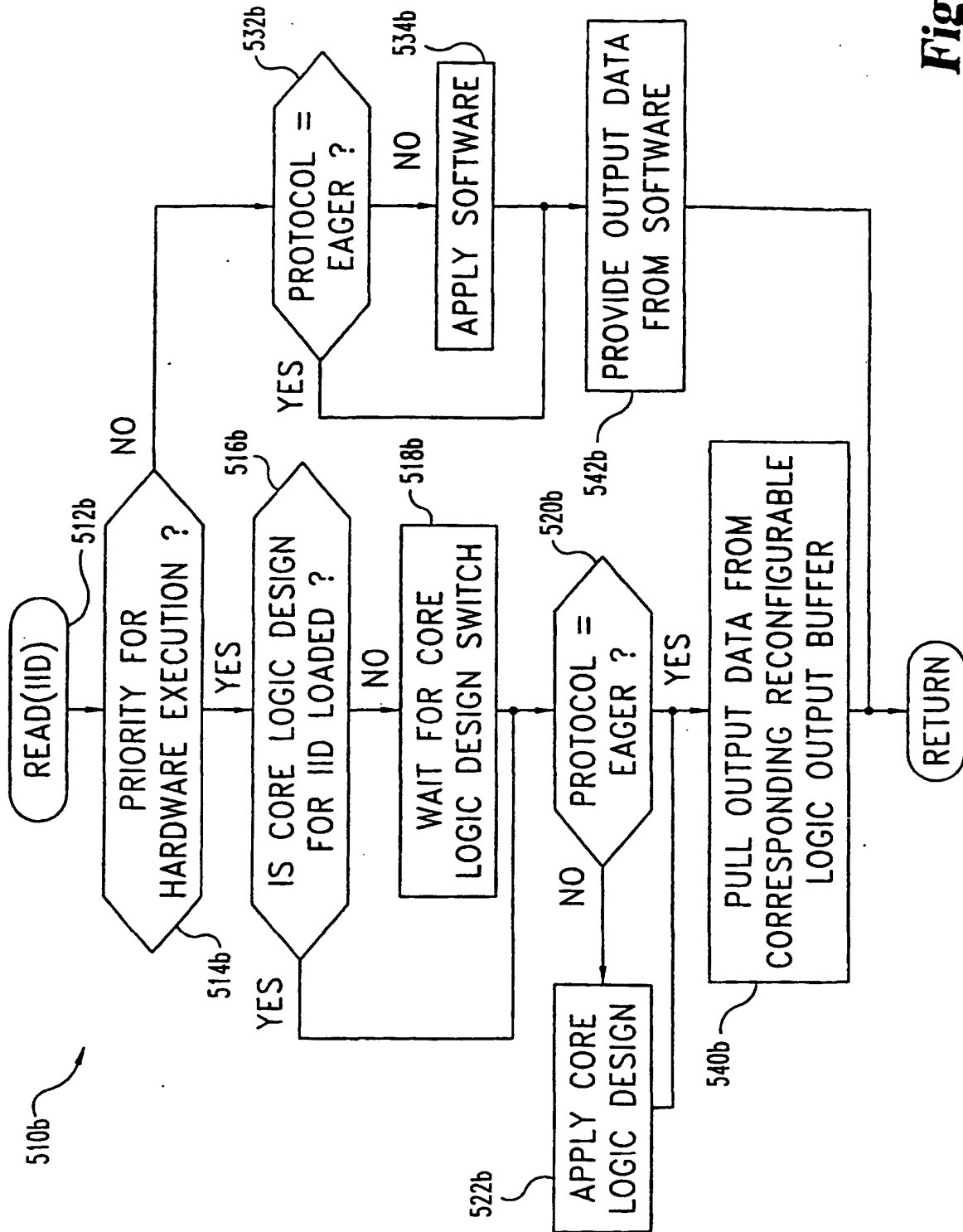
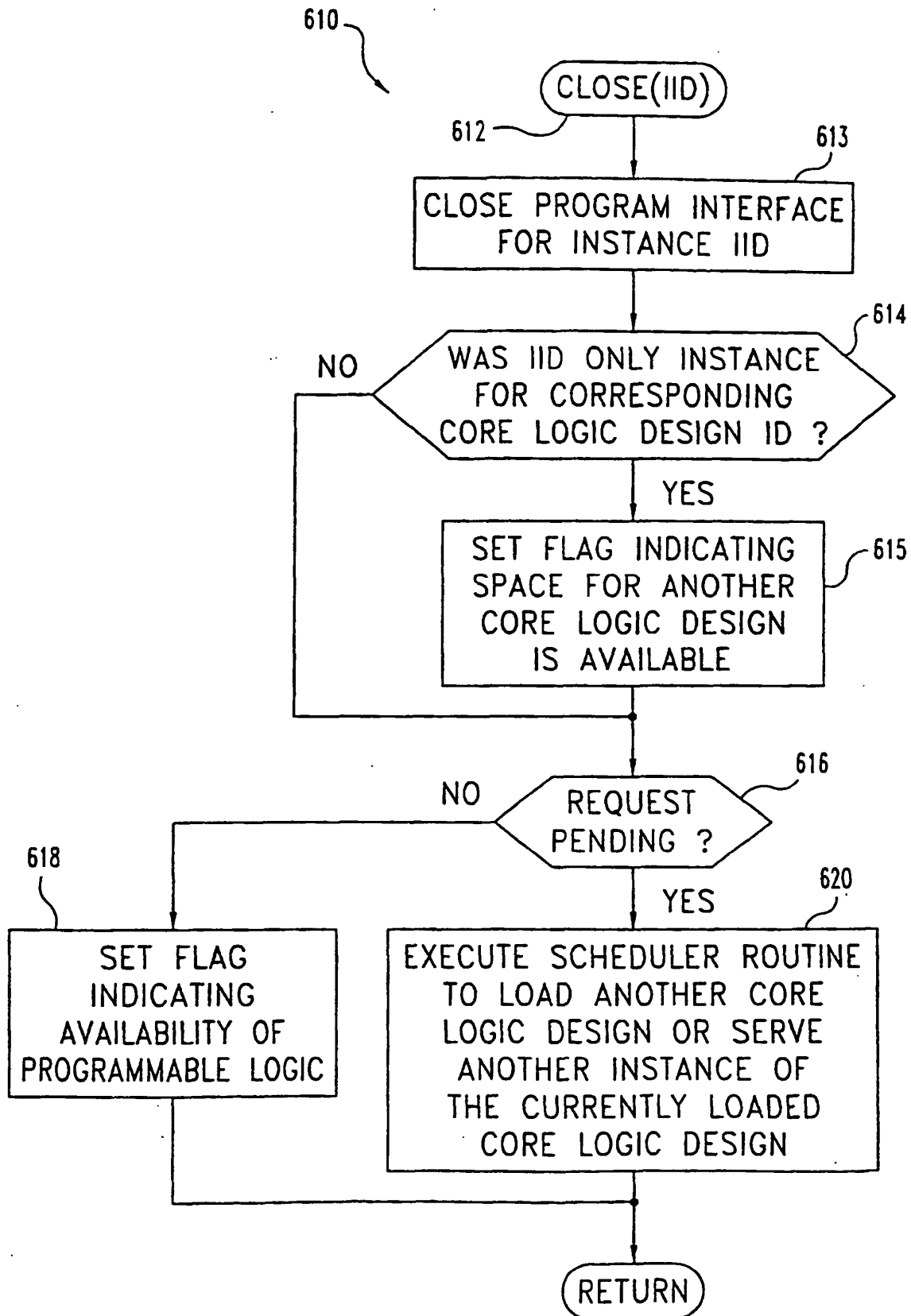
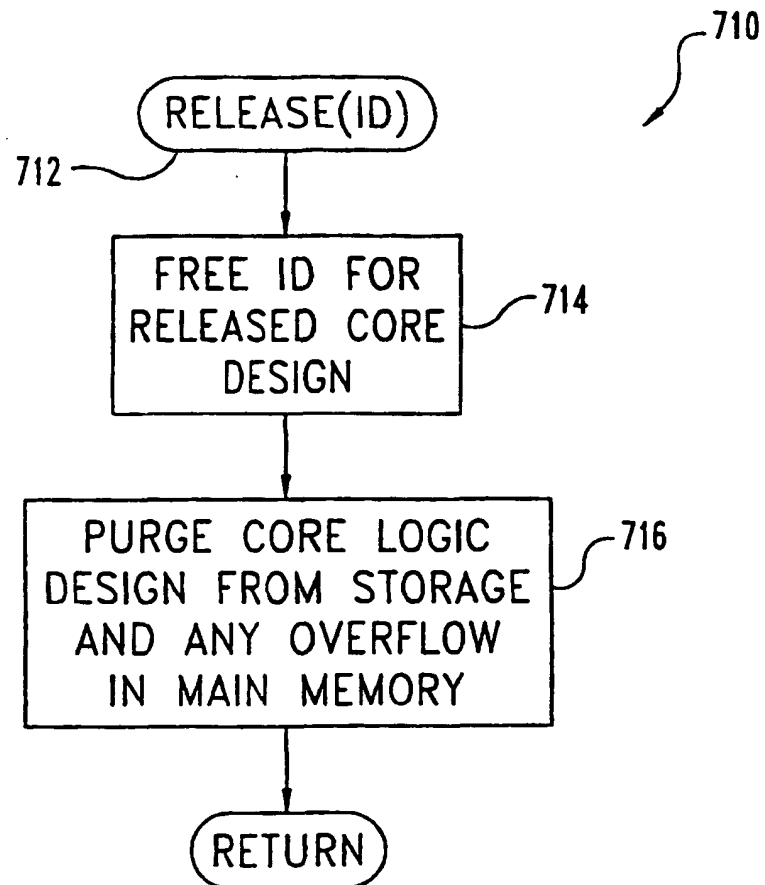


Fig. 8

**Fig. 9**

**Fig. 10**

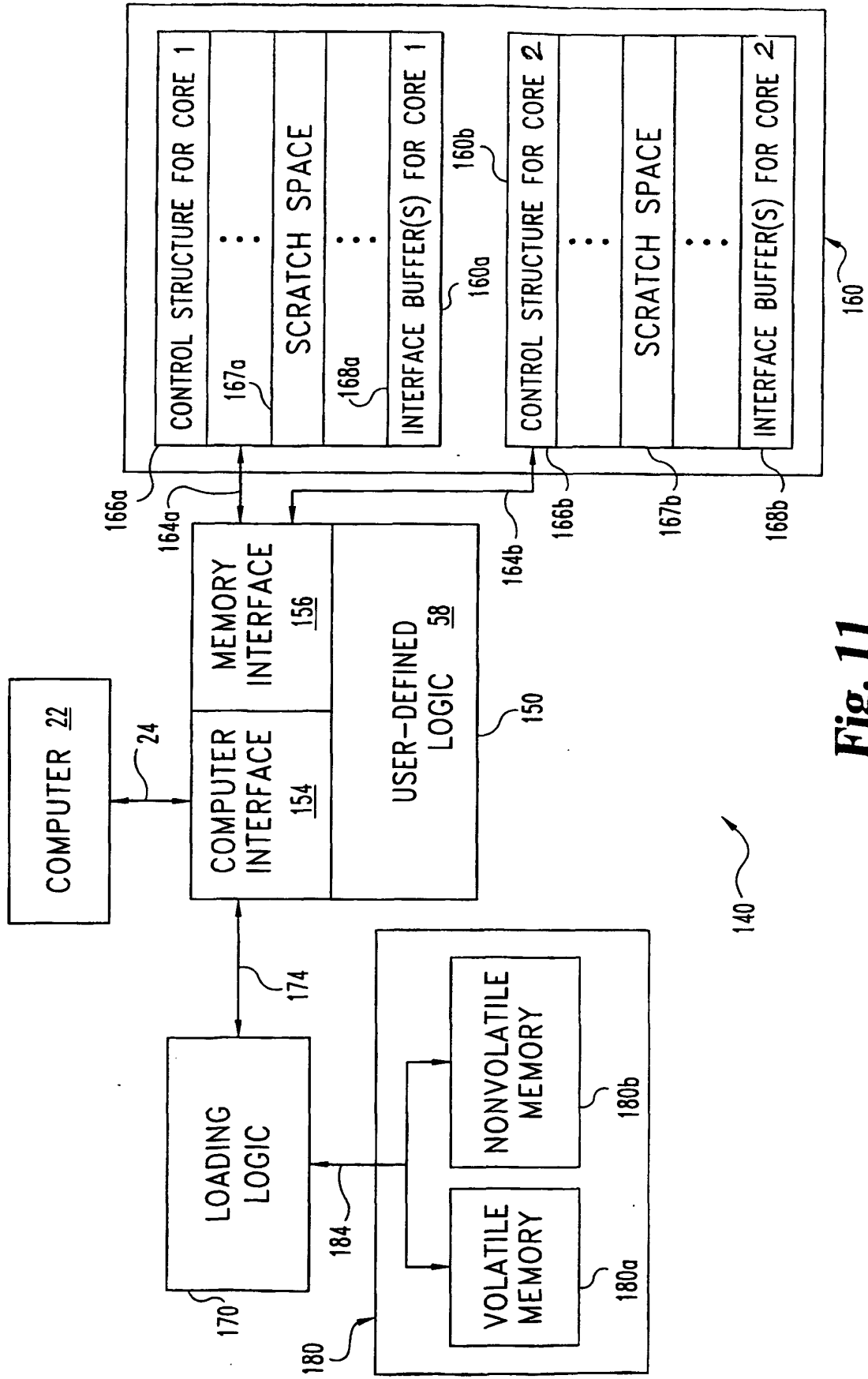
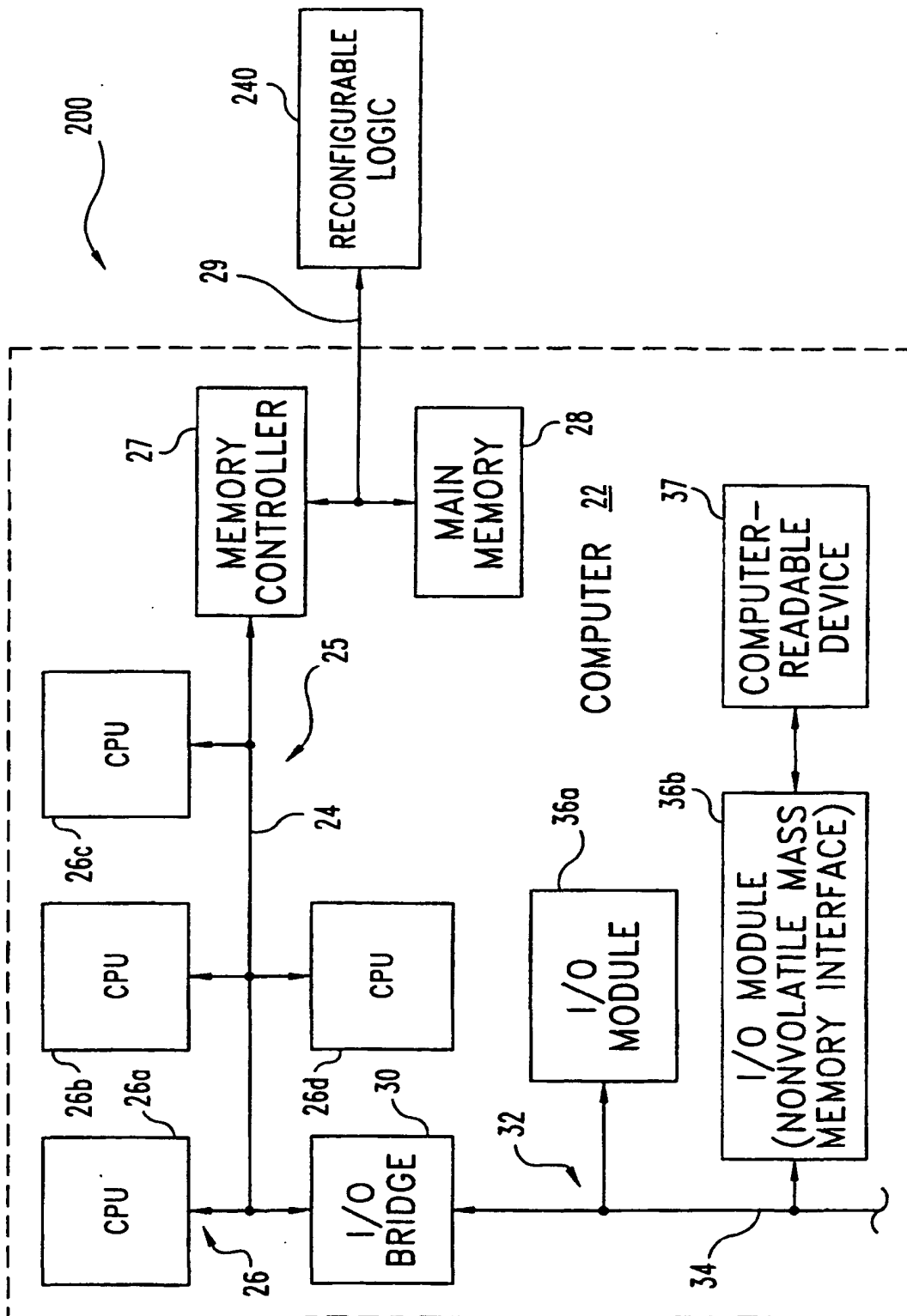


Fig. 11

**Fig. 12**

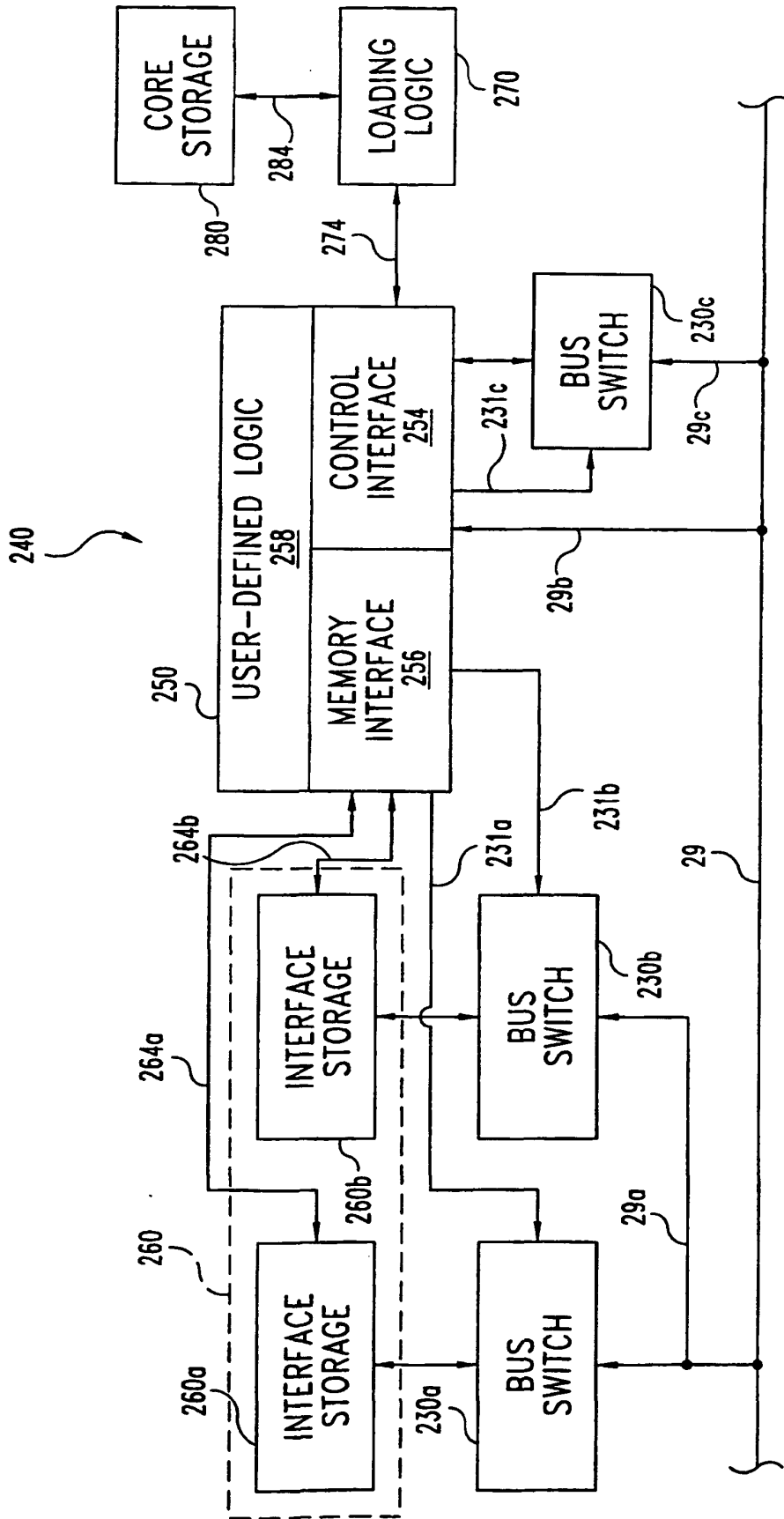


Fig. 13