



APPARATUS AND METHOD FOR INCREASED OPERAND
AVAILABILITY IN A DATA PROCESSING UNIT WITH A
STORE THROUGH CACHE MEMORY UNIT STRATEGY

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

This invention relates generally to data processing systems and, more particularly, to data processing systems that are implemented using pipeline techniques and a store through (write
10 through) cache strategy. Apparatus and method for processing instructions in a period between the time of completion of a write instruction operand address and the time of completion of the write instruction operand.

15 2. Description of the Related Art

The pipeline technique is widely used to increase the performance of data processing units. In this technique the data processing unit is partitioned into various segments, each segment
20 processing a portion of an instruction for a selected period of time. Using this technique, the execution of an individual instruction will typically require a longer time in a pipelined system than execution of an instruction in a non-pipelined data processing
25 unit. However, an instruction can be completed



during each selected period of time in the pipelined data processing system, thereby increasing the rate of instruction execution in a pipelined data processing unit.

5 The increased instruction execution rate is achieved by maintaining an orderly sequence of instruction execution. However, operand processing operations, typically performed in an execution unit of a data processing unit, can take varying amounts
10 of time. The pipelining technique can accommodate this processing time variability by providing a sufficiently long selected period of time to permit any possible operation by the execution to be completed in the selected period of time. This
15 solution adversely impacts the performance of the data processing system. A second solution to execution unit processing time variability is to provide a relatively short execution unit selected period of time and suspend processing of other
20 instruction segments for operations in the execution unit requiring longer periods of time. This approach, relatively easy to implement in a pipelined data processing unit, results in portions of the data processing unit being idle for substantial periods of
25 time. Finally, the problem processing time variability by the execution unit can be addressed by parallel (execution) processing units along with



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control apparatus to reassemble the resulting
operands in correct sequence. This approach requires
substantial additional apparatus in the data
processing unit and a substantial increase in control
5 functionality to prevent compromise of the processing
operations.

The operations involving increased execution
time by the execution unit can impact the performance
of the data processing unit in the following manner.
10 The processing of a write instruction can result in
the associated operand address, even when processed
in a virtual memory environment (i.e., the data
processing unit associates a virtual address with an
operand while the execution cache unit and the main
15 memory unit typically associate a real address with
an operand, the translation of addresses taking place
in a virtual memory management unit) that is
completed at an earlier time than the completion of
the associated operand itself. In the store through
20 (write through) cache strategy of the preferred
environment of the present invention, the real
address is required for storage in the main memory
unit. During the associated delay, processing of
instructions involving the execution unit is
25 suspended pending completion of the operand.

A need has therefore been felt for apparatus and
a related technique to permit a cache unit associated



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with an execution unit of a pipelined data processing unit to continue processing operations in the interval between the availability of an operand address associated with a write instruction and the
5 availability of the operand associated with the write instruction.

FEATURES OF THE INVENTION

It is an object of the present invention to provide an improved data processing system.

10 It is a feature of the present invention to provide an improved data processing system having at least one pipelined data processing unit and a memory unit included therewith.

It is another feature of the present invention
15 to provide an increased instruction execution rate for pipelined data processing units using a store through strategy for the execution unit cache memory units.

It is still another feature of the present
20 invention to provide an execution cache unit that can process instructions between the time when an operand address associated with a write operation is available and the time that the operand associated with the write operation is available.

25 It is a more particular feature of the present invention to process read instructions in an execution cache unit prior to completion of a pending



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write instruction by the execution cache unit when the read instructions do not impact the write instruction.

SUMMARY OF THE INVENTION

5 The aforementioned and other features are accomplished, according to the present invention, by including in the E-cache unit apparatus for storing a write instruction operand address while the execution unit is preparing the write instruction operand.

10 When storing the write instruction operand address, a "hit" signal is stored therewith when the location addressed by the write instruction address in the tag directory unit has "valid" operand stored therewith. Apparatus is included in the E-cache unit to

15 determine when an address newly applied to the E-cache unit conflicts with the stored write instruction operand address. When an address newly applied to the E-cache unit is associated with a read instruction, does not conflict with the stored write

20 instruction operand address, and results in a "hit" signal when applied to the E-cache tag directory unit, the associated read instruction is processed by the E-cache unit. When these conditions are not true, the address is stored in an E-cache unit input

25 register until the write instruction operand has been forwarded, along with the stored write instruction

operand address, to the memory unit and stored in the E-cache storage unit when the "hit" signal is stored with the write instruction operand address.

These and other features of the invention will
5 be understood upon reading of the following description along with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the overall system which includes the apparatus of the present
10 invention.

Figure 2 is a more detailed block diagram of the overall system of Figure 1.

Figure 3 is a logic block diagram of major elements of the production pipeline cycles.

15 Figure 4 is a block diagram of a cache memory unit and related data processing system components used in the present invention.

Figure 5 is flow diagram illustrating the processing of address signals by the execution cache
20 unit according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

1. Detailed Description of the Figures

The present invention is adapted to function in a data processing system in which certain types of
25 instructions are executed by an earlier unit and dropped out of the production line while other types of instructions are executed at the end of the



production line. The address unit of the data processing unit includes means for executing the instruction if it is a "non-memory" instruction. The "non-memory" instruction, by having been executed in
5 the address unit, is effectively dropped or removed from the production line and therefore requires no further cycles in the production line thereby improving the system throughput.

Figure 1 shows a block diagram of a cycle
10 production pipeline data processing system 1. Included are a central processing unit (CPU) 2, a virtual memory management unit (VMMU) 4, a cache unit 6, a memory subsystem 8, and input/output peripheral unit 10. The cache unit 6, memory unit 8, and
15 input/output peripheral unit 10 are all coupled in common to a system bus 12. The memory 8 stores instructions and operands. Those operands and instructions, having the highest probability of being executed immediately, are transferred to cache unit 6
20 from the memory subsystem 8.

The CPU 2 receives instructions from the cache unit 6 and in the execution of these instructions sends the virtual address portion of the instruction to VMMU 4. The VMMU 4 translates the virtual address
25 into a physical address which is applied to cache unit 6 for fetching the necessary operands to allow the CPU 2 to execute the instructions.



The input/output unit 10 represents typically any number of peripheral controllers with their devices, or an input/output processor which controls peripheral controllers and devices, or it may
5 represent typically a communications subsystem.

Figure 2 shows in block diagram form the major elements that make up the CPU 2 and the cache unit 6. The CPU 2 includes an instruction (I) unit 2-2, an A unit 2-4, and a number of execution (E) units 2-6.
10 The execution units 2-6 could be a scientific instruction processor or a commercial instruction processor. However, for simplicity of description, only the operation of one of the execution units 2-6 is described which is sufficient to understand the
15 invention.

The cache unit 6 includes an I-cache 6-2 and an E-cache 6-4. The I-cache 6-2 stores the instructions that are to be executed and the E-cache 6-4 stores the operands upon which the instructions operate.
20 The I-unit 2-2 performs essentially two functions. It prefetches instructions from I-cache 6-2 and then cracks those instructions to determine how the other units, namely the A unit 2-4 and the E unit 2-6, will further process the instruction.

25 The A unit 2-4 receives the instruction from the I-unit 2-2 and executes the instruction if it is a register-to-register instruction or a branch



instruction. When the instruction is to be executed by the E unit 2-6, the A unit 2-4 sends a virtual address to the VMMU 4 which translates it into a physical address for the E-cache unit 6-4. E-cache
5 6-4 sends the operands to the E unit 2-6 for the completion of the execution of the instruction originally received by the instruction unit 2-2 from the I-cache unit 6-2.

The A unit 2-4 will also complete the execution
10 of branch instruction and send the branch address back to the instruction unit 2-2 so that it may request the next instruction at the location in I-cache 6-2 specified by the branch address. Both the A unit 2-4 and the E unit 2-6 include register
15 files which store the contents of the registers which are accessible to the programmers, that is, so called software visible registers. Both the I-cache 6-2 and the E-cache 6-4 are coupled to system bus 12 and their contents are updated with instructions and
20 operands received from memory 8.

Instructions are executed in a production pipeline fashion by the elements of CPU 2. That is, the I unit 2-2 receives an instruction from I-cache 6-2, cracks it, and then sends the instruction to the
25 A unit 2-4. The A unit 2-4 either executes the instruction or sends the virtual address to the VMMU 4 for translation in order to address the E-cache





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6-4. E-cache 6-4 sends the designated operands to the E unit 2-6.

While the A unit 2-4 is executing its portion of the first instruction from the I unit 2-2, the I unit
5 2-2 is fetching the second instruction and subsequent instructions from I-cache 6-2. When the A unit 2-4 sends the virtual address specified by the first instruction to the VMMU 4 and notifies the I unit 2-2 of that event, the I unit 2-2 sends the second
10 instruction to the A unit 2-4. The VMMU 4 addresses the E-cache 6-4 while the A unit 2-4 is processing the second instruction in the pipeline. When the E unit 2-6 is executing the first instruction, the VMMU 4 may be addressing E-cache to fetch the operands of
15 the second instruction while the A unit 2-4 is generating a virtual address of the third instruction. Meanwhile, the I unit 2-2 is cracking the fourth instruction and fetching one of the subsequent instructions. Therefore, in this typical
20 example, there could be five instructions progressing down the production line.

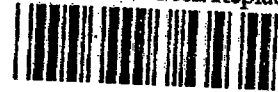
However, since the A unit 2-4 can execute certain software visible register instructions, they are removed from the production line as soon as the
25 execution of those instructions is completed by the A unit. Similarly, when the A unit 2-4 is processing a branch instruction and the conditions of the branch

are met, the A unit 2-4 immediately sends the branch address to the I unit 2-2 and that branch instruction will be removed from the production line. This mode and method of operation results in increased
5 throughput as compared to the prior art.

Figure 3 shows in greater detail the elements of the instruction unit 2-2, the A unit 2-4, the execution unit 2-6 and their respective interconnections. The P-counter 2-200 of the
10 instruction unit 2-2 is loaded by the A unit 2-4 with a virtual address. This virtual address is the address in I-cache 6-2 of the location of the next instruction that is to be placed into the pipeline. During the I-FETCH cycle, the virtual address is
15 transferred to I-cache 6-2 via an adder 2-202 and either a register VA0 2-204 or a register VA1 2-206. Either register VA0 2-204 or register VA1 2-206 is used until a branch instruction is fetched. Then, if register VA0 2-204 is active, the address called for
20 by the branch instruction would be stored in register VA1 2-206.

The reason the branch address is held separately in the VA0 2-204 and VA1 2-206 registers is because if it is a conditional branch, the condition may or
25 may not be met. If the condition is not met, then no branch will result. This gives the system the choice of either using or not using the address called for





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by the branch. The P counter 2-200, under firmware control, is incremented by one for one word instruction, incremented by two for a double word instruction, or replaced by a branch address.

5 The instruction is read out of I-cache 6-2 into either string buffers A 2-220 or string buffers B 2-221. Here again, one set of string buffers receives successive instructions from I-cache 6-2 until there is a branch instruction. Then the
10 instruction following the branch instruction is stored in buffers in the other string. For example, if the string buffers A 2-220 were being used then the instruction following the branch instructions would be stored in the string buffers B 2-221. The
15 throughput is improved by storing both sets of instructions in case the branch conditions are met and the I unit 2-4 fetches the branch string from string buffers B 2-221.

20 The instruction is read out of I-cache 6-2 into either string buffers A 2-220 or string buffers B 2-221. Here again, one set of string buffers receives successive instructions from I-cache 6-2 until there is a branch instruction. Then the
25 instruction following the branch instruction is stored in buffers in the other string. For example, if the string buffers A 2-220 were being used then the instruction following the branch instructions

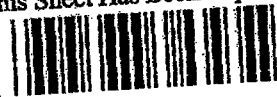


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would be stored in the string buffers B 2-221. The throughput is improved by storing both sets of instructions in case the branch conditions are met and the I unit 2-4 fetches the branch string from string buffers B 2-221.

The instruction is then sent to the instruction crack and resource control 2-210 which determines the kind of instruction it is. That is, if this is a software visible register to register instruction, then it will be executed by the A unit 2-4 if it is a memory instruction that will be executed by the E unit 2-6.

The instruction is sent from the crack logic 2-210 to an A-unit firmware address generator 2-208 which addresses an A-unit control store 2-430. The contents of the addressed location is stored in an RDR (A) register 2-406 in the A unit 2-4. The instruction signals I INSTR 0-31 from the string buffers 2-220 or 2-221 are transferred to the instruction (RINSTR) register 2-400 in the A-unit 2-4. If the instruction is to be executed by the E unit 2-6 it is also stored in an instruction first in a first out register (FIFO) 2-600 in the E unit 2-6. The instruction is also stored in an OP-CODE register 2-402 in the A unit 2-4 under control of a signal I-BEGIN from the I unit 2-4. Both the RINSTR register 2-400 and the OP CODE register 2-402 store



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double words of 32 bits each. If an instruction requires 2 or 3 double words, then the OP CODE for that instruction remains in the OP CODE register 2-402 while each of the double words of the instruction in turn are stored in the instruction register 2-400.

The output of the OP CODE register 2-402 is used primarily for addressing a register file 2-404 under control of OP CODE and firmware bits stored in the OP CODE register 2-402 and the register RDR (A) 2-406 respectively. The register file 2-404 includes the software visible registers. If the instruction being executed is a memory instruction, then a virtual address is generated and sent to the VMMU 4 via an arithmetic logic unit (ALU) 2-412. Depending upon the instruction being executed by the A unit 2-6, the input to the ALU 2-412 may be applied to the A side, by the RINSTR register 2-400, the OP CODE register 2-402, the register file 2-404 or a program counter 2-416. ALU 2-412 B side inputs are provided by an index shifter 2-410 for index or offset operations, via an adder 2-408 or from register file 2-404. If this is a register instruction, for example, a shift operation of the contents of a software visible register in the register file 2-404, then the output of the register file 2-404 may be applied to the shifter 2-414, be shifted the number of bits

specified by the instruction and stored back in the register file 2-404 in the same register from which it was read.

For the conditional branch instruction, signals
5 from RINSTR 2-400 and from the ALU 2-412 are applied to branch logic 2-401. The output, load signal A-P-LD, enables the P counter 2-200 to accept the branch address signals A-BRANCH which are sent to I-CACHE 6-2.

10 When the A unit 2-4 has completed the execution of the instruction, an A-DONE signal is sent to the crack logic 2-210 of the I unit 2-2. This informs the I unit 2-2 to send the next instruction stored in the string buffers 2-220 or 2-221 to the A unit 2-4
15 and if required, to the E unit 2-6. If an instruction calls for execution by the E unit 2-6, then the I unit 2-2 sends that instruction to the instruction FIFO 2-600 under control of signal I-ELAST and signal I-EFIRST. These signals control
20 the loading of the instruction FIFO 2-600.

The I-BEGIN signal is received by the A unit 2-4 when the CRACK signal is generated, the system is not in a hold mode and no logic block including the clock logic is in a stall mode.

25 The CRACK signal is generated when the ready logic and flops 2-222 is ready to crack the instruction, the string buffers A 2-220 or string





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buffers B 2-221 store at least one instruction, and the A unit 2-4 had generated the ADONE signal indicating that the A unit is available for processing the next instruction.

5 The I unit 2-2 generates the I-EFIRST and the I-ELAST signals by the ready logic and flops 2-222 if the instruction being cracked is to be executed by the E unit 2-6. Both signals are applied to the I FIFO 2-600. The I-EFIRST signal enables the I-FIFO
10 2-600 to store a double word instruction. The I-ELAST signal enables the I-FIFO 2-600 to store a single word instruction.

Note that the I unit 2-2 sends the instruction to be executed in the A unit 2-4, and only to FIFO
15 2-600 if the instruction is to be executed in the E unit 2-6. In the E unit 2-6, the next instruction the FIFO 2-600 will execute is applied to the next address generator 2-602 which generates the E unit control store 2-604 address location. The firmware
20 word is stored in a register RDR (E) 2-606. The instruction FIFO 2-600 stores up to four instructions.

When the A unit 2-4 sends its virtual address to the VMMU 4, the VMMU 4 generates the physical address
25 which addresses the E-cache 6-4. The contents of the addressed location is stored in a data FIFO 2-630 in the E unit 2-6 by signal LD-DAT-0015 for a single

word transfer or signal LD-DAT 1631 for a double word transfer. Signal LD-DAT-0015 also increments by one the FIFO 2-630 write address to accept the second word of the transfer if the first word was not at an
5 E-CACHE 6-4 word boundary. This data is the operands on which the instruction will operate. The E-unit 2-6 executes instructions whose operands are stored in software visible registers of register file 2-630. A typical instruction is the multiply instruction.

10 For this instruction, the A unit 2-4 generates a dummy cycle by sending the virtual address hexadecimal 40 to the VMMU 4. This results in the E-CACHE 6-4 generating a dummy cycle by sending signal LD-DAT 1631 to the FIFO 2-630 with a "dummy"
15 operand.

If in the I unit 2-2, the instruction calls for a branch and has a displacement, then the displacement from the crack unit 2-210 is applied to the adder 2-202 to be added to the contents of the P
20 counter 2-200 and stored in either register VA0 2-204 or register VA1 2-206 and applied to the I-cache 6-2.

A multiplier 2-616 is coupled to the A & B ports of register file 2-610 to generate and store partial products in conjunction with the shifter 2-618 and
25 the Q-register 2-620. The partial products are applied to a result multiplexer (MUX) 2-622 and stored in accumulator location in register file





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2-610. When the multiplication is completed the final result is stored in one of the software visible registers of register file 2-610.

A swapper logic 2-612 receives operands from the
5 B side of register file 2-610 for swapping words within double words and swapping bytes within single words. A 16-bit word is made up of two 8-bit bytes. A double word is made up of two 16-bit single words or four 8-bit bytes. A sign extender 2-614 repeats
10 the sign of all the high order positions of a double word to the left of the first significant bit of the double word.

The CT1 and CT2 counters 2-624 are used in the calculation of the exponent of a floating point
15 resultant. A mantissa of a floating point operand is processed through the ALU 2-608 and a shifter 2-618 in a conventional manner.

The software visible registers in both the register files 2-404 with A unit 2-4 and 2-610 in the
20 E unit 2-6 are updated on successive cycles so that they both contain the same information. This is accomplished by firmware signals from register RDR (A) 2-406 which are applied to logic 2-420 to generate an update signal A-UPDT which enables the
25 register file 2-610 and six A-ADR signals which are applied to the address terminals of register file 2-610 to store the data from the D terminal of the



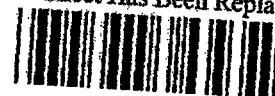
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register file 2-404 to the D terminal of register file 2-610. Similarly, the E-UPDT signal from register RDR (E) 2-606 enable register file 2-404 to store the data at the address specified by signals

5 E-ADR from logic 2-601. Logic 2-601 signals E-ADR from instruction signals from the instruction FIFO 2-600 and firmware signals from RDR (E) 2-606.

The A unit 2-4 program counter 2-416 stores the address of the next instruction. P counter 2-200 in
10 the I unit 2-2 also stores the address of the next instruction. The reason for the two registers is that, in case of a conditional branch, P counter 2-200 in the I unit 2-2 stores the branch address in case it is to be used, whereas the program counter
15 2-416 will not store the branch address but stores the next address in the sequence presently being executed.

Referring next to Fig. 4, the components of the E-cache unit 6-4, necessary for understanding the
20 present invention, are illustrated. An address associated with an instruction is transferred from the address unit 2-4 to the VMMU unit 4 wherein the virtual address (from the address unit 2-4) is translated into a real address. The real address is
25 entered into the real address register 6-401. In the prior art, the address of the real address register is applied to the tag directory unit 6-403 and when



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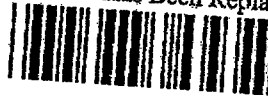
the tag directory unit 6-403 stores the applied address along with a "valid" signal (indicating that the associated operand is not compromised), then a "hit" signal is generated and, for a read instruction, the operand in the storage unit 6-404 at a location associated with the address in the real address register 6-401 is transferred to the execution unit 2-6 via data out register 6-411. When the address in the real address register 6-401 is not stored in the tag directory unit 6-403 or the address is stored but a "valid" signal is not present therewith, then a "miss" signal is generated. For a read instruction, the address in the real address register is entered in the miss register 6-402, applied to the bus interface unit 7 and applied, along with control signals, to the system bus 12. The required operand is retrieved from the memory unit 8 and transferred via system bus 12, bus interface unit 7 and bus data in register 6-408 to the storage unit 6-404 where the operand is stored at a location determined by the address in the real address register 6-401. The "valid" signal is stored in an associated location in the tag directory unit 6-403. When the "miss" signal is present (i.e., the "hit" signal is not present) and a write instruction is associated with the address in the real address register 6-401, then an operand from the execution



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unit is applied to the system bus through the data in register 6-409, the bus data out register 6-410 and the interface unit. This write instruction operand is applied to the system bus along with the write
5 operand address from the real address register 6-401 and the write operand is stored in the memory unit 8 at a location determined by the write operand address. When the "hit" signal is present for a write instruction, the operand is also stored in the
10 storage unit 6-404 at a location determined by the address in the real address register 6-401. The automatic storage of a write operand in the memory unit 8 is referred to as write-through or store through cache strategy.

15 In the present invention, a write address register 6-421 is provided so that additional cache activity can be accomplished while the write instruction operand, associated with a write operand address in the write address register 6-421 can be
20 determined. In addition, when the address in the real address register 6-401 is being transferred to the write address register 6-421, the write operand address is applied to the tag directory unit 6-403. When the application of the write operand address in
25 the real address register 6-401 to the tag directory unit 6-403 produces a "hit" signal, a "hit" signal is stored in a location 6-421A associated with the write



operand address.

The E-cache unit 6-4 of the present invention includes a block store ram 6-420. When the address in the real address register 6-401 is transferred to
5 write address register 6-421, the address is stored in the block store ram 6-420. The block store ram 6-420 has the property that, when the same address is applied to the block store ram as is stored in the block store ram, a "busy" signal is generated. The
10 "hit" signal and the "busy" signal are used as control signals in the present invention to control processing activity in the E-cache unit 6-4.

Referring next to Fig. 5, the operation of the present invention is illustrated by means of a flow
15 diagram. In step 501, a next sequential address from the first-in, first-out (fifo) register of VMMU 4 is entered into the real address register 6-401 of the execution cache unit 6-4. In step 502, a determination is made whether the address entered in
20 the real address register 6-401 is associated with a read instruction or a write instruction. When the address is associated with a read instruction, the read instruction procedure is executed by the execution cache unit in step 503 and a next address
25 from the VMMU 4 is entered in the real address register 6-401 in step 501. When the address in real address register 6-401 is associated with a write



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address in step 502, then the contents of the real address register 6-401 are applied to the tag directory unit 6-403 and a determination is made whether the tag directory unit 6-403 has the applied address stored therein along with a "valid" status signal in step 504. When the tag directory unit 6-403 does not store the applied address along with a "valid" status signal, then the contents of the real address register are stored in the write address register without a "valid" signal stored in the location 6-421A. When, in step 504, the applied address and a "valid" status signal are present, then the address in the real address register 6-401 is stored in the write address register 6-421 and a "valid" signal is stored in the write address register location 6-421A in step 507. In step 508, the address from the real address register 6-401 are entered in the block store ram 6-420. In step 509, a determination is made whether the write operand is available, i.e., is the E-MWRITE signal from the execution unit present. When the E-MWRITE signal is present, then, in step 510, the address from the write address register 6-421 and the associated operand from the execution unit 2-6 are applied to the bus interface unit. In step 511, when the "valid" signal is present in the write address register 6-421, the contents of the write address



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register 6-421 are applied to the storage unit 6-404 and the associated operand from the execution unit 2-6 is stored at the addressed location in the storage unit 6-404. In step 512, the "busy" signal
5 (and associated address) are removed from the block store ram 6-420 and the next address from the VMMU 4 is stored in the real address register. When, in step 509, the associated operand is not ready from the execution unit 2-6, then the next address is entered
10 from the VMMU 4 in the real address register 6-401 in step 513. In step 514, a determination is made as to whether the address in the real address register is a read instruction or a write instruction. When the address in the real address register is associated
15 with a write instruction, then the address is held in the real address register 6-401 until the "busy" signal is removed from the block store ram in step 516. When the "busy" signal is removed from the block store ram 6-420, then the contents of real
20 address register 6-401 are applied to the tag directory unit 6-403 to determine if the identical address is stored along with a "valid" signal in step 504. When, in step 514, the address in the read address register is associated with a read
25 instruction, then the address in the real address register 6-401 is applied to the block store ram 6-420 and a determination is made in step 517 as to

whether the address of the real address register reserved by the address stored in the write address register 6-421 as indicated by the presence of a "busy" signal from the block store ram 6-420. When
5 the block store ram 6-420 provides a "busy" signal, then the address in the real instruction register 6-401 is held therein in step 521 until the "busy" signal from the block store ram 6-420 is removed in step 522. When the "busy" signal from the block
10 store ram 6-420 is removed, then the read procedure is executed in step 519 and a next address is entered into the real address register 6-401 in step 501. When, in step 517, the block store ram 6-420 does not provide a "busy" signal, then the address in the real
15 address register 6-401 is applied to the tag directory unit 6-403 to determine if the address stored in the real address register 6-401 is stored along with a "valid" signal in the tag directory unit 6-403 in step 518. When the address in the real
20 address register 6-401 is stored along with a "valid" signal in the tag directory unit 6-403, then the read instruction procedure for the cache memory unit is executed in step 519. When, in step 518, the address stored in the real address register 6-401 and an
25 associated "valid" signal are not stored in the tag directory unit 6-403, then the address in the real address register 6-401 is held therein in step 520



until the "busy" signal is removed in step 522. The read procedure associated with the address stored in the real address register is executed in step 519.

2. Operation of the Preferred Embodiment

5 The present invention provides a technique for using the time between the completion of a write instruction operand address by the VMMU unit and the completion of the preparation of the write instruction operand. The present invention provides
10 for the storing of the write instruction operand address along with an indicia indicating the presence of a valid operand at the location determined by the write instruction operand address. In the present invention, a read instruction can be processed by the
15 E-cache unit when the read instruction operand address does not conflict with the stored write instruction operand address and when the valid read instruction operand is stored in the E-cache. The conflict between the read instruction operand address
20 and the write instruction operand address is resolved by the presence of the "busy" signal from the block store cache unit. The "busy" signal maintains the read instruction address in the real address register until the write operation is processed by the E-cache
25 unit and the "busy" signal is removed. Similarly, when the read instruction address operand is not stored in the tag directory unit along with a "valid"



signal, the missing operand must be retrieved from the memory unit. This operand retrieval can conflict with the write instruction still pending in the E-cache unit and, therefore, the read instruction
5 operand address is stored in the real address register without further interaction with the E-cache unit until the pending write instruction is completely processed and the "busy" signal is removed from the block store ram. The processing of the
10 pending write instruction includes the storage of the write instruction operand in the cache unit when the "valid" bit is still present after completion of the write instruction operand.

As will be clear to those skilled in the art,
15 the flow diagram of Fig. 5 is meant to illustrate the operation of the present invention and is not meant as representation of actual apparatus. For example, many of the decision steps can be implemented by switches responding to control signals rather than by
20 a logical decision network. Similarly, in Fig. 4, many of the control signal paths that are used to implement a cache unit in the prior art have not been illustrated to emphasize the operation of the present invention.

25 The foregoing description is included to illustrate the operation of the preferred embodiment and is not meant to limit the scope of the invention.



The scope of the invention is to be limited only by the following claims. From the foregoing description, many variations will be apparent to those skilled in the art that would yet be encompassed by the spirit and scope of the invention.

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This Sheet Has Been Replaced

What is claimed is:

- 1 1. A data processing system comprising:
 - 2 a memory unit;
 - 3 a system bus coupled to said memory unit; and
 - 4 a plurality of processing units coupled to said
 - 5 system bus, wherein said data processing units and
 - 6 said memory unit operate asynchronously with respect
 - 7 to said system bus, each of said data processing
 - 9 units including:
 - 10 an address unit responsive to instructions
 - 11 for providing operand addresses of operands to be
 - 12 processed, wherein each operand has an operand
 - 13 address associated therewith;
 - 14 an execution unit responsive to a write
 - 15 instruction for providing a write operand for storage
 - 16 in said memory unit at an associated write operand
 - 17 address determined by said address unit;
 - 18 a cache means coupled to said execution
 - 19 unit for storing a write operand from said execution
 - 20 unit in a cache means location determined by said
 - 21 associated write operand address from said address
 - 22 unit when said cache means stores a valid operand at
 - 23 said associated write operand address location in
 - 24 response to a write instruction, said cache means





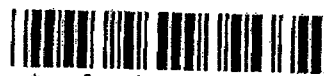
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25 providing a read operand from an associated read
26 operand address location to said execution unit in
27 response to a read instruction, said cache means
28 further including apparatus for processing an
29 intervening read instruction by said cache means
30 after an executing write instruction address has been
31 applied to said cache means and before said
32 associated executing write instruction operand has
33 been applied to said cache means; and

34 an interface unit receiving write operand
35 and associated write operand addresses from said
36 cache means and for applying said write operands and
37 associated write operand addresses from said cache
38 means to said system bus for transfer to said memory
39 unit.

1 2. The data processing system of claim 1 wherein
2 said cache means apparatus includes busy means
3 responsive to an intervening read instruction address
4 for preventing processing of said intervening read
5 instruction by said cache means until completion of
6 said executing write instruction by said cache means
7 when said intervening read instruction address is
8 identical to said associated executing operand
9 address.

1 3. The data processing system of claim 2 wherein





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2 said cache means apparatus includes valid means
3 responsive to said intervening instruction address
4 for preventing execution of said intervening read
5 instruction by said cache means until said executing
6 write instruction has been executed by said cache
7 means when said cache means does not store a valid
8 operand at an intervening read instruction address
9 location.

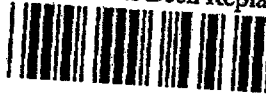
1 4. The data processing system of claim 2 wherein
2 said cache means apparatus includes register means
3 for storing said executing write instruction address
4 until receipt of said executing write instruction
5 operand.

1 5. The data processing system of claim 4 further
2 comprising a virtual memory management unit for
3 translating operand addresses from said address unit
4 to operand addresses related to storage locations in
5 said cache means and said memory unit.

1 6. The data processing system of claim 1 wherein
2 said cache means apparatus processes a second
3 intervening read instruction.

1 7. The data processing system of claim 3 wherein
2 said cache means apparatus includes an input address





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3 register, said input address register storing said
4 intervening read instruction address when said
5 intervening read instruction is prevented from being
6 processed in said cache means.

1 8. A method of expediting instruction execution in a
2 data processing system having at least one pipelined
3 data processing unit and a memory unit asynchronously
4 coupled to a system bus, wherein said data processing
5 units include cache units having a store through
6 strategy, said method comprising the steps of:

7 storing a write operand address determined by a
8 write instruction in a cache unit prior to receipt of
9 an associated write operand; and

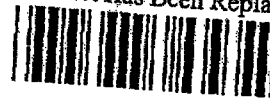
10 processing an intervening read instruction
11 having an intervening read operand address applied to
12 said cache unit after said storing of said write
13 operand address and prior to receipt of said
14 associated write operand.

1 9. The method of expediting instruction execution of
2 claim 8 further comprising the steps of:

3 comparing an address of said intervening read
4 instruction with said stored write operand address;
5 and

6 preventing processing of said read instruction
7 by said cache unit until said write instruction has





8 been processed by said cache unit.

1 10. The method of expediting instruction execution
2 of claim 9 further comprising the steps of;

3 determining when a valid operand is stored in
4 said cache unit at a location determined by said
5 intervening read instruction address; and

6 preventing processing of said intervening read
7 instruction by said cache unit until said write
8 instruction has been processed by said cache unit
9 when a valid operand is not stored in said cache unit
10 at said intervening read instruction address
11 location.

1 11. The method of expediting instruction execution
2 of claim 8 further comprising a step of processing a
3 second intervening read instruction prior to receipt
4 of said write operand.

1 12. The method of expediting instruction execution
2 of claim 8 further comprising a step of preventing
3 processing of a second write instruction by said
4 cache unit prior to completion of processing of said
5 write instruction by said cache unit.

1 13. The method of expediting instruction execution
2 of claim 10 further comprising a step of storing an





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3 intervening read instruction address in an input
4 register of said cache unit until said write
5 instruction has been processed by said cache unit
6 when said intervening read instruction is prevented
7 from being processed.

1 14. A data processing system having a memory unit
2 and a plurality of data processing units coupled by a
3 system, wherein said data processing system is
4 implemented using pipeline techniques, each data
5 processing system including a cache unit, each cache
6 unit comprising:

7 a storage unit for storing operands in a
8 plurality of storage unit locations;

9 a directory unit having a plurality of locations
10 each related to a one of said storage unit locations,
11 said directory unit locations along with signals
12 stored therein identifying an operand address of an
13 operand stored in said storage unit, said directory
14 unit having at least a valid bit location associated
15 with said directory unit locations;

16 an input address register for storing an operand
17 address from its data processing unit;

18 a write address register for storing a write
19 address associated with a write instruction while a
20 write operand determined by said write instruction is
21 not available; and



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22 block store means for providing a busy signal
23 when an operand address in said input address
24 register and a write operand address in said write
25 address register are identical, wherein a read
26 address stored in said input address register after
27 storage of a write address in said write address
28 register and prior to receipt of said write operand
29 causes retrieval of an operand at said read address
30 location.

1 15. The data processing system of claim 14 wherein
2 an absence of a valid operand at said read address
3 location in said storage unit prevents further
4 processing related to said read address in said input
5 register until said write operand has been processed
6 by said cache unit.

1 16. The data processing system of claim 14 wherein
2 retrieval of said read operand related to said read
3 address in said input unit causes a second read
4 address to be entered in said input register and
5 retrieval of a second read operand from a second read
6 address location of said storage unit.

1 17. The data processing system of claim 14 wherein
2 said write address register includes a location
3 indicating if said write operand address is present





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4 with a valid signal in said directory unit, said
5 write operand being stored in said storage unit at
6 said write address location when a predetermined
7 signal is present in said write address location.

1 18. The data processing system of claim 14 wherein
2 said data processing unit is comprised of an
3 execution unit, said cache unit being coupled to said
4 execution unit.

1 19. The data processing system of claim 14 wherein
2 said data processing unit is comprised of a bus
3 interface unit coupled to said system bus for
4 buffering signals transferred between said data
5 processing unit and said system bus, wherein said
6 write address and said write operand are applied to
7 said interface unit in processing an associated write
8 instruction by said cache unit.

1 20. The data processing system of claim 14 wherein a
2 second write address entered in said input register
3 prior to completion of processing of said write
4 instruction is prevented from further interaction
5 with said cache unit until said write instruction
6 completion.

