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# RESOURCE CONFLICT DETECTION METHOD AND APPARATUS INCLUDED IN A PIPELINED PROCESSING UNIT

## BACKGROUND OF THE INVENTION

### Field of Use

This invention relates to pipelined data processing systems and more particularly to apparatus for resolving resource conflicts within such systems.

### Prior Art

Many techniques have been developed in order to improve the performance of high performance systems. These have involved the development of socalled pipelined processors which process instructions stored in cache memories in such a manner that more than one instruction is actually being processed at any one given time. In such a system, one instruction might be completed within a given machine cycle at the same time as another instruction had only been partially completed.

While such systems achieve high performance, instructions are placed serially into the pipeline and as soon as the stage has completed its operation, the instruction is passed onto the next processing stage. Therefore, instructions are executed in the order in which they enter the pipeline. In order to improve system performance, some systems overlap the operations being executed by certain stages within the pipeline. An example of this type of system is described in U.S. Patent No. 4,760,519.

While the above improves performance, instructions are still required to be executed in the order in which they are introduced into the pipeline. The performance

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of a pipelined system has been improved by having the processing unit operate in a production line fashion in which earlier stages are able to complete the execution of certain types of instructions ahead of earlier introduced instructions. This processing unit is subject of related copending application titled "Production Line Method and Apparatus for High Performance Instruction Execution."

While pipelined processing units provide high performance, their performance still depends greatly on the order of the instructions in the instruction stream. That is, if consecutive instructions have data and control dependencies and contend for resources, then "holes" in the pipeline or production line will develop and performance will suffer.

To improve performance, in certain systems it may be possible to arrange the code or schedule it so that dependencies and resource conflicts are minimized. Registers can also be allocated so that register conflicts are reduced. However, register conflicts caused by data dependencies cannot be eliminated in this fashion. The problem of resource conflicts becomes even more important in the case of the production type processing unit in that any halt in operation will greatly affect performance.

Accordingly, it is a primary object of the present invention to provide method and apparatus for detecting resource conflicts which permits high performance pipeline operation.

It is another object of the present invention to provide a method and apparatus which maximizes operation and requires a minimum of complexity.

## SUMMARY OF THE INVENTION

The above and other objects of the present invention are achieved in a preferred embodiment of a pipelined processing unit which includes an instruction unit stage containing resource conflict apparatus for detecting and resolving conflicts in the use of register and indicator resources during the different phases of instruction execution. The instruction unit includes a plurality of resource registers corresponding in number to the number of instructions which can be processed concurrently by the processing unit. Decode circuits in response to each new instruction received by the instruction unit generate one or more sets of bit indication signals designating those resources required by the specific pipeline stage(s) executing the instruction for completing the execution of the instruction which are shared by those stages capable of completing the execution of instructions.

For a given instruction, there will be one set of bit indication signals generated for each pipeline stage that can complete the execution of that instruction. For each instruction executable by a last pipeline stage which corresponds to the main or primary execution unit in the preferred embodiment, the set of bit indication signals corresponding to that last pipeline stage is stored in a next available one of the resource registers. Comparison circuits compare the set of bit indication signals for each new instruction that corresponds to resources needed by an earlier pipeline stage which in the preferred embodiment corresponds to a secondary execution unit, with the

stored sets of bit indication signals for determining the presence of any resource conflict. When the comparison circuits detect a match between the set of bit indication signals and another set of stored bit indication signals, an output lock signal is generated which signals a resource conflict. The lock signal causes the instruction unit to stall its operation inhibiting the instruction which produced the conflict from entering the pipeline until there is no longer a conflict.

According to preferred embodiment, as the primary execution unit completes the execution of each instruction, it sends back a done signal to the instruction unit. This enables the instruction unit to clear the set of bit indication signals stored in the corresponding one of the resource registers. If this action removes the resource conflict, the comparison circuits turn off the lock signal and the instruction is permitted to enter the pipeline.

By determining which register and indicator resources are shared by the primary and secondary execution units and allowing instructions to enter the pipeline for execution out of sequence as long as there is not a resource conflict, the high performance of the processing unit is maintained.

In the preferred embodiment, the primary and secondary execution units, each include register file storage which contain the software visible registers utilized by the processing unit. Only those registers which are shared by the execution units in executing instructions will be signaled as potential conflicts. In the preferred embodiment, the primary execution unit includes several execution units, each of which

executes a different subset of the instruction set. These correspond to commercial, scientific and general instructions. Only those indicators which can create potential conflicts and shared by the earlier and last stages are included as resources within the set of bit indicator signals. Any resource which is only used by instructions for which pipeline operation can not proceed (also called complex instructions), is excluded. In the case of certain types of scientific instructions, several indicators are consolidated into a single indicator for detecting conflicts for those types of scientific instructions in which pipeline operation can proceed. To facilitate the detection of conflicts, the indicator resources are divided into different classes as a function of instruction type and executing unit. Also, the arrangement reduces substantially, circuit complexities. Since in the preferred embodiment, the instruction unit and execution units are constructed from separate integrated circuit chips, such reductions in complexity are most important in terms of performance, cost, testability, and reliability.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying drawings. It is to be expressly understood, however, that each of the drawings are given for the purpose of illustration and description only and are not intended as a definition of the limits of the present invention.

## DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the pipelined processing unit which includes the apparatus and method of the present invention.

Figures 2a through 2c show in greater detail, the different units of Figure 1.

Figures 3a and 3b are diagrams used to explain the operation of the preferred embodiment of the present invention.

Figure 4 is a diagram showing the processing of a sequence of instructions according to the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

### SYSTEM ORGANIZATION

Figure 1 shows in block diagram form, a production data processing system 10. As shown,the system includes a central processing unit (CPU) 20, a virtual memory management unit (VMMU) 40 and a cache unit 60. The cache unit 60 couples to a system bus 80 through a bus interface unit (BIU) 100. The processing unit (CPU) is constructed according to the principles of the present invention.

As shown, the main elements of CPU 10 include an instruction unit 20-2, an A-unit 20-4 and a number of execution (E) units 20-6. In the preferred embodiment, the execution units 20-6 include a scientific instruction processing unit (S-Unit) and a commercial instruction processing unit (C-Unit). The cache unit 60 includes an instruction cache (I-cache) 60-2 for

storing instructions which are to be executed and an execution cache unit (E-cache) 60-4 for storing operands or data which are to be operated on according to the instructions being executed.

The I-unit 20-2 performs two main functions. It prefetches instructions from I-cache unit 60-2 and cracks or decodes those instructions to determine how the other units, namely the A-unit 20-4 and the E-unit 20-6 will further process those instructions. In addition, the I-unit 20-2 includes branch address generation circuits for executing certain branch instructions which can then be removed from the production line.

The A-unit 20-4 generates addresses from instructions it receives from the I-unit 20-2. Additionally, it has the capability of executing certain types of instructions such as register-to-register type instructions enabling their removal from the production line. When the instruction is a type of instruction which is to be executed by the E-unit 20-6, the A-unit 20-4 sends a virtual address to VMMU 40 which translates it into a physical address for fetching the specified operands from the E-cache unit 60-4. The operands fetched from the E-cache unit 60-4 are then transferred to the E-unit 20-6 for completing the execution of the instruction originally received by the I-unit 20-2 from the I-cache unit 60-2. The A-unit 20-4 includes means for confirming when it has a branch instruction and has sent the branch address back to the I-unit 20-2 which will have already requested the next instruction from I-cache unit 60-2.

Both the A-unit 20-4 and E-unit 20-6 include register files which store the contents of the registers which are programmer accessible, as explained in greater detail herein. Both the I-cache unit 60-2 and E-cache unit 60-4 are updated with instructions and operands fetched from main memory via system bus 100 and BIU 80.

## Production Line Mode of Operation

Instructions are executed in a production like fashion by the elements of CPU 20. That is, the I-unit 20-2 receives each instruction from I-cache unit 60-2, cracks it and then sends the instruction to the A-unit 20-4. The A-unit 20-4 either executes the instruction or sends the virtual address to the VMMU 40 for translation in order to fetch the required operands from E-cache unit 60-4 which are in turn sent to E-unit 20-6.

While the A-unit 20-4 is executing its portion of a first instruction received from I-unit 20-2, the I-unit 20-2 is fetching a second instruction and subsequent instructions from I-cache unit 60-2. When the A-unit 20-4 sends the virtual address specified by the first instruction to VMMU 40 and notifies the I-unit 20-2 of that event, the I-unit 20-2 sends the second instruction to A-unit 20-4. The VMMU 40 addresses E-cache unit 60-4 while the A-unit 20-4 is processing the second instruction introduced into the production pipeline. When the E-unit 20-6 is executing the first instruction, VMMU 40 may be fetching operands from the E-cache unit 60-4 specified by the second instruction while the A-unit 20-4 is generating a

virtual address for a third instruction. At the same time, the I-unit 20-2 is cracking a fourth instruction and fetching a next instruction. Thus, there could be five instructions progressing down the production line at a given instant of time.

However, since the I-unit 20-2 can execute certain branch instructions and the A-unit 20-4 can execute certain software visible register instructions, these instructions are removed from the production line as soon as the execution of these instructions are completed. Also, when the A-unit 20-4 is processing a branch instruction and the conditions of the branch are met, the A-unit 20-4 immediately confirms the branch address received from the I-unit 20-2 and the branch instruction is removed from the production line.

It is important that the production line operation proceed without interruption. However, there are situations in which there may be conflicts in the resources specified by the instructions being introduced into the production line. The arrangement of the present invention utilizes the fact that certain units of the production line execute a subset of the total number of instructions. Therefore, it takes advantage in terms of performance that only certain registers and indicator resources will ever be in conflict between the A-unit 20-4 and E-unit 20-6.

The reduction in resources is reflected in the resource control word(s) generated by the I-unit 20-2 as a result of cracking each instruction as explained herein. Additionally, complex instructions are specially handled. A complex instruction is an instruction which can have many potential trap conditions which make it very difficult to predict with

sufficient certainty, the operating state of the pipeline before the trap took place so that the operation can be restored to that state following the processing of the trap. Such complex instructions are detected by the I-unit and cause it to stop the pipeline. This has the advantage of reducing substantially, chip circuit complexity which is important for the reasons previously mentioned.

## Programmer Visible Registers

Figure 2a shows the programmer accessible or visible registers and indicator resources which are shared by the A- and E-units. As shown, there are forty program visible registers which can be loaded and read by various instructions. These include seven general word operand registers, ten address registers, seven general double word operand registers, twelve control registers and three quad word scientific accumulators and one descriptor segment base register. These registers are located in the A-unit 20-4 and E-unit 20-6.

Thirty-two of these registers correspond to locations within register file memories included in the A- and E-units, as indicated in Figure 1. Whenever, either the A-unit 20-4 or one of the E-units 20-6 writes into a shared register location, the other unit receives a copy of the data written into that location. The reading and writing of the register file memories are controlled by microprogrammed control store units which are located off the A-unit and E-unit chips.

Each of the control store units store sequences of microinstruction words which are read out and loaded into a read data register (RDR) as required for executing instructions received from I-unit 20-2. The A- and E-units each include an arithmetic and logic unit (ALU), in addition to a shifter for performing those operations required for executing the received instructions. The operations and updating of the register file memories within the A- and E-units are described in the previously referenced copending application entitled, "A Mechanism for Automatically Updating Multiple Unit Register File Memories."

The indicator registers I, CI and SI are separate hardware registers located in the A-unit. These registers are updated by both the A- and E-unit circuits. That is, the E-unit 20-6 includes indicator logic circuits which in response to the execution of certain instructions generate signals for updating the indicator registers. The I register contains the program status indicators for general and extended integer instructions. These indicators are assigned to the I register bit positions as follows:

bit0 = overflow indicator OV;
bit1 = reserved for future use
bit2 = a carry indicator C of the latest operation designated to affect this bit;
bit3 = a bit test indicator B representing the status of the last bit tested;
bit4 = an input/output indicator I representing the status of the last peripheral interrogate operation;and
bit5 = a greater than indicator G, bit6 = a less than indicator L and bit7 = an unlike signs indicator U representing the result of the last compare operation.

The CI register which is cleared at initialization time is updated during the execution of commercial instructions. The indicators are assigned to the CI register bit positions are follows:

bit0 = overflow indicator OV;

bit1 = truncation indicator TR which is set during alphanumeric operations;

bit2 = sign fault indicator SF which is set during decimal operations;

bits 3,4 & 7 = reserved for future use;

bit5 = greater than G indicator which is set during the execution of certain decimal and alphanumeric instructions; and

bit6 = less than indicator L which is set during the execution of certain decimal and alphanumeric instructions.

The SI register which is cleared at initialization time is updated during the execution of scientific instructions. The indicators are assigned to the SI register bit positions as follows:

bit0 = exponent underflow indicator;

bits 1,4 and 7 = reserved for future use;

bit2 = significance error indicator used during a floating point to integer conversion operation;

bit3 = precision error indicator used during a floating point to integer conversion operation;

bit5 = greater than indicator G;and

bit6 = less than indicator L.

According to the teachings of the present invention, only those indicators and registers which can create potential resource conflicts are designated by the resource control words as explained herein. That is, those instructions which can set the I/O

indicator, the CI indicators and certain SI indicators also stop pipeline operation and, therefore, have been eliminated. A single bit is used for the group of scientific instructions which do not stop pipeline operation.

## I-UNIT 20-2

Figure 2b shows the I-unit 20-2 in greater detail. The I-unit 20-2 includes an I chip 20-20 and glue logic circuits 20-22 which interconnect the I chip to the other chips of the CPU. The I chip 20-20 is logically divided into an I fetch unit (IFU) 20-200 for fetching instructions from the I-cache unit 60-2 and an I crack unit (ICU) 20-250 for "cracking" or decoding the fetched instructions.

The IFU 20-200 includes the adder, multiplexer and register elements 20-202 through 20-218 arranged as shown. The IFU 20-200 uses a local program counter 20-208 to generate branch addresses. Initially, the P counter 20-208 and one of the virtual address registers (20-212 or 20-214) are loaded with a virtual address received from A-unit 20-4 via multiplexer circuit 20-206 or 20-210, respectively, in response to a load signal A-P-LD also received from the A-unit 20-4. The virtual address points to the location in I-cache unit 60-2 which stores the next instruction that is to enter the pipeline. During an I fetch cycle, the virtual address is transferred to I-cache unit 60-2 from either VA0 register 20-212 or VA1 register 20-214 through multiplexer circuit 20-218.

Either VA0 register 20-212 or VA1 register 20-214 is used to furnish the virtual address until a branch instruction is decoded by the I-unit 20-2. At that time, the I-unit 20-2 will switch the VA register such that if VA0 register is active, then the address called for by the branch instruction is stored in VA1 register 2-214. If the ICU 20-250 detects a small (seven or sixteen bit) displacement branch instruction, then the I-unit will generate the branch address by sending a sixteen bit displacement value to IFU 20-200 via multiplexer circuit 20-204. This value is added via adder 20-202 to the contents of the P counter 20-208 to create the branch address. It is then loaded into the VA register selected by the VA pointer.

The ICU 20-205 includes two sets of string buffers (SBA and SBB) which correspond to blocks 20-252 and 20-254. Each buffer includes eight sixteen bit registers and receives data from the I-cache unit, two words or thirty-two bits at a time. As shown, each instruction read out of I-cache unit 60-2 is loaded into either buffer 20-252 or 20-254. The ICU 20-250 maintains a current string pointer denoting which of the two string buffers is in use, in addition to input and output and count pointers for each set of buffers.

One of the string buffers receives a stream of successive instructions from I-cache unit 60-2. If there is a branch instruction, the instructions of the new stream following the branch are stored in the other string buffer. As shown, each instruction of the instruction stream being processed is transferred via multiplexer 20-256 to the I crack logic circuits of block 20-260 and to the A- and E-units via multiplexer 20-258. The I crack logic circuits of block 20-260

include three cracking or decoding circuit areas ICKHI, ICKMD and ICKLO. Each of the crack areas decode or crack in parallel, a different group of bits of each instruction.

The results of the first stage are applied to a second stage of cracking or decoding which corresponds to the block labeled ICRK. The ICRK stage determines exactly what instruction is being processed with which address syllable etc. That is, it determines the specific kind of instruction which is to be executed. If it is a software visible register to register instruction, it will be executed by the A-unit 20-2, and if it is a memory instruction, it will be executed by the E-unit 20-6. The ICRK stage provides signals to update the string buffer counters 20-270 and the resource control pointer circuits of the resource control area block 20-280. The I crack circuits 20-260 also apply the instruction word signals to the control store I/A address generation circuits 20-220 of the glue logic circuits 20-22. The generation circuits 20-220 address the A-unit control store which reads out a microinstruction word into the A-unit RDR register for executing the instruction.

The last part of the ICU 20-250 is the resource control area 20-280 which is constructed according to the teachings of the present invention. The block 20-280 operates in preventing instructions which can produce resource conflicts from entering the pipeline. As shown, block 20-280 includes a number of resource control registers RSRCO-RSRC3 corresponding in number to the number of stages in the pipeline which can be processing instructions. Block 20-280 also includes a set of OR circuits 20-282 for logically ORing signals

from corresponding bit positions of each of the resource control registers which are applied to a first set of inputs of the compare logic circuits of block 20-284. The compare logic circuits 20-280 receive at a second set of input signals from the ICRK stage which are generated as part of an A resource control word as the result of cracking or decoding the next instruction as described herein.

Additionally, the resource area 20-280 includes a two-bit pointer EOUTPTR which selects which one of the four resource registers will be used to store the resource word for the next instruction to be executed by the E-unit 20-6. Each time a word is stored, the EOUTPTR pointer is incremented by one. As the instructions are completed by the E-unit 20-6 and removed from the pipeline, the E resource registers are cleared in sequence. Another two bit pointer EDONEPTR is used to select the register to be cleared. The EDONEPTR pointer is incremented by one, each time an E-unit instruction is completed.

## RESOURCE CONTROL WORDS

When an instruction is cracked, the circuits 20-260 determine which of the resources that could be potentially needed by the A- and E-units will be used in the A-unit for executing the instruction. Figure 3 shows the format of the A and E resource control words used to represent all of the register and indicator resources shared between the A- and E-units. As seen from the Figure, the resources selected from the complement of visible and indicator registers of Figure 2a that could be potentially needed by both the A- and

E-units simultaneously are: the seven K registers, the seven R registers, the M1 and M2 registers and the OV, C, B, G, L, U, and S indicators.

Each of these resources is represented by a different bit in the A resource control word (ARSRC) and a corresponding bit in the E resource control word (ERSRC) as shown in Figure 3. Since up to four E-unit instructions can be in various stages of processing in the pipeline at one time, there can be up to four ERSRC words which can be stored within resource control area 20-280. The pertinent signals for generating the resource control words are included in an appendix.

## DESCRIPTION OF OPERATION

With reference to Figures 1 through 3, the operation of the present invention will now be described relative to processing the sequences of instructions of Figures 4a through 4g. As previously discussed, in the production line mode of operation, the A-unit 20-4 can potentially use resources for each instruction received by the I-unit 20-2. Also, these same resources in the case of certain instructions can be used by one of the E-units 20-6 (e.g., E, CIP or SIP).

Accordingly, in response to each instruction received, the I-unit crack logic circuits determines which unit will execute the instruction and the corresponding resource control word. That is, the I crack logic circuits from the combination of instruction bits, generate an E-unit instruction signal EINSTR when the instruction is to be executed by one of the E-units 20-6. This signal is used to transfer the instruction to the E-unit instruction FIFO buffer under

the control of I instruction signals I-EFIRST and I-ELAST. That is, signal I-EFIRST enables the E-IFIFO buffer to be loaded with the first double word of the instruction while signal I-ELAST enables the loading of a last instruction double word into the E-IFIFO buffer.

When the I-unit is ready to crack the instruction, it generates a CRACK signal indicating that it is ready to decode the next instruction, that one of the string buffers contains at least one instruction double word or a single word instruction and that the A-unit has generated an A-DONE signal indicating that it has completed the execution of the previous instruction. The CRACK signal causes the generation of an I-BEGIN signal which is sent to the A-unit during the cycle that the I-unit sends the first instruction double word of a valid instruction to the A-unit.

Considering the operation in greater detail, Figure 4a depicts a first sequence of instructions which produces several different types of resource conflicts. The first conflict occurs between an E-unit load register (LDR) instruction specifying the use of programmer visible register R1 and the later occurring A-unit add instruction specifying the use of the same R1 register. The second conflict occurs between an E-unit load register (LDR) instruction specifying register R3 and another E-unit add instruction that specifies the use of register R3 for address generation taking place in the A-unit. The final conflict occurs between this E-unit add instruction and the branch on overflow instruction occurring during instruction execution.

Figures 4b through 4f depict the states of the E resource registers RSRC0 through RSRC3 and EDONE and EOUT pointers during successive I cycles of operation required for processing the sequence of instructions. The instruction sequence is stored in I cache unit 60-2. The instructions having the indicated mnemonics are shown in hexadecimal form. For example, the first instruction is coded as 9800 0000 0014 and is a three word load R1 register instruction using an immediate memory address of hexadecimal 14. The VMMU 40 converts this virtual address into a physical address which is applied to E cache unit 60-4 to fetch the memory operand value (labeled MEMVAL1). This value is to be loaded into register R1 located in the register file of the E-unit 20-6 upon execution of the LDR instruction.

It is assumed that the resource registers are empty and the EOUT and EDONE pointers are both pointing to E resource register RSRC0 prior to the start of the instruction sequence. The I-unit 20-2, during the first cycle of Figure 4b, fetches the LDR instruction from the I cache unit 60-2 using the address specified by the VA0 register 20-212 of Figure 2b and stores it in SBA string buffer 20-252. That is, IFU 20-200 is initialized by A-unit 20-4 which transfers an address to VA0 register 20-212 via multiplexer 20-210 (i.e., position A-VAD). The I cache unit 60-2 reads out the first two words of the three word LDR instruction into the SBA buffer 20-252. The IFU 20-200 continues to fetch instructions until the instruction buffer is full.

During the second cycle, the LDR instruction is applied via multiplexer 20-256 to the I crack logic circuits. These circuits crack the instruction's

op-code which result in the ICRK stage generating an E resource word ERSRC = 00400000 and an all ZERO A resource word ARSRC. The coding of the resource bits indicate that the E-unit 20-6 requires the use of general register R1 in executing the LDR instruction and that the A-unit 20-4 does not require any of the resources it shares with the E-unit. The bit ER1 is set to a binary ONE state as a result of decoding the instruction. The equation for ER1 is included in the appendix. Next, the I-unit 20-2 applies signal I-BEGIN to enable the A-unit op-code register to be loaded with the first word of the LDR instruction for continued processing.

During the next clock cycle, the E resource word ERSRC value is loaded into E resource register RSRC0. Also, the EOUT pointer is incremented by one to point to the next resource register RSRC1. The results are as shown in Figure 4b. The immediate memory address (the second and third words of the instruction) is also forwarded to A-unit 20-4.

During a fourth clock cycle, the second LDR instruction fetched by IFU 20-200 from the I cache unit 60-2 is cracked by the I-unit 20-2. This results in the generation of an E resource word ERSRC = 00200000 and an A resource word ARSRC having all zeros. The coding of the E resource bits indicate that the E-unit 20-6 requires the use of general register R2 in executing the LDR instruction. That is, bit ER2 is set to a binary ONE state as a result of cracking the instruction's op-code. Again, the A-unit does not require any resources. The OR circuits 20-282 logically combine the stored groups of E resource word bit positions which are, in turn, compared with the A

resource word. Since there is no match (i.e., the LOCK signal is a binary ZERO), the ICRK stage generates signal I-BEGIN. This again enables the instruction word op-code to be transferred to the A-unit 20-4.

During a fifth clock cycle, the E resource word ERSRC is loaded into E resource register RSRC1. Again, the EOUT pointer is incremented by one to point to E resource register RSRC1. The results are as shown in Figure 4c. Also, the IMA for the LDR instruction is sent to A-unit 20-4.

During a sixth clock cycle, the first ADD instruction fetched by IFU 20-200 from I cache unit 60-2 is cracked by the I crack logic circuits 2-260. This results in the generation of an E resource word ERSRC = 0000 0000 and an A resource word ARSRC = 0040 0060. The coding of the E resource word bits indicates that the E-unit does not require any resources in executing the ADD instruction and that the A-unit 20-4 requires the use of the general register R1 and the overflow (OV) and carry (C) indicators. The bit AR1 is set to a binary ONE state as a result of decoding the instruction's op-code. The OV and C indicator bits are also set based on such decoding.

The OR circuits 20-282 logically combine the store groups of E resource word bit positions which are compared with the A resource word. In this case, the R1 bits in the A resource word ARSRC and E resource word stored in register RSRC0 match. This causes compare circuits 20-284 to force the LOCK signal to a binary ONE. Signal LOCK, in turn, causes the ICRK stage to force the STALL signal to a binary ONE preventing the ADD instruction from entering the pipeline.

In greater detail, the STALL signal prevents instructions from entering the pipeline by inhibiting signal I-BEGIN and I-EFIRST from switching to binary ONES. The STALL signal is applied to the string buffer pointers and prevents the string buffer OUT pointer from changing state. Thus, the OUT pointer remains pointing to the instruction which produced the conflict until the conflict is removed.

It will be noted that since the ADD instruction is being executed by the A-unit 20-4, the all ZEROS E resource word is not stored in register RSRC2. However, if the instruction were to be executed by the E-unit 20-6, the all ZEROS resource word would be stored in register RSRC2 for design simplicity.

During a next clock cycle that the E-unit 20-6 completes the execution of the first LDR instruction, it signals this fact by sending signal E-DONE to the I-unit 20-2. This causes the ICRK stage to clear E resource register RSRC0 to ZEROS resulting in signals LOCK and STALL being forced to ZEROS. At that time, the EDONE pointer is incremented by one so that it points to E resource register RSRC1. The results are as shown in Figure 4d. The ADD instruction is now allowed to enter the pipeline and is sent to A-unit 20-4 for execution.

During the next clock cycle, when the third LDR instruction is cracked by the I crack logic circuits 2-260, this results in the generation of an E resource word ERSRC = 0010 0000 and an A resource word ARSRC = 0000 0000. The coding of the E resource word bits indicates that the E-unit 20-6 requires the use of general register R3, while the A resource word bits indicate that the A-unit does not require any resources

it shares. The bit ER3 is set to a binary ONE state as a result of decoding the instruction's op-code. Since there is no conflict, the LOCK signal remains a binary ZERO which enables the LDR instruction to enter the pipeline (i.e., it is loaded into the A-unit op-code register). When the E-unit 20-6 completes its execution of the second LDR instruction, it generates signal E-DONE which results in clearing E resource register RSRC1 to ZEROS and incrementing EDONE pointer by one so that it now points to E resource register RSRC2.

During the next clock cycle, the E resource word ERSRC is loaded ito E resource register RSRC2. Also, the EOUT pointer is incremented by one so that it now points to E resource register RSRC3. The results are as shown in Figure 4e. The IMA for the LDR instruction is also sent to A-unit 20-4.

During the next clock cycle, the second ADD instruction fetched from hexadecimal location 9A31 is cracked by the I crack logic circuits 2-260. This results in the generation of an E resource word ERSRC = 0040 0060 and an A resource word ARSRC = 0010 8000. The coding of the resource word bits indicates that the E-unit 20-6 requires the use of general register R3 and indicators OV and C and that the A-unit 20-4 requires the use of general register R1 and address register B1. The bits ER3, OV, and C are set to binary ONES as a result of decoding the instruction op-code. The bits AR1 and AB1 are set to binary ONES based on similar decoding.

The compare circuits 20-284 compare the corresponding bit positions in the A resource word ARSRC to the E resource word contents of the RSRC

registers and detect a match between the R3 bits in the ARSRC word and the E resource word stored in register RSRC2. This forces signals LOCK and STALL to binary ONES preventing the second ADD instruction from entering the pipeline.

In the above situation, the conflict results from two E-unit instructions. That is, the conflict occurs only because A-unit 20-4 requires the use of a shared resource to generate an operand address, and that resource has already been tagged for use by a preceding E-unit instruction.

In a subsequent clock cycle, when the E-unit 20-6 completes the execution of the third LDR instruction, it signals this by again generating signal E-DONE. This causes E resource register RSRC2 to be cleared, forcing signals LOCK and STALL to binary ZEROS. At the same time, EDONE pointer is incremented by one so that it points to register RSRC3. This enables the ADD instruction to enter the pipeline. Also, the E resource word is loaded into register RSRC3 and the EOUT pointer is incremented by one to point to register RSRC0. The results are as shown in Figure 4f.

During the next clock cycle, the SUB instruction is cracked by the I crack logic circuits 20-260. This results in the generation of an E resource word ERSRC = 0000 0000 and an A resource word ARSRC = 0010 0000. The coding of the resource bits indicates that the E-unit 20-6 requires no resources in executing this instruction while the A-unit 20-4 requires the use of general register R3. That is, bit AR3 is set to a binary ONE state by decoding the instruction's op-code.

The compare circuits 20-284 compare the corresponding bit positions in the A resource word ARSRC to the E resource word contents of the RSRC registers and find no match. This enables the SUB instruction to be transferred to A-unit 20-4.

During the next clock cycle, the I crack logic circuits 20-260 crack the branch on overflow instruction. As a result, this generates an E resource word ERSRC = 0000 0000 and an A resource word ARSRC = 0000 0040. The coding of the resource bits indicates that the E unit 20-6 requires no resources in executing this instruction, while the A-unit 20-4 requires the use of the overflow indicator. That is, bit AOV is set to a binary ONE state by decoding the instruction's op-code.

The compare circuits 20-284 compare the corresponding bit positions in the A resource word ARSRC to the E resource word contents of the RSRC registers and find a match between the OV bits in the ARSRC word and E resource contents of register RSRC3. This forces signals LOCK and STALL to binary ONES, preventing the branch instructions from entering the pipeline. As soon as E-unit 20-6 completes the execution of the second ADD instruction, it sends signal E-DONE which clears E resource register RSRC3 forcing signals LOCK and STALL to binary ZEROS. At that time, EDONE pointer is incremented by one to point to register RSRC0. The BOV instruction is transferred to the A-unit 20-4 for execution.

From the above, it is seen how the present invention enables the identification of those instructions which can be processed by different stages of the pipeline without any conflict in resources,

thereby speeding up performance. The resource conflict circuits are designed to enable instructions of the different execution units to enter the pipeline if such instructions can be processed without having to stop the pipeline.

For example, there is a certain type of scientific instruction set (IEEE standard), most of which can be processed without having to stop the pipeline as contrasted with native mode scientific instructions which have been categorized as complex instructions. The following is a sequence of these instructions.

| Instruction | Description | Exec. Unit |
|---|---|---|
| ISML | IEEE sci. multiply | E |
| ISCR | IEEE sci. compare/reg. | E |
| . | . | . |
| . | . | . |
| . | . | . |
| SBL | Sci. branch on less than | A |

As mentioned, the scientific instruction sets use a separate set of resources (accumulators and indicators) from those used by non-scientific instructions. Therefore, the only potential conflict involving such instructions could occur between a scientific instruction being executed in E-unit 20-6 and a subsequent scientific branch instruction executed in A-unit 20-4.

The ISML instruction of the above sequence is the first instruction cracked by the ICRK circuits 20-260. Since it does not affect any indicators, it does not

set the S bit in the E resource word ERSRC. The cracking of the next instruction ISCR establishes that this instruction affects the scientific G, L, and U indicators. Therefore, it sets the S bit in the E resource word ERSRC. Accordingly, when the ICRK circuits 20-260 crack the SBL instruction, the S bit is set in the A resource word ARSRC, since the instruction affects the less than (L) indicator. Therefore, compare circuits 20-284 detect a conflict between the S bits in the A and E resource words. As a result, the SBL instruction is not permitted to enter the pipeline until the E-unit 20-6 completes the execution of the ISCR instruction. If there were not a compare instruction included in the sequence, the branch instruction could immediately enter the pipeline and be processed. When several instructions are included between the compare and branch instructions, the compare instruction would be completed before the branch instruction is cracked. The invention eliminates delays by only stopping pipeline operation when there is an actual resource conflict, otherwise instructions are allowed to enter the pipeline.

## APPENDIX

The mnemonics of the instructions are given in the publication entitled, "Hardware Version of DPS6 Programmers Pocket Guide," Order No. CU75-02 (August 1984) and subsequent updates. The notations in the Boolean equations are as follows:

| | |
|---|---|
| EQ 0100 | EQUAL TO HEXADECIMAL 0100 |
| GT 3 | GREATER THAN HEXADECIMAL 3 |
| EQ 2 | NOT EQUAL TO HEXADECIMAL 2 |
| NLT 018 | NOT LESS THAN HEXADECIMAL 018 |
| NGT 01E | NOT GREATER THAN HEXADECIMAL 01E |
| LT 3 | LESS THAN HEXADECIMAL 3. |

The I-BEGIN signal is generated by the Boolean equation:

I-BEGIN = CRACK & ^STALL & ^HOLD

wherein CRACK = READY & ^NONELEFT & ADONE.

The ^ signifies a negated signal, i.e., ^HOLD should be read as the "NOT HOLD" signal.

The Boolean equation for the I-EFIRST signal is:

I-EFIRST = CRACK & ^STALL & EINSTR.

The Boolean equation for signal EINSTR is generated as a function of combinations of bits of the different types of instructions that require execution by the E-unit 20-6. The Boolean equation is:

EINSTR = GCS + (IO + IOLD + SC + MASK + BIT4 + LB + LEV + INCDEC & ^RAS + MTM + MUL + DIV + STM + SSBP) & ^EII + (BSTORE + EBIM0) & IMO + EMSK & EII + MLV & (SI + ESI & EII1) + (ESO+EDO) & (^ERAS&(EII1 + EII23) + AS3EII45) + EEII & (EII1 + EII23) + (SDO + SO) & ^RAS & ^IMO & ^EII.

## DESCRIPTION OF EQUATION TERMS

GENERIC, COMMERCIAL, OR SCIENTIFIC INSTRUCTIONS

```
GCS = I-INST (0-8).EQ.0;
```

IO INSTRUCTION

```
IO = (I-INST (0-8).EQ.0100)
```

IOLD INSTRUCTION

```
IOLD = I-INST (0-8).EQ.0103
```

SINGLE OPERAND INSTRUCTIONS

```
SO = (I-INST (0-3).EQ.8 & ((I-INST (4-8).EQ.1) +
     (I-INST (4-8).GT.3))
```

SINGLE OPERAND INSTRUCTION THAT USES B REGISTERS IN THE E-UNIT 2-6

```
SSBP = I-INST (0-8).EQ.0106
```

SINGLE OPERAND INSTRUCTIONS THAT USE OVERFLOW: (NEG, CAD, AID, SID, INC., DEC. INSTRUCTIONS)

```
SOV = SO & ((I-INST (4-8).EQ.4) + (I-INST (4-8).EQ.01D)
      + (I-INST (4-7).EQ.4)) + INCDEC
```

LB INSTRUCTION

```
LB = SO & (I-INST (4-8).EQ.05)
```

BIT INSTRUCTIONS (LBF, LBT, LBC, LBS)

```
BIT4 = (I-INST (0-5).EQ.022) & (I-INST (8).EQ.0)
```

BASIC DOUBLE OPERAND OR SCIENTIFIC INSTRUCTIONS

```
SDO = (I-INST (0-3).GT.8) & (I-INST (4-8).NEQ.2)
```

```
    BASIC INSTRUCTIONS WITH IN-LINE MASK WORD: (SRM, NSAVE,
    NRSTR, SAVE, RSTR)
    MASK = (I-INST (0).EQ.1) & (RLBP.NEQ) & I-INST (4-8).
           EQ.015) + (I-INST (0-7).EQ.085) + (I-INST
5          (0-7).EQ.08F)

    SCIENTIFIC SINGLE AND DOUBLE OPERAND INSTRUCTIONS
    SC = ((I-INST (0-3).GT.8) & ((I-INST (4-8).EQ.011) +
         (I-INST (4-8).EQ.013) + (I-INST (4-8).EQ.018) +
         (I-INST (4-8).EQ.01A))) & ^EII1 & ^EII23 &
10       ^AS3EII45

    DOUBLE OPERAND INSTRUCTION THAT USES M REG AND DOES NOT
    STOP PIPELINE
    STM = (I-INST (O).EQ.1) & (RLBP.NEQ.0) & (I-INST (4-8)
          .EQ OE)

15  WHERE RLBP = I-INST (1-3)

    MULTIPLY INSTRUCTION
    MUL = (I-INST (0).EQ.1) & (RLBP.NEQ.0) & (I-INST (4-8)
          .EQ 016)

    DIVIDE INSTRUCTION
20  DIV = (I-INST (0).EQ.1) & (RLBP.NEQ.0) & (I-INST1 (4-8)
          .EQ 06)

    MODIFY OR TEST M REGISTER INSTRUCTION
    MTM = (I-INST (0-3).GT.8) & (I-INST (4-8).EQ.0)
```

```
   SO, DO STORE INSTRUCTIONS NEG, SSBP, CPL, CALL, CL,
   CLH, LBF, DEC, LBT, LBS, INC, LBC, STS,SDI, CAD (ALSO
   LEN) STM, STH, SRM, SWR, SWB, STR, STB
   BSTORE = SO & ((I-INST(4-8).EQ.4) + (I-INST(4-8).EQ.6)
5            + (I-INST(4-6).EQ.3) + (I-INST(4-7).EQ.OA) +
             (I-INST(4-7).EQ.8) + (I-INST(4-8).EQ.018) +
             (I-INST(4-8).EQ.01A) + (I-INST(4-7).EQ.OE)) +
             BIT4 + SDO & ((I-INST(5-7).EQ.7) +
             (I-INST(4-8).EQ.015) + (I-INST(4-6).EQ.7))

10 SHORT VALUE IMMEDIATE INSTRUCTIONS
   SI = (I-INST(0).EQ.0) & (RLBP.NEQ.O) &
        (I-INST(4-7).GT.OB)

   IMO INSTRUCTIONS THAT USE B REG IN E-UNIT 2-6 (LDB,
   LAB, STB, SWB)
15 EBIMO = (I-INST(0-3).GT.8) & ((I-INST(4-8).EQ.019) +
           (I-INST(4-8).EQ.017) + (I-INST(4-8).EQ.01D) +
           (I-INST(4-8).EQ.01F))

   LEV INSTRUCTION
   LEV = SO & (I-INST(4-8).EQ.01C)

20 INC AND DEC INSTRUCTIONS
   INCDEC = SO & ((I-INST(4-8).EQ.011) + (I-INST (4-8)
            .EQ 015))

   MLV OR MLVK INSTRUCTION
   MLV = I-INST(6-7).EQ.3

25 EXTENDED INTEGER SINGLE OPERAND INSTRUCTIONS
   ESO = (I-INST(0-3).EQ.8) & (I-INST(4-8).NLT.018) &
         (I-INST(4-8).NEQ.01B) & (I-INST(4-8).NGT.01E)
```

```
    EII SO THAT USE OVERFLOW & DOES NOT STOP PIPELINE:
    KINC, KDEC, KNEG, KNEGB INSTRUCTIONS
    ESOV = ESO & (I-INST(6-7).LT.3) & (I-INST(6-8).NEQ.1)

    EII SHORT VALUE IMMEDIATE INSTRUCTIONS
 5  ESI = EBK & (I-INST(8).EQ.1)

    EXTENDED INTEGER DOUBLE OPERAND INSTRUCTIONS
    EDO = (I-INST(0-3).GT.8) & (I-INST(4-7).NLT.4)

    EXTENDED INTEGER INSTRUCTION (EII) INSTR WITH IN-LINE
    MASK DOUBLEWORD
10  EMSK = (I-INST(0).EQ.1) & (RLBP.NEQ.0) & (I-INST(4-8)
           .EQ.OF)

    WHERE RLBP = I-INST (1-3)

    EII INSTRUCTIONS EXECUTED IN E-UNIT 2-6 THE INSTRUCTION
    INCLUDES A REGISTER ADDRESS SYLLABLE (RAS) OR AN (IMO)
15  (KDIV, KMUL, KMULP, KDIVP INSTRUCTIONS)
    EEII =  KDIV + KMUL + KDIVP + KMULP
    KDIV =  (I-INST(0).EQ.1) & (RLBP.NEQ.0) & (I-INST(4-8)
            .EQ.017)
    KMUL =  (I-INST(O).EQ.1) & (RLBP.NEQ.0) & (I-INST(4-8)
20          .EQ.01F)
    KDIVP = (I-INST(0) & (RLBP.NEQ.0) & (I-INST(4-8)
            .EQ.01C)
    KMULP = (I-INST(0).EQ.1) & (RLBP.NEQ.0) & (I-INST(4-8)
            .EQ.01E)
25  EII1  = I-INST(9-15).EQ.06C
    EII23 = I-INST(9-15).EQ.07C
    AS3EII45 = I-INST(9-15).EQ.058
```

```
RAS = (I-INST(9-11).EQ.5) & (I-INST(12).EQ.0) &
      (I-INST(13-15).NEQ.0)
IMO = I-INST(9-15).EQ.070
KAS = (I-INST(23-28).EQ.01A) & NC
ERAS = (I-INST(24-28).EQ.01A) & NC
NC = I-INST (29-31).NEQ.0
EII = EII1 + EII23 + AS3EII45
```

The A resource bits are generated according to the following Boolean equations:

```
AB1 = (RLB.EQ.1) & (SDO&BRG&RAS + IMO&I-INST(0)&(I-INST
                   (4-8).EQ.01B) + EDO & EB & ERAS &
                   (EII1+EII23)) +
      (REGN.EQ.1) & ((CMN+SDO&BRG) & RAS + (SO+SDO) &
                   ((RM.NEQ.5) + (I-INST(12).EQ.1))) +
      (REGN.EQ.5) & (SO+SDO) & (RM.GT.4) & (I-INST(12)
                   .EQ.1) +
      (REN.EQ.1) & (ESO+EDO) & (EII1 & (ERAS & (I-INST
                   (20-23).EQ.OE) + ((REM.NEQ.5) +
                   (I-INST(28).EQ.1)) & (EMAP.EQ.1)) +
                   EII23 & ((EMAP.EQ.0) + (REM.GT.0) &
                   ((I-INST(28).EQ.1)
                   (REM.EQ.7) + (REM.NGT.3))) +
                   AS3EII45 & (EMAP.EQ.0) &
                   (REM.GT.0) & ((I-INST(28).EQ.1) +
                   (REM.GT.3)) +
                   (EMAP.EQ.1) & ((I-INST(28).EQ.0) +
                   (REM.GT.0)))) +
      (REN.EQ.1) & ((SO+SDO)&ASN + GCS&ISM) & ((MAP.EQ.
                   0) + (MAP.EQ.1) & (REM.GT.0) &
                   ((I-INST(28).EQ.1) + (REM.LT.4) +
                   (REM.EQ.7)) + (MAP.EQ.2) & (REM.GT.0)
```

```
                    & ((I-INST(28).EQ.1) + (REM.GT.3)) +
                    (MAP.EQ.3) & ((I-INST(28).EQ.0) +
                    (REM.GT.0))) +
          (REN.EQ.5) & (ESO+EDO) & EII1 & (EMAP.EQ.1) &
                    (REM.GT.4) & (I-INST(28).EQ.1).

AOV =  GOV + SHOV&(SSH) + OSHOV&(LSH) + (SOV+ADDSUB)&
       RAS + (AIDSID+ADDSUB)&IMO + OSHOV & ESH1 +
       NSHOV & ESHO & NSH + (ESOV+EDOV) & ERAS &
       (EII1+EII23) + ESI & ADV & EII1.

AC  = (SOV+ADDSUB) & RAS + (AIDSID+ADDSUB) & IMO +
       (ESOV+EDC) & ERAS & (EII1+EII23) + ESI & ADV &
       EII1 + GC + (SHC & SSH) + (OSHC & LSH) + OSHC &
       ESH1 + NSHC & ESHO & NSH.

AR1 = (LSH + ESHO + ESH1) & LSO + SSH & SSORDD +
       (RLB.EQ.1) & (SI&^MLV + BR + SSH + LSH +
       RAS&ERIMO + SDO&^SC&^BRG&^MUL&^DIV&^STM&^MTM&^
       ERIMO&(RAS+IMO)) + (REGN.EQ.1) & RAS & (SO&^
       SSBP&^CMN&^LB&^BIT4&^LEV+SDO&^SC&^BRG&^MUL&^DIV&^
       STM&^MTM) + (REN.EQ.1) & (ESO&^KAVM + EDO&^EEII&
       ^EMSK) & EII1 & ERAS & (I-INST(20-21).LT.3) +
       (RM.EQ.1) & (SO + SDO) + (RM.EQ.5) & (SO + SDO)
       & (NBITS.GT.8) & (NBITS.NEQ.OC) + (REM.EQ.1) &
       (((SO + SDO) & ASN + GCS & ISM) & (MAP.EQ.0) &
       (ENBITS.GT.0) + (ESO +EDO) & (EII1 & (EMAP.EQ.1)
       + EII23 & (EMAP.EQ.0) & (ENBITS.GT.0) + AS3EII45
       & (EMAP.EQ.0) & (ENBITS.EQ.0))) + (REM.EQ.5) &
       (ESO+EDO) & EII1 & (EMAP.EQ.1) & (ENBITS.GT.8) &
       (ENBITS.NEQ.OC).
```

```
AR3  = (RLB.EQ.3) & (SI&^MLV + BR + SSH + LSH +
       RAS&ERIMO + SDO&^SC&^BRG&^MUL&^DIV&^STM&^MTM&^
       ERIMO&(RAS+IMO)) + (REGN.EQ.3) & RAS & (SO&^
       SSBP&^CMN&^LB&^BIT4&^LEV + SDO&^SC&^BRG&^MUL&^
       DIV&^STM&^MTM) + (REN.EQ.3) & (ESO&^KAVM + EDO&^
       EEII&^EMSK) & EII1 & ERAS & (I-INST(20-21).LT.3)
       + (RM.EQ.3) & (SO + SDO) + (RM.EQ.7) & (SO +
       SDO) & (NBITS.GT.8) & (NBITS.NEQ.OC) + REM.EQ.3)
       & (((SO + SDO) & ASN + GCS & ISM) & (MAP.EQ.0) &
       (ENBITS.GT.0) + (ESO + EDO) & (EII1 &
       (EMAP.EQ.1) + EII23 & (EMAP.EQ.0) &
       (ENBITS.GT.0) +AS3EII45 & (EMAP.EQ.0) &
       (ENBITS.EQ.0))) + (REM.EQ.7) & (ESO+EDO) & EII1
       & (EMAP.EQ.1) & (ENBITS.GT.8) & (ENBITS.NEQ.OC).

AS =   SCB & I-INST(1).
```

The E resource bits are generated according to the following Boolean equations:

```
EIOV  =  MLV&SI + ESI&MLV + MAS&(SOV+ADDSUB)&^ EII +
         IMO & SOV & AIDSID + (MUL+DIV)&^ EII
         + (ESOV+EDOV)&EII&(MAS+EIMO) +
         (KDIV+KMUL+KDIVP)&EII.

ER1   =  (RLB.EQ.1) & (SI&MLV + (MUL+DIV)&^ EII + SDO&^
         SC&^ EII&MAS&^ STM&^ BRG ERIMO & IMO + LXALSO
         & EII) + (REGN.EQ.1) & (MUL + DIV + STM + BIT4
         + LB) & RAS + (BIT4 + LB) & RAS &
         (I-INST(16-31).EQ.0) + (REN.EQ.1) & EEII &
         ERAS & EII1 & (I-INST(20-23).NEQ.OE).
```

```
ER3    =  (RLB.EQ.3) & (SI&MLV + (MUL+DIV)&^ EII + SDO&^
          SC&^ EII&MAS&^ STM&^ BRG ERIMO & IMO + LXALSO
&
          EII) + (REGN.EQ.3) & (MUL + DIV +STM + BIT4 +
          LB) & RAS + (REN.EQ.3) & EEII & ERAS & EII1 &
          (I-INST(20-23).NEQ.OF).

ES     =  GCS & ISI.
```

Description of A and E resource word equation terms:

```
RLB  = I-INST(0-3);
REGN = I-INST(13-15;
REN  = I-INST(29-31);
REM  = I-INST(25-27).
```

See other portions of Appendix for instruction abbreviations.

The RSRC registers are loaded according to the following case statement:

```
If ($CLK & Q120 & ^HOLD1 & I-EFIRST)
   THEN (CASE (EOUTPTR) OF (
        RSRC0 = ERSRC,
        RSRC1 = ERSRC,
        RSRC2 = ERSRC,
        RSRC3 = ERSRC)).
```

The EOUTPTR is updated according to the following case statement:

```
If ($CLK & Q120 & ^HOLD1 & I-EFIRSTX & ^LOADP)
   THEN (EOUTPTR = EOUTPTR.PLUS.1);
If ($CLK & Q120 & ^HOLD1 & LOADP)
   THEN (EOUTPTR = 0.
```

The RSRC registers are cleared according to the following case statement:

```
If ($CLK & Q120 & E-DONE-R & ^(I-EFIRST&^HOLD1 &
(EOUTPTR.EQ.EDONEPTR)))
   THEN (CASE (EDONEPTR) OF (
        RSRC0 = 0,
        RSRC1 = 0,
        RSRC2 = 0,
        RSRC3 = 0)).
```

The EDONEPTR is updated according to the following case statement:

```
If ($CLK & Q120 & E-DONE-R & ^LOADP) THEN
   (EDONEPTR = EDONEPTR.PLUS.1);
If ($CLK & Q120 & LOADP) THEN
   (EDONEPTR = 0).
```

The LOCK and STALL signals are generated according to the following Boolean equations:

```
LOCK   =  CRACK & ((RSRC0 + RSRC1 + RSRC2 + RSRC3) &
          ARSRC.NEQ.0 + (RSRC0(0-20) + RSRC1(0-20) +
          RSRC2(0-20) + RSRC3(0-20)).NEQ.0 & (IO + IOLD
          + GCS & (GENE & ^OGC + COMM))).

STALL  =  STALL1 + STALLX (external) + EMPTY (no
          instruction in buffers);
STALL1 =  LOCK + (LESTOP + RT6A + RT6E) & CRACK + EFULL
          & EINSTR & CRACK + (STORCNT.EQ.2) & EINSTR &
          CRACK &^EC-STCOMP + STATE4 & ADONE & ^CPCK &
          ^GNCK & ^RSCK & ^CSCK + RTV02 + RTV05 + RTV06
          + RTV12 + RTV13 + RTV14 + RTV16 + ISTL +
          CRACK & (SCB & RE-DONE1-E +LAOUT + LEOUT) +
          (RINT + RUN-OUT) & CRACK.
```

It will be obvious that many changes may be made to the apparatus and method of the present invention without departing from its teachings. For example, the resource conflict apparatus may be used in a pipelined processing unit which contains any number of stages which are capable of completing the execution of instructions with different instruction sets and shared resources.

While in accordance with the provisions and statutes there has been illustrated and described the best form of the invention, certain changes may be made without departing from the spirit of the invention as set forth in the appended claims and that in some cases, certain features of the invention may be used to advantage without a corresponding use of other features.

What is claimed is:




Claims

1. An instruction apparatus for detecting the presence of resource conflicts in a pipelined processing unit comprising a plurality of serially coupled pipeline stages, each stage for performing a different operation on each instruction to be processed by said processing unit, said instruction apparatus comprising:

instruction crack decode means for generating a number of sets of bit indications, each set containing a predetermined number of bits corresponding to a number of resource words for each new instruction fetched by said instruction apparatus, said resource words being coded to specify those resources required by a corresponding number of said stages capable of completing execution of instructions; and,

resource control means coupled to said instruction crack decode means, said resource control means including:

a number of register means for storing a corresponding number of said resource words specifying those resources being used by instructions currently under execution by said processing unit; and,

comparison means coupled to said register means and to said instruction crack decode means, said comparison means for comparing each of said bit indications generated by said decode means with corresponding bit indications of said resource words stored in said register means, said comparison means generating an output lock signal in response to an equal comparison between any two corresponding bit indications for indicating a resource conflict.

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2. The instruction apparatus of claim 1 wherein said instruction crack decode means includes logic circuit means in response to said output lock signal generating a stall signal for inhibiting the transfer of said each new instruction producing said resource conflict into said pipeline stages for execution.

3. The instruction apparatus of claim 1 wherein said number of register means are connected to receive a set of bit indications corresponding to one of said number of resource words for said each new instruction to be executed by a last one of said plurality of pipeline stages, said instruction apparatus further including first pointer means coupled to said register means and to said instruction crack decode means, said first pointer means specifying which one of said number of register means is to be loaded with said set of bit indications generated for each new instruction in the absence of said resource conflict.

4. The instruction apparatus of claim 3 wherein said crack decode means further includes means for generating a transfer signal in the absence of said resource conflict for transferring said each new instruction into said pipeline stages for execution and for incrementing said first pointer means to specify a next one of said number of register means.

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5. The instruction apparatus of claim 3 wherein said resource control means further includes second pointer means coupled to said register means and to said crack decode means, said second pointer means specifying which one of said register means stored the resource word corresponding to an instruction which is to be next completed, said crack decode means in response to each output signal from said last one of said pipeline stages indicating that an instruction has been completed modifying said second pointer means to point to said resource word corresponding to said instruction which is to be next completed.

6. The instruction apparatus of claim 5 wherein said resource control register means further includes means for clearing to ZEROS, said one of said register means in response to said each output signal.

7. The instruction apparatus of claim 1 wherein said number of stages which can complete the execution of instructions is two and said predetermined number of bits of each resource word include bits representative of resources required for both the initial processing and execution of said different types of instructions.

8. The instruction apparatus of claim 7 wherein said execution stages are an A-unit which is the stage adjacent to said instruction apparatus stage and an execution unit corresponding to said last stage.

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* C L M S *



9. The instruction apparatus of claim 7 wherein said resources include register resources used in the initial processing of said different types of instructions and indicator resources used for the execution of said different types of said instructions by said number of stages capable of executing instructions.

10. The instruction apparatus of claim 9 wherein said number of stages include different types of execution units and wherein said indicator resources are divided into a plurality of different classes according to use by said different types of execution units.

11. The instruction apparatus of claim 8 wherein an all ZEROS resource word for said execution unit is generated by said crack and decode means upon cracking an instruction whose execution is to be completed in said A-unit; an all ZEROS resource word is generated for said A-unit by said crack and decode means upon cracking an instruction whose execution is to be completed in said execution unit; and non ZEROS resource words are generated by said crack and decode means upon cracking an instruction which is to be partially executed in said A-unit and whose execution is to be completed in said execution unit.

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12. The instruction apparatus of claim 1 wherein said predetermined number of bits correspond to only those specific register and indicator resources which actually will produce a conflict so as to enable as many new instructions as possible to be transferred into said pipeline stages for execution.

13. The instruction apparatus of claim 1 wherein said crack decode means include means for detecting when said each new instruction is a complex instruction and generating an output signal for inhibiting cracking of any new instruction until said complex instruction has been completed.

14. A method for detecting the presence of resource conflicts in a pipelined processing unit comprising a number of serially coupled pipeline stages, each stage for performing a different operation on each instruction to be executed by said processing unit, said method comprising the steps of:

(a) storing in a number of resource registers of first stage of said pipelined processing unit, bit indications designating those resources being utilized by the instructions currently under execution by said pipeline stages;

(b) generating a number of sets of bit indications corresponding to a number of resource words for each new instruction to be processed which are coded to specify those resources required for executing said new instruction;

(c) comparing predetermined ones of said number of sets of bit indications with said stored bit indications;

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(d) generating a signal in response to an equal comparison between any two corresponding bit indications indicating a resource conflict for inhibiting the transfer of said new instruction into said pipeline stages;

(e) repeating step (c) and generating a signal when there is no equal comparison indicating the removal of said resource conflict;

(f) transferring said new instruction into said pipeline stages for execution in response to said signal indicating said no equal comparison in step (e); and,

(g) loading said signal indications of another predetermined one of said number of sets of bit indications into a next available one of said number of said resource registers.

15. A method for detecting the presence of conflicts in the use of resources required for executing instructions which are shared between a plurality of serially coupled stages of a pipeline processing unit, each stage for performing a different operation and each of a number of said plurality of said stages including means for completing the execution of one or more types of instructions, said method comprising the steps of:

(a) generating a different resource word for each of said number of stages which can complete the execution of said one of said different types of instructions, each resource word containing a predetermined number of bits, each representative of a different one of said resources shared between said plurality of said stages;

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(b) storing in a first one of said number of said plurality of stages, each resource word generated for each instruction whose execution is to be completed by at least a last one of said number of said plurality of stages;

(c) comparing said different resource words generated in response to each instruction received by said first one of said number of stages with said resource words stored in step (b); and,

(d) inhibiting said first stage from transferring said each instruction into a next one of said pipeline processing unit stages when there is a comparison between any two corresponding bit indications signaling a resource conflict.

16. The method of claim 15 wherein said number of stages which can complete the execution of instructions is two and said predetermined number of bits of each resource word include bits representative of resources required for both the initial processing and execution of said different types of instructions.

17. The method of claim 16 wherein said execution stages are an A-unit which is the stage adjacent to said first stage and an execution unit corresponding to said last stage.

18. The method of claim 16 wherein said resources include register resources used in the initial processing of said different types of instructions and indicator resources used for the execution of said different types of said instructions by said number of stages capable of executing instructions.

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19. The method of claim 18 wherein said number of stages include different types of execution units and wherein said indicator resources are divided into a plurality of different classes according to use by said different types of execution units.

20. The method of claim 17 wherein an all ZEROS resource word for said execution unit is generated in step (a) upon cracking an instruction whose execution is to be completed in said A-unit; an all ZEROS resource word is generated for said A-unit in step (a) upon cracking an instruction whose execution is to be completed in said execution unit; and non ZEROS resource words are generated in step (a) upon cracking an instruction which is to be partially executed by said A-unit and whose execution is to be completed by said execution unit.

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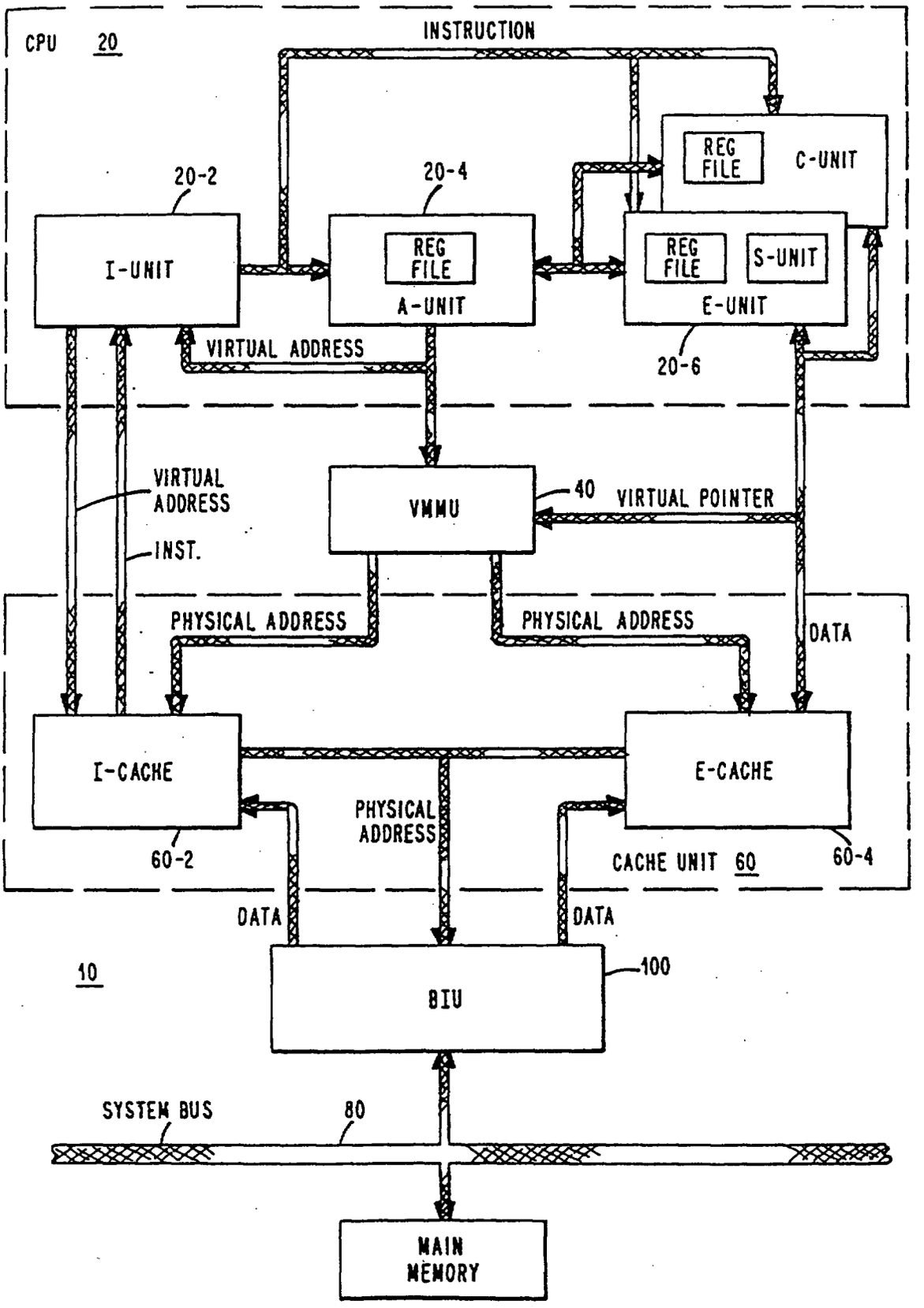

CPU 20
INSTRUCTION
REG FILE
C-UNIT
20-2
20-4
I-UNIT
REG FILE
A-UNIT
REG FILE
S-UNIT
E-UNIT
VIRTUAL ADDRESS
20-6
VIRTUAL ADDRESS
INST.
VMMU
40
VIRTUAL POINTER
PHYSICAL ADDRESS
PHYSICAL ADDRESS
DATA
I-CACHE
E-CACHE
PHYSICAL ADDRESS
60-2
CACHE UNIT 60
60-4
DATA
DATA
10
BIU
100
SYSTEM BUS
80
MAIN MEMORY

Fig. 1.

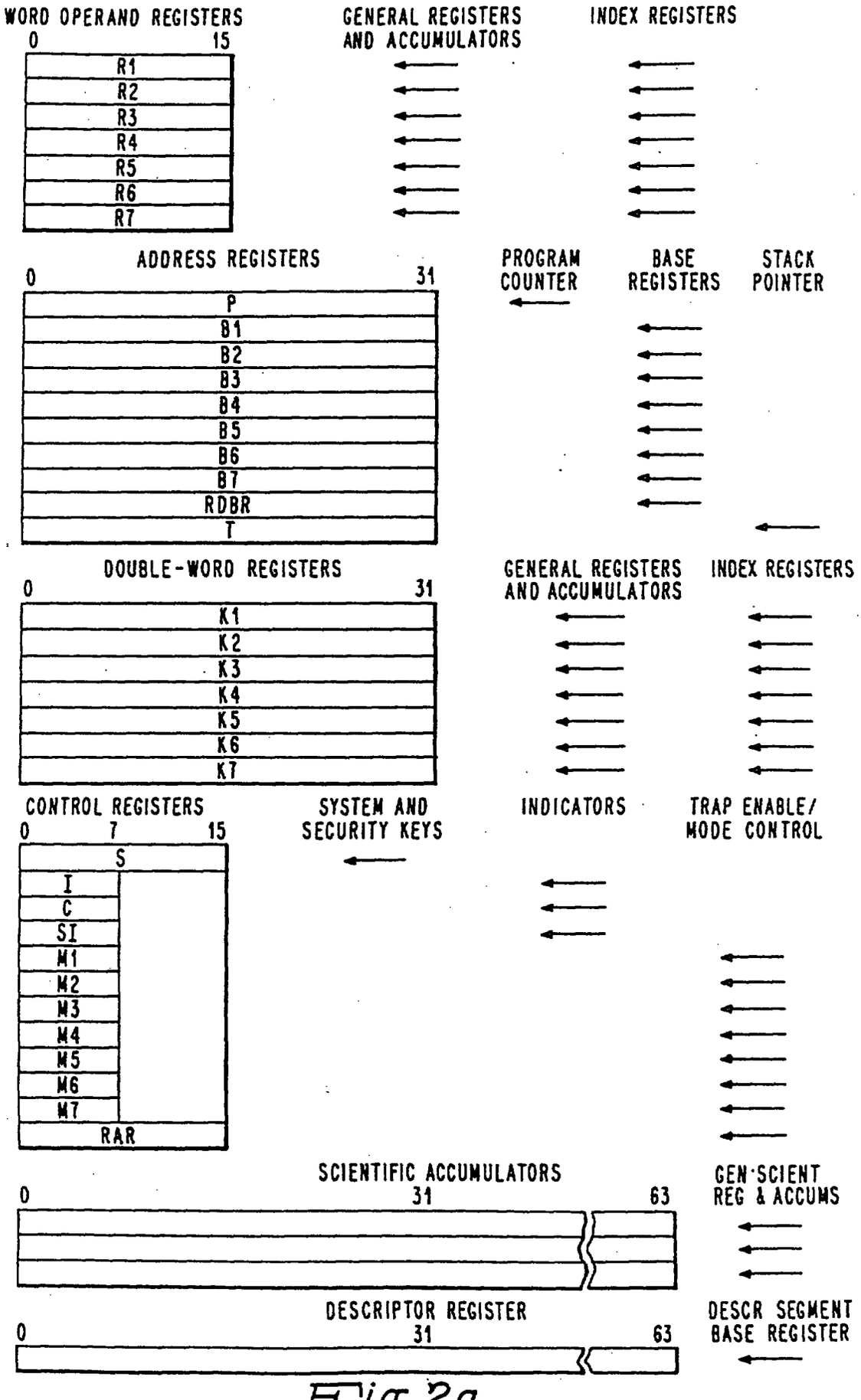

WORD OPERAND REGISTERS
0
15
R1
R2
R3
R4
R5
R6
R7
GENERAL REGISTERS AND ACCUMULATORS
INDEX REGISTERS
ADDRESS REGISTERS
0
31
P
B1
B2
B3
B4
B5
B6
B7
RDBR
T
PROGRAM COUNTER
BASE REGISTERS
STACK POINTER
DOUBLE-WORD REGISTERS
0
31
K1
K2
K3
K4
K5
K6
K7
GENERAL REGISTERS AND ACCUMULATORS
INDEX REGISTERS
CONTROL REGISTERS
0
7
15
S
I
C
SI
M1
M2
M3
M4
M5
M6
M7
RAR
SYSTEM AND SECURITY KEYS
INDICATORS
TRAP ENABLE/ MODE CONTROL
SCIENTIFIC ACCUMULATORS
0
31
63
GEN·SCIENT REG & ACCUMS
DESCRIPTOR REGISTER
0
31
63
DESCR SEGMENT BASE REGISTER

Fig. 2a.

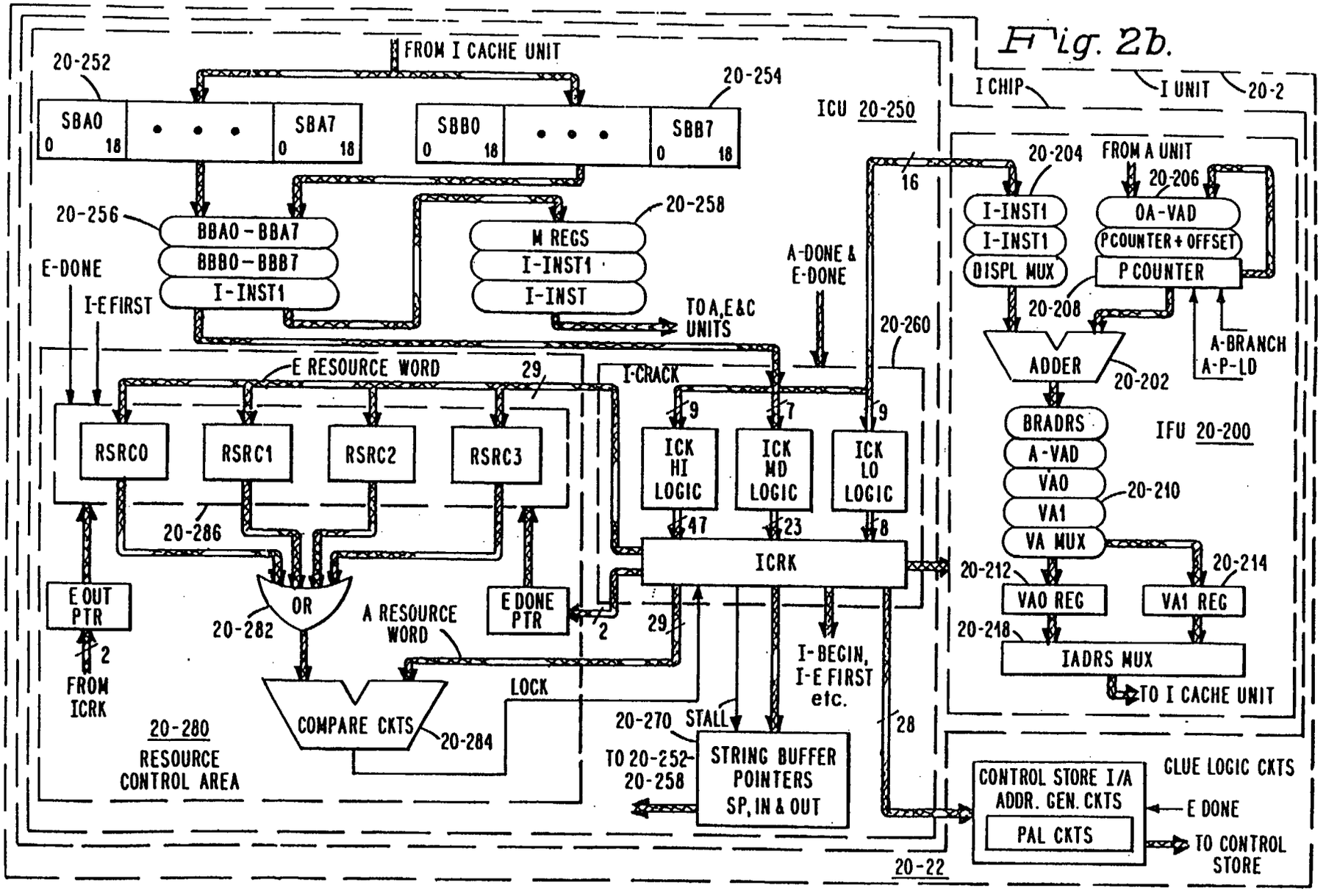

FROM I CACHE UNIT
20-252
SBA0
SBA7
20-254
SBB0
SBB7
ICU 20-250
I CHIP
I UNIT
20-2
20-204
FROM A UNIT
20-206
I-INST1
I-INST1
DISPL MUX
OA-VAD
PCOUNTER + OFFSET
P COUNTER
20-256
BBA0 - BBA7
BBB0 - BBB7
I-INST1
20-258
M REGS
I-INST1
I-INST
E-DONE
I-E FIRST
TO A,E&C UNITS
A-DONE & E-DONE
16
20-260
20-208
ADDER
20-202
A-BRANCH
A-P-LD
E RESOURCE WORD
29
I-CRACK
9
7
9
RSRC0
RSRC1
RSRC2
RSRC3
ICK HI LOGIC
ICK MD LOGIC
ICK LO LOGIC
BRADRS
A-VAD
VA0
VA1
VA MUX
IFU 20-200
20-210
47
23
8
ICRK
20-286
20-212
20-214
E OUT PTR
OR
A RESOURCE WORD
E DONE PTR
VA0 REG
VA1 REG
20-218
IADRS MUX
TO I CACHE UNIT
2
29
I-BEGIN, I-E FIRST etc.
FROM ICRK
20-282
LOCK
20-270
STALL
28
20-280
RESOURCE CONTROL AREA
COMPARE CKTS
20-284
TO 20-252-20-258
STRING BUFFER POINTERS SP, IN & OUT
CONTROL STORE I/A ADDR. GEN. CKTS
PAL CKTS
GLUE LOGIC CKTS
E DONE
TO CONTROL STORE
20-22

Fig. 2b.

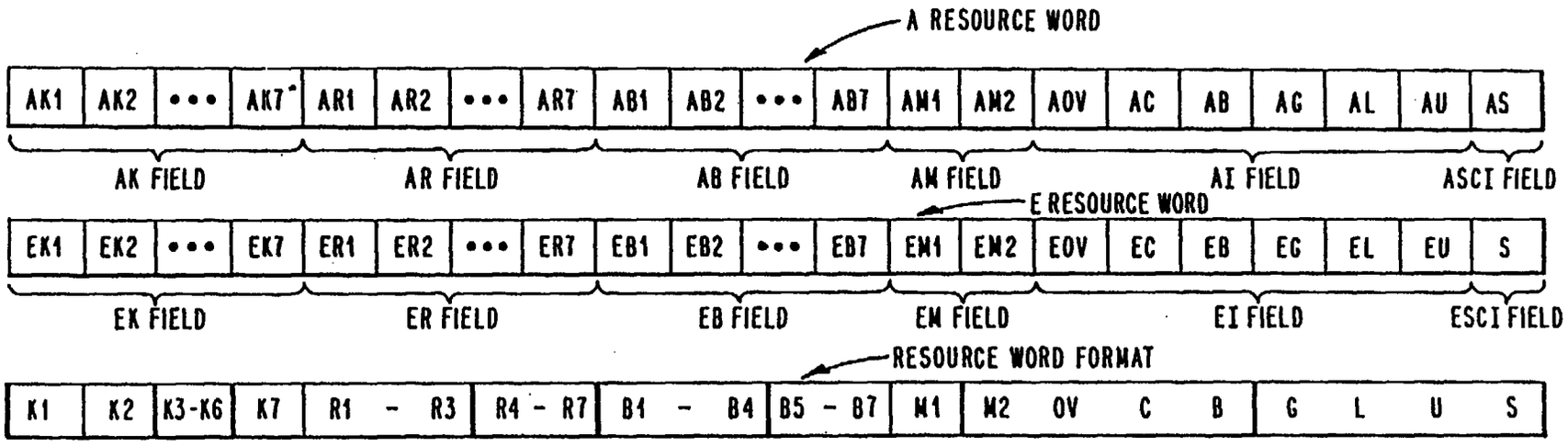

A RESOURCE WORD
AK1 AK2 ••• AK7 AR1 AR2 ••• AR7 AB1 AB2 ••• AB7 AM1 AM2 AOV AC AB AG AL AU AS
AK FIELD
AR FIELD
AB FIELD
AM FIELD
AI FIELD
ASCI FIELD
E RESOURCE WORD
EK1 EK2 ••• EK7 ER1 ER2 ••• ER7 EB1 EB2 ••• EB7 EM1 EM2 EOV EC EB EG EL EU S
EK FIELD
ER FIELD
EB FIELD
EM FIELD
EI FIELD
ESCI FIELD
RESOURCE WORD FORMAT
K1 K2 K3-K6 K7 R1 - R3 R4 - R7 B1 - B4 B5 - B7 M1 M2 OV C B G L U S

Fig. 3.

| INSTRUCTION | MNEMONIC | EXEC. UNIT |
|---|---|---|
| 9800 0000 0014 | LDR $R1, MEMVAL1 | E |
| A800 0000 0016 | LDR $R2, MEMVAL2 | E |
| 9A70 0008 | ADD $R1, #8 | A |
| B804 | LDR $R3, MEMVAL3 | E |
| 9A31 | ADD $R1, $R1.$R3 | E |
| B070 | SUB $R3, #1 | A |
| 0455 | BOV OVERFLOW | A |

Fig. 4a.

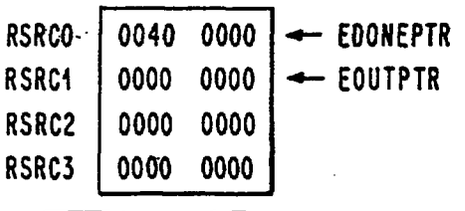



Fig. 4b.

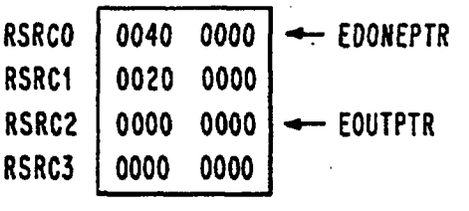



Fig. 4c.

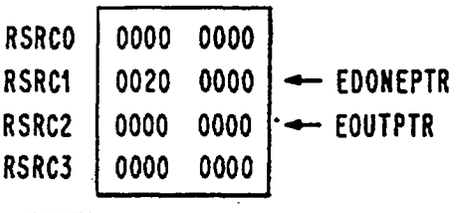



Fig. 4d.

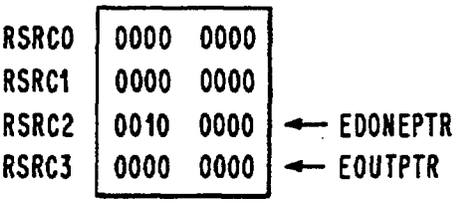



Fig. 4e.

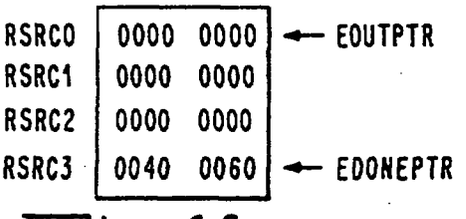



Fig. 4f.

## ABSTRACT

### RESOURCE CONFLICT DETECTION METHOD AND APPARATUS INCLUDED IN A PIPELINED PROCESSING UNIT

A pipelined processing unit includes an instruction unit stage containing resource conflict apparatus for detecting and resolving conflicts in the use of register and indicator resources during the different phases of instruction execution. The instruction unit includes a plurality of resource registers corresponding in number to the number of instructions which can be processed concurrently by the processing unit. Decode circuits in response to each new instruction received by the instruction unit generate one or more sets of bit indication signals designating those resources required by the specific pipeline stage(s) executing the instruction for completing the execution of the instruction which are shared by those stages capable of completing the execution of instructions. Comparison circuits compare the set of bit indication signals for each new instruction that corresponds to resources needed by an earlier pipeline stage which in the preferred embodiment corresponds to a secondary execution unit, with the stored sets of bit indication signals for determining the presence of any resource conflict.

(Figure 1)

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☑ Claim(s) : paged 39 to paged 44
☐ Drawing(s) : paged ..... to paged .....
☐ Abstract : paged ..... to paged .....

DATE OF RECEIPT 5/6/98



CLAIMS:

1. Resource conflict detection apparatus included in a pipelined processing unit comprising a plurality of serially coupled pipeline stages (20-2, 20-4, 20-6), each stage for performing a different operation on each instruction to be processed by said processing unit (20), wherein

- instructions are supplied to the first (20-2) of said stages in succession for execution;
- said processing unit (20) comprises a plurality of resources (Fig. 2a) usable by at least two of said stages in performing said operations.
- said first stage (20-2) comprises an instruction decoding means (20-260) for sensing and decoding each received instruction, and wherein
- said apparatus is provided for detecting and preventing potential conflicts in the requirements for use of said resources in said instructions;

said apparatus comprising:

- a plurality of registers (RSRCO-3), each holding data units representing the resources required by a decoded instruction;
- means for transferring data units generated by the decoding of an instruction to said registers;
- a comparator unit (20-282, 20-284) for comparing correponding bits of the data units stored in said registers and the data unit last generated by the decoding, and for generating an output signal when there is a match, and
- a circuit responsive to said output signal for causing the processing unit to inhibit execution of the instruction corresponding to the last generated data unit;

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characterized in that

said decoding means (20-260) when sensing each received instruction generates a data unit the individual bits thereof respectively represent one of said resources required for use by said instruction; wherein one of said data units is generated for each of a respective one of said stages capable of performing the last operation in the execution of one of the different types of instructions; and wherein said circuit causes said processing unit (20) to inhibit said first stage (20-2) from transferring the instruction corresponding to said last-generated data unit into a next one (20-4 or 20-6) of said stages.

2. The apparatus of claim 1 wherein said instruction crack decode means includes logic circuit means in response to said output lock signal generating a stall signal for inhibiting the transfer of said each new instruction producing said resource conflict into said pipeline stages for execution.

3. The apparatus of claim 1 wherein said number of register means are connected to receive a set of bit indications corresponding to one of said number of resource words for said each new instruction to be executed by a last one of said plurality of pipeline stages, said instruction apparatus further including first pointer means coupled to said register means and to said instruction crack decode means, said first pointer means



specifying which one of said number of register means is to be loaded with said set of bit indications generated for each new instruction in the absence of said resource conflict.

4. The apparatus of claim 3 wherein said crack decode means further includes means for generating a transfer signal in the absence of said resource conflict for transferring said each new instruction into said pipeline stages for execution and for incrementing said first pointer means to specify a next one of said number of register means.

5. The apparatus of claim 3 wherein said resource control means further includes second pointer means coupled to said register means and to said crack decode means, said second pointer means specifying which one of said register means stored the resource word corresponding to an instruction which is to be next completed, said crack decode means in response to each output signal from said last one of said pipeline stages indicating that an instruction has been completed modifying said second pointer means to point to said resource word corresponding to said instruction which is to be next completed.

6. The apparatus of claim 5, wherein said registers store data units for later stages in said series, and said comparator units compares corresponding bits of the data units stored in said registers

and the data unit for an earlier stage in said series last generated by said decoding member.

7. The apparatus of claim 6, wherein said resources include register resources used in the initial processing of said different types of instructions and indicator resources used for the execution of said different types of said instructions by said number of stages capable of executing instructions.

8. Resource conflict detection method in the use of resources required for executing instructions which are shared between a plurality of serially coupled stages (20-2, 20-4, 20-6) of a pipeline processing unit (20), each stage for performing a different operation and including means for completing the execution of one or more types of instructions, comprising the following steps:

a) supplying instructions to the first (20-2) of said stages in succession for execution where they are sensed and decoded;

b) generating data units by the decoding of an instruction;

c) transferring said generated data units to a plurality of registers (RSRCO-3) which hold data units representing the resources required by a decoded instruction;

d) comparing corresponding bits of the data units stored in said registers with corresponding bits of the data unit last generated by the decoding;

e) generating an output signal when there is a match; and

f) inhibiting the execution of the instruction corresponding to the last generated data unit;

characterized in that:

step b) comprises the generating of a different resource data word for each of said number of stages which can complete the execution of said one of said different types of instructions, each resource data word containing a predetermined number of bits, each representative of a different one of said resources shared between said plurality of said stages;

step d) comprises the comparing of said different resource data words generated during instruction decoding with resource data words stored in a first one of said number of said plurality of stages and being indicative for each instruction whose execution is to be completed by at least a last one of said number of said plurality of stages, wherein one of said resource data words is generated for each of a respective one of said stages capable of performing the last operation in the execution of an instruction; and

step f) comprises the inhibiting of said first stage (20-2) from transferring said each instruction into a next one (20-4 or 20-6) of said stages when there is a match between any two corresponding bits of said resource data words, thereby indicating a resource conflict.

9. The method of claim 8 wherein an all ZEROS resource data

word is generated for the execution unit of the last stage (20-6) upon instruction decoding when execution is to be completed in an address unit (20-4) positioned prior to said execution unit (20-6), an all ZEROS resource data word is generated for said address unit (20-4) upon instruction decoding when execution is to be completed in said execution unit (20-6); and NON-ZEROS resource data words are generated upon instruction decoding when said instruction is to be partially executed by said address unit (20-4) and then completed by said execution unit (20-6)

10. The method of claim 9 wherein said resources include register resources used in the initial processing of said different types of instructions and indicator resources used for the execution of said different types of said instructions by said number of stages capable of executing instructions.

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