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Manufacturing of 64-Bit Vliw Microprocessor

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Abstract-In the two decades since FPGAs introduced, the way which digital logic is designed and deployed has been radically changed. FPGAs have made possible entirely new types of applications. It is very important to design microprocessor as the part of core of electronic systems, so development and production. On making use of the technology of FPGA to design the microprocessor of logic function, it can quickly realize the function, complete design, cut down development cycle, save cost and quickly realize productions. The subject of the Paper is to design VLIW (is the abbreviation of "Very Long Instruction Word") microprocessor based on FPGA. It designs VLIW microprocessor which contains 64-bit instruction word and 192-bit data, each VLIW instruction word consists of three operations in parallel. The VLIW microprocessor can be designed using a pipeline technology of four stages, and have been implemented by taking advantage of the technology of FPGAs. According to the basic principle of VLIW microprocessor, it is rationally divided into five main modules: Fetch module, Decode module, Register file, Execute module, Write back module. Each main module is reasonably divided again, and realized the function of every module based on the principle of FPGAs, so as to implement five main modules.

INTRODUCTION

The objective is to design a 64-bit VLIW Microprocessor supporting the following instruction set: addition, subtraction and multiplication. Second objective is to model the dynamic branch prediction in 4-stage 64-bit microprocessor to achieve better throughput. Figure 1.1 shows the complete implementation steps in designing a processor. The programming objective of the pipelining fall into the following categories:

1. Accuracy: The application produces that results that are close to the correct results.
2. Performance: The application produces the most efficient code possible.
3. Latency: The application produces a single output with in less time.
4. Throughput: The application produces more number of tasks that can be completed per unit time.
5. Area: The application produces less number of flip flops and slices.

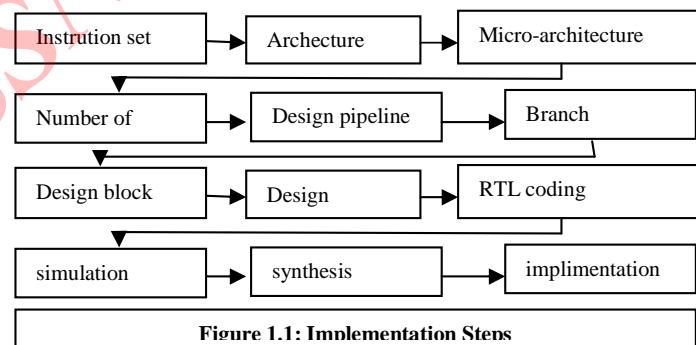


Figure 1.1: Implementation Steps

TOOLS USED

The tools used in the thesis are as follows:

Simulation Software:

1. Xilinx, 13.1 and design compiler are used for synthesis and analysis.
2. Modelsim 10.1 has been used for modeling and simulation.

Hardware used:

Xilinx Spartan 3E (Family), XC4VFX12 (Device), Tool used

HDL (Top Level Source Type), XST-VHDL/VERILOG (Synthesis Tool). ISE Simulator -VHDL/VERILOG (simulator) and Verilog (Preferred Language).

Table : Comparison between CISC, RISC, VLIW Architecture [11]

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VLIW (Very Long Instruction Word)

VLIW has been developed to exploit Instruction-Level Parallelism by using a long instruction word which contains multiple fixed numbers of operations. Those operations can be fetched, decoded, issued, and executed at the same time without causing any data or control hazards. Therefore, all operations within a single VLIW instruction must be absolutely independent. Very long instruction word (VLIW) describes a computer processing architecture in which a language compiler or pre-processor breaks program instruction down into basic operations that can be performed by the processor in parallel (that is, at the same time). These operations are put into a very long instruction word which the processor can then take apart without further analysis, handing each operation to an appropriate functional unit. VLIW is sometimes viewed as the next step beyond the reduced instruction set computing (RISC) architecture, which also works with a limited set of relatively basic instructions and can usually execute more than one instruction at a time (a characteristic referred to as superscalar). The main advantage of VLIW processors is that complexity is moved from the hardware to the software, which means that the hardware can be smaller, cheaper, and require less power to operate. The Crusoe family of processors from Transmeta uses very long instruction words that are assembled by a pre-processor that is located in a flash memory chip. Because the processor does not need to have the ability to discover and schedule parallel operations, the processor contains only about a fourth of the transistors of a regular processor. The lower power requirement enables computers based on Crusoe technology to be operated by battery almost all day without a recharge. The Crusoe processors emulate Intel's x86 processor instruction set. Theoretically, pre-processors

Architectures Characteristics	CISC	RISC	VLIW
Instruction Size	Varies	One size, usually 32Bits	One size
Instruction Format	Field placement varies	Regular, consistent placement of fields	Regular, consistent placement of fields
Instruction Semantics	Varies from simple to complex; possibly many dependent operations per	Almost always one simple operations	Many simple, independent Operations
Registers	Few, sometimes special	Many, general-purpose	Many, general-purpose
Memory References	Bundled with operations in many different types of Instructions	Not bundled with operations, i.e., load/store architecture	Not bundled with operations, i.e., load/store architecture
Hardware Design Focus	Exploit microcode Implementations	Exploit implementations One pipeline & no microcode	No complex design logic

could be designed to emulate other processor architectures.

Crusoe- Crusoe is a family of "smart" microprocessors from Transmeta that combines a relatively simple, low-powered hardware processor with software that makes the hardware processor look like an x86 Intel.

CONCEPT AND BENEFITS (VLIW)

In VLIW architecture, parallel execution of multiple instructions is made possible by issuing a long instruction word. A single long instruction word is designed to achieve simultaneous execution of a fixed number of multiple operations. Those operations must be independent of each other to avoid possible data hazards. Indeed, several

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independent instructions are integrated inside a very long instruction word.

Memory operation	ALU operation	ALU operation	Branch operation
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Figure: An Example of VLIW Instructions [16]

The VLIW instruction is wide enough to allow the concurrent operation of multiple functional units. Its size normally ranges from 64 to 128 bits, and even up to 1024 bits. Figure above shows a typical format of VLIW instructions. Many bits on the long instruction enable a single instruction word to sufficiently control the several functional units directly and independently in every cycle. Since it is the long instruction word which delivers the potential ILP to the hardware, a VLIW processor can be designed with a simpler hardware compared to an equivalent superscalar processor: it need not include the special units the run-time dependency check and instruction scheduling. The block diagram of a simple VLIW processor is shown in Figure below. VLIW architecture is, by essence, meant to activate multiple functional units at the same time. Therefore, the VLIW compiler should uncover independent operations to be executed in parallel. This means that the compiler must perform a detailed analysis on the data-flow and control-flow at compile time (which is when the potential ILP is fixed). Since the ILP within a basic block is quite limited, the VLIW architecture needs to examine more instructions to find more ILP. It is possibly achieved by looking at the instruction stream beyond the control-flow limits. For that purpose, several techniques such as loop unrolling and trace scheduling have been introduced in the VLIW design techniques. In addition, VLIW can uncover more parallelism by searching over a wider range of static code. Also, it is quite beneficial to know the source code

structure to find parallelism in the VLIW architecture. However, several limitations such as long compilation time, not enough compatibility, and code explosion make VLIW architectures difficult to use in practice [15]. In conclusion, we can say that VLIW architectures do not have the hardware complexity of current superscalar architectures. The two approaches in the current high-performance microprocessor design.

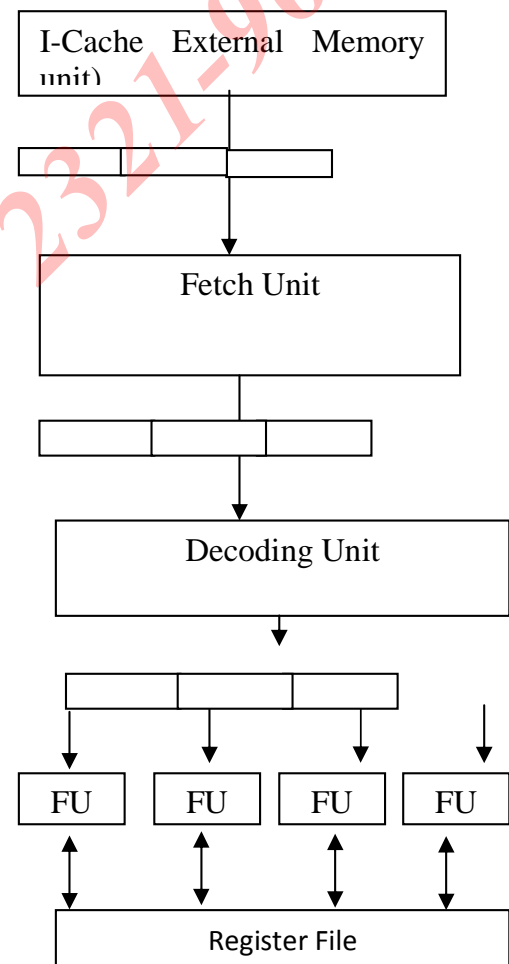


Figure: VLIW Hardware [16]

In the following Part, more detailed techniques for the VLIW architecture is explained. The key to higher performance in microprocessors for a broad range of

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applications is the ability to exploit fine-grain, instruction-level parallelism. [16]. some methods for exploiting fine-grain parallelism include:

- pipelining
- multiple processors
- superscalar implementation
- specifying multiple independent operations per instruction

Pipelining is now universally implemented in high-performance processors. Little more can be gained by improving the implementation of a single pipeline. Using multiple processors improves performance for only a restricted set of applications. Superscalar implementations can improve performance for all types of applications. Superscalar (super: beyond; scalar: one dimensional) means the ability to fetch, issue to execution units, and complete more than one instruction at a time. Superscalar implementations are required when architectural compatibility must be preserved, and they will be used for entrenched architectures with legacy software, such as the x86 architecture that dominates the desktop computer market. Specifying multiple operations per instruction creates a very-long instruction word architecture or VLIW. A VLIW implementation has capabilities very similar to those of a superscalar processor-issuing and completing more than one operation at a time-with one important exception: the VLIW hardware is not responsible for discovering opportunities to execute multiple operations concurrently. For the VLIW implementation, the long instruction word already encodes the concurrent operations. [17].This explicit encoding leads to dramatically reduced hardware complexity compared to a high-degree superscalar implementation of a RISC or CISC. The big advantage of VLIW, then, is that a highly concurrent (parallel) implementation is much simpler and cheaper to build than

equivalently concurrent RISC or CISC chips. VLIW is a simpler way to build a superscalar microprocessor.

PIPELINING AND BRANCH PREDICTION MECHANISM

It is a technique that allows for simultaneous execution of parts, or stages, of instructions to more efficiently process them. It is first introduced in IBM 7030 (Stretch Computer). 1986 was the first pipelined CISC processor. RISC processors in 80s were pipelined and were efforts to get IPC of 1. With a RISC processor, 1 instruction is executed while the next is being decoded and its operands are being loaded while the following instruction is being fetched all at the same time. shows the three, four and five stage VLIW Pipeline respectively.

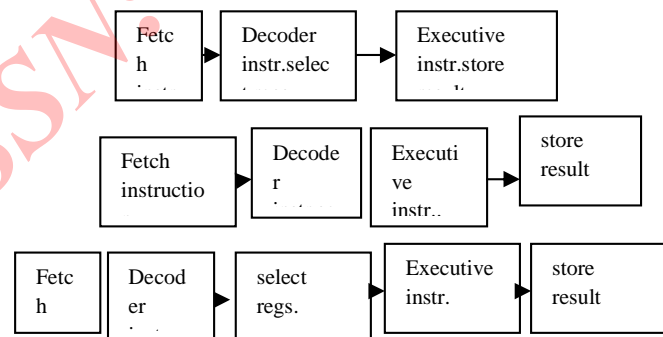


Figure: Three, Four and Five - stage VLIW Pipelines

Thus typical pipeline generally consists of four stages:

- Stage 1: Fetches instruction from memory.
- Stage 2: Decodes instruction and fetches any required operands
- Stage 3: Executes instructions
- Stage 4: Stores results

Each stage processes instructions simultaneously after a delay to fill the pipeline and this allows CPU to execute 1 instruction per clock cycle.

Apart from the CISC and RISC microprocessors, there has a different generation of microprocessor based on a concept

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called very long instruction word (VLIW). VLIW microprocessors make use of a concept of instruction level parallelism (ILP) executing multiple instructions in parallel. [18]. VLIW microprocessors have not the only type of microprocessors that take advantage of executing multiple instructions in parallel. Superscalar super pipeline CISC/RISC microprocessors are also able to achieve parallel execution of instructions.

PRINCIPLE OF PIPELINING

The basic principle behind pipelining is to allow to start the process of executing one instruction before the previous one has completed and it shows that even if there are delays in any one stage of the process for one instruction, it is still more efficient than non-pipelined processors. Figure 3.2 shows the processing of a sequence of instructions using a basic pipeline and Figure 3.3 shows the processing of a sequence of instructions using 4-stage pipelined.

- 1) Fetch
- 2) Decode
- 3) Execute
- 4) Writeback

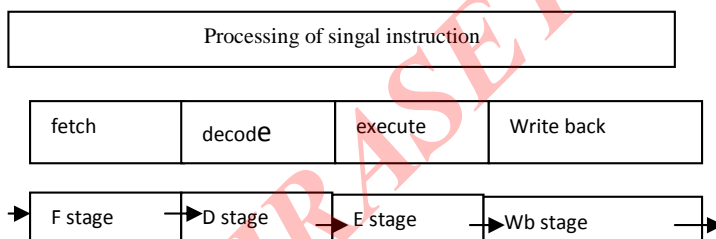


Figure 3.2: Processing of a sequence of instructions using basic pipeline [19]

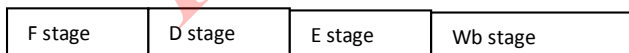


Figure: Processing of a sequence of instructions using a 4-stage pipeline. [19]

DESIGN ISSUES

Following are the design issues:

Cycle	In	In processing				Out finished
1 Cycle	Instr. 1	F1				
2 Cycle	Instr. 2	F2	D 1			
3 cycle	Instr. 3	F3	D2	E1		
4 cycle	Instr. 4	F4	D3	E2	Wb1	Instr.1
5 cycle	Instr. 5	F5	D4	E3	Wb2	Instr.2

- Data dependencies and branch instructions have to be handled carefully.
- Data dependency means next instruction depends on result of last one which has not taken place due to previous one in pipeline. Conditional jumps may be problem if last stage in pipeline and condition changes later after jump has been processed

Design issues – single cycle instruction

- Microprocessor stalled when instruction stage does not take one clock cycle.
- Stalling can be because of delays in reading from memory, poor instruction set design, dependencies between instructions.

Performance issues in Pipelined systems

- Memory speed - caches. Fast memory b/w processor and slower memory.
- Copy from main memory also kept in cache to speed up further references.
- Caches - problem of coherency. Results kept in cache must go to main before it is Read or deleted in cache.
- Instruction Latency: Poor instructions that may take more than one clock should be avoided.
- Highly encoded instructions that use complex decoders
- Variable length instructions with multiple references to memory.
- Instructions that access main memory.
- Complex instructions that require multiple clocks like floating point multiplication.
- Dependency Issues – If one instruction sets the conditions in the condition code Register and

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next tries to read those bits, 2nd has to wait for 1st to complete

- Instruction scheduling – and common sub expression elimination.

Pipeline Clock Rate

The clock rate of the pipeline and the CPU is limited to its slowest stage.

Example 1: 4 stage pipeline with delays of 20ns, 20ns, 100ns, 40ns.

The clock period must be at least 100ns to handle the delay at the 3rd stage (100ns). This Results in a maximum clock rate of 10MHz.

Thus, when all stages have same delay time, the pipeline will achieve maximum Performance.

The Speedup ratio (Sn) is expressed by this formula:

$$S_n = n * T_1 / (n + k - 1) * T_k$$

n = number of instructions

T₁ = time needed to process 1 instruction (non-pipeline) k = number of stages in the pipeline

T_k = clock period of the pipeline

Example 2: Let T₁ = 180 ns
(time needed to process 1 instruction) k = 4
(stages in the pipeline)

T_k = 50 ns (clock period of the pipeline)
Applying the formula, it results out as:

$$S_n = n * 180 / (n + 4 - 1) * 50$$

For steady state (n > ∞), the maximum speedup is S_n = 180 / 50 is 3.6. But in reality, the speedup would be slightly less than this for some reasons.

- The reason is that this does not account for the first few cycles needed to fill the pipeline; in addition the 180ns includes the time needed for the latches at the end of each stage. In a non-pipelined CPU, these

latches and their associated delays do Not exist and the actual time needed to process an instruction would be slightly less than 180ns.

- The other reason is pipelines do cause and encounter problems.
- One problem is memory access. A pipeline must fetch an instruction from memory in a single clock cycle but main memory usually is not fast enough to supply data quickly. RISC processors must include cache memory which is at least as fast as the pipeline. If the RISC CPU cannot fetch 1 instruction per clock cycle, it cannot execute 1 instruction per clock cycle. The cache must separate instructions and data to prevent memory conflicts from different stages of the pipeline.
- Another problem is caused by branch statements. When a branch statement is executed, the instructions already in the pipeline should not exist. They are instructions located sequentially after the branch statement and not the instructions to which the branch statement jumps. There is not much that the pipeline can do about this but instead an optimizing compiler is needed to reorder the instructions to avoid this problem.

FIELD PROGRAMMABLE GATE ARRAY

A field programmable gate array (FPGA) is a semiconductor device that can be configured by the customer or the designer after manufacturing hence the name “field-programmable”. Field Programmable gate arrays (FPGAs) are truly revolutionary devices that blend the benefits of both hardware and software. FPGAs are programmed using a logic circuit diagram or a source code in Hardware Description Language (HDL) to specify how the chip will work. They can be used to implement any logical function that an Application Specific Integrated Circuit (ASIC) could perform but the ability to update the functionality after shipping offers advantages for many applications. FPGAs contain programmable logic components called “logic blocks”, and a hierarchy of reconfigurable interconnects that allow the blocks to be

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“wired together” somewhat like a one chip programmable breadboard. Logic blocks can be configured to perform complex combinational functions or merely simple logic gates like AND and XOR. In most FPGAs, the logic block also includes memory elements, which may be simple flip flops or more complete blocks of memory. FPGAs blend the benefits of both hardware and software.

FPGA FOR FLOATING POINT COMPUTATIONS

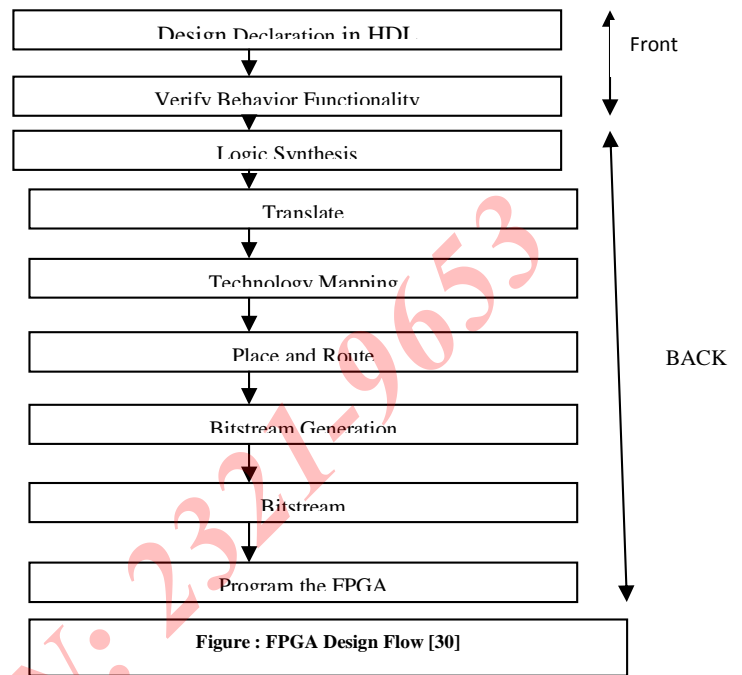
With gate counts approaching ten million gates, FPGA’s are quickly becoming suitable for major floating point computations. However, to date, few comprehensive tools that allow for floating point unit trade offs have been developed. Most commercial and academic floating point libraries provide only a small number of floating point modules with fixed parameters of bit-width, area and speed [18]. Due to these limitations, user designs must be modified to accommodate the available units. The balance between FPGA floating point unit resources and performance is influenced by subtle context and design requirements. Generally, implementation requirements are characterized by throughput, latency and area. FPGAs are often used in place of software to take advantage of inherent parallelism and specialization. For data intensive applications, data throughput is critical.

1. If floating point computation is in a dependent loop, computation latency could be an overall performance bottleneck.

FPGA IMPLEMENTATION

The FPGA that is used for the implementation of the circuit is the Xilinx Spartan 3E (Family), XC4VFX12 (Device). The working environment/tool for the design is the Xilinx ISE 13.1 is used for FPGA Design flow of Verilog code.

FPGA DESIGN FLOW



otherwise modifications and necessary corrections will be done in the HDL code. This is called as the behavioral simulation.

PROPOSED ARCHITECTURES

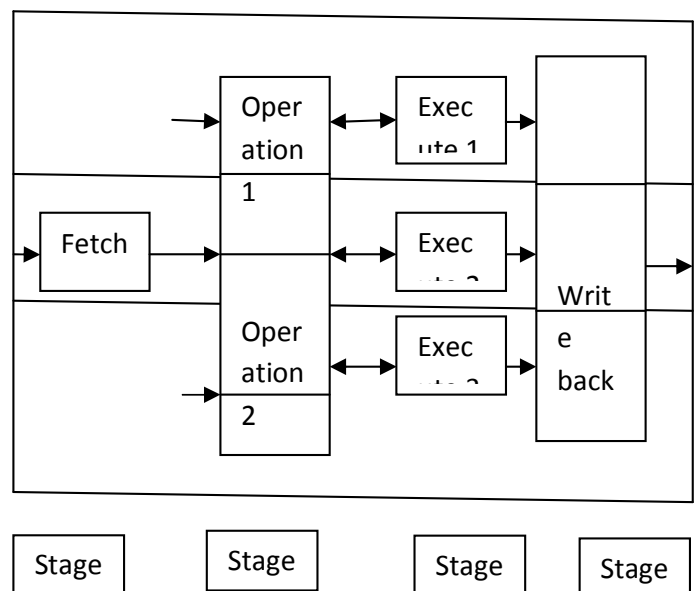


fig: Block Diagram of Proposed Architecture. [31]

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CONCLUSION

A design of 4-stage 64-bit VLIW microprocessor performing arithmetic, logical and compare operation and branch instructions is presented in this paper. According to the basic principle of VLIW microprocessor, it is rationally divided into five main modules. Such as fetch module, decode module, register file, execute module, write back module. Each main module is reasonably divided again, and realized the function of every module based on the principle of FPGAs, so as to implement five main modules. At last, the whole function of VLIW microprocessor is completely finished. It completes the data of empty operation, addition, subtraction, multiplication, load, and move, read, comparison, XOR, NAND, NOR, NOT, shift left, shift right, barrel shift left, barrel shift right in VLIW Microprocessor.

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