APEmille: a parallel processor in the teraflop range

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APEmille is a SIMD parallel processor under development at the Italian National Institute for Nuclear Physics (INFN). It is the third machine of the APE family, following Ape and Ape100 and delivering peak performance in the Tflops range. APEmille is very well suited for Lattice QCD applications, both for its hardware characteristics and for its software and language features. APEmille is an array of custom arithmetic processors arranged on a tridimensional torus. The replicated processor is a pipelined VLIW device performing integer and single/double precision IEEE floating point operations. The processor is optimized for complex computations and has a peak performance of 528Mflop at 66MHz. Each replica has 8 Mbytes of locally addressable RAM. In principle an array of 2048 nodes is able to break the Tflops barrier. Two other custom processors are used for program flow control, global addressing and inter node communications. Fast nearest neighbour communications as well as longer distance communications and data broadcast are available. APEmille is interfaced to the external world by a PCI interface and a HIPPI channel. A network of PCs act as the host computer. The APE operating system and the cross compiler run on it. A powerful programming language named TAO is provided and is highly optimized for QCD. A C++ compiler is foreseen. The TAO language is as simple as Fortran but as powerful as object oriented languages. Specific data structures, operators and even statements can be defined by the user for each different application. Effort has been made to define the language constructs for QCD.

1. INTRODUCTION

APEmille is a parallel processor oriented to the lattice calculation and suitable for massively parallel homogeneous problems. It is a SIMD array processor with local addressing capability and has a tridimensional toroidal topology with efficient communications.

APEmille is the third computer of the APE family, currently under development. The previous ones - Ape and Ape100 - had similar characteristics, although they did not support many APEmille capabilites, first of which the local addressing and the hardware double precision, and although they were much less powerful: in fact APEmille peak power is in the teraflop range, while Ape100 was a 100Gflop machine and Ape was a 1 Gflop one.

The main target of this machine is the quantum chromo dynamics simulations, and big effort has been made to optimize the performance in that area and to achieve easy programmability by tuning the programming language with some QCD oriented extensions. Nevertheless many other applications are good candidates both for the machine architecture and the programing environment: fluid dynamics, seismic migration, atmosphere, neural networks.

2. ARCHITECTURAL STRUCTURE

APEmille is based on a number of architectural keypoints:

- it is a Single Instruction Multiple Data (SIMD) machine, in fact each node performs the same instruction at the same time on its own data;
- it is based on Very Long Instruction Word (VLIW) processors, in which each field of the instruction word drives a different internal device of the processor, thus exploiting internal parallelism;
- it has a Harvard architecture, in fact program memory and data memories are physically different; the data memory is distributed, each node has its own one;
it is based on the replication of three custom processors, named Tarzan, Jane and Cheetah: Tarzan, which is replicated every eight nodes, drives the program flow and issues the global addressing to its nodes; Jane is the node processor and is capable of floating point as well as integer computations; Cheetah is the communication processor and is replicated every eight nodes as well.

Tarzan drives the program flow for all the nodes taking into account global conditions (results of its own computations) as well as aggregate evaluation of local conditions (those computed by the Janes). Tarzan computes global addresses and delivers them to the nodes.

Jane is capable of performing the basic operation $a \times b + c$ called normal which can have either real or complex operands. In fact Jane can manage real and complex numbers in hardware. Real numbers can be both in single and double precision, while the hardware representation of complex numbers is single precision. Jane is capable of starting a new normal operation at each clock cycle and has an eight stage pipeline for double precision numbers and a six stage one for single precision. Integer, logical and bitwise operations are performed in shorter pipes. Jane has local addressing capability: in fact every node can add a different local offset to the global address provided by Tarzan.

Cheetah can perform first neighbour and longer distance homogeneous communications (in which the distance between senders and receivers is the same for all nodes), broadcast communications (in which only a few nodes are senders, while all the others are receivers), and - not in the first APEmille release - unhomogeneous communications, in which each node can send (or ask for) data to (from) a node at an arbitrary distance. In the last kind of communications conflicts on the destinations may occur, so this communication model will require some additional hardware in the Cheetah processors.

APEmille to upload programs, upload/download data and run all the software tools. Either the host or a specialized device (such as a disk array accessible via HIPPI) can be used for mass storage.

3. HARDWARE CHARACTERISTICS

APEmille is scalable from eight processing nodes up to 2048. In fact eight nodes are assembled on the same board together with their communication and driving logic, so only multiples of eight nodes are possible. The eight nodes are connected as if they were on the vertices of a cube, in a $2 \times 2 \times 2$ configuration. Intermediate size machines will have $2 \times 2 \times 8$, $2 \times 8 \times 8$ and $8 \times 8 \times 8$ configurations. The full APEmille configuration is $32 \times 8 \times 8$. The APEmille custom processors are designed by the APE Group and implemented as standard cell ASIC design methodology.

Tarzan is only capable of integer computations and has a dedicated device for address computation, the AGU (Address Generation Unit). Tarzan has a register file (multiport internal RAM) with 64 register (32 bits each). It has its own static data memory and drives the program memory, which also feeds Jane with microcode. SDRAM (synchronous dynamic RAM) technology is used for program memory.

Jane is capable of integer and floating point computations. It has a 512-deep register file with five ports: three output ports (used for the three operands in a normal operation), one input port (to store the result) and one input/output port (to exchange data with memory or with the other nodes). At each clock cycle Jane is capable of starting one normal operation and exchanging one 32 bit word with the external world. The memories used for Jane data are SDRAM.

Cheetah is a bitsliced device: four identical chips are required on each board to drive the communication of the 32bit words exchanged among the Janes. Each chip manages one quarter of the word.
Table 1
APEmille peak performances and memory sizes

|                  | Peak performances (flop/s) | Data memory size (bytes) |
|------------------|-----------------------------|-------------------------|
|                  | 66MHz clock cycle | 100MHz clock cycle | Min   | Max   |
| Node             | 528M                     | 800M                    | 8M    | 32M   |
| Board            | 4.224G                   | 6.4G                    | 64M   | 256M  |
| Subcrate         | 16.9G                    | 25.6G                   | 256M  | 1G    |
| Crate            | 67.5G                    | 102.4G                  | 1G    | 4G    |
| Tower            | 270G                     | 409.6G                  | 4G    | 16G   |
| APEmille         | 1.081T                   | 1.6T                    | 16G   | 64G   |

4. APEmille NUMBERS

APEmille clock frequency is 66MHz in the first release and will be 100MHz in the final release. As Jane is capable of starting a new normal operation each clock cycle, it performs 66M up to 100M normal operations per second. When dealing with complex numbers, a normal operation consists in 8 floating point operations, so Jane’s peak power is 528Mflop/s in the first release and 800Mflop/s in the final one. These numbers are especially valid for QCD. Performances for the different configurations are described in table 1. The nodes’ memory sizes of the different configurations are described in the table as well. The program memory is 512KWords 176 bits each (due to the VLIW architecture). Tarzan data memory is a 256Kbytes static RAM. The APEChannel will be driven by a 33MHz clock, thus providing a bandwidth of 133MB/s.

5. SOFTWARE AND LANGUAGES

Three kinds of software tools will be provided with APEmille. The first are the language related tools: cross compilers, optimisers, libraries. The second ones are the Operating System related tools, i.e. the OS itself, the monitor program, and the graphic symbolic debugger. The last group is composed of the simulator and the graphic profiler. Part of this software is already working: the compilation chain, from the assembler down to the machine dependent optimizer, is already producing executable code that runs on the simulator in a single board configuration. Part of the operating system is supporting the simulator work. The machine independent optimizer is being developed and will be the core of the APEmille high level language compilers. Two compilers are foreseen, the TAO compiler and a C++ compiler. TAO is the APE extensible language with fortran flavour. This language allows the user to define new operators and new statements or overload old ones. This means that it is possible to extend the TAO language toward an application oriented language so that codes become shorter, more comprehensible and need less comments and documentation. Moreover maintenance and upgrade of application codes becomes easier. An example of extension, on which we spent much effort, is the QCD header file. This file, included by QCD application programs, extends the TAO language with data structures suitable for the QCD (like spinor, su3 etc.) and operators applicable to these data types.

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