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The Benefit of F.P.G.A. Technology for Petroleum Reservoir Engineering

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Abstract

The Petroleum Reservoir Simulators is the main tool and the most important component of the Reservoir Management. Reservoir simulation has a history almost as old as the history of computers. So, the major limitation simulations have today is directly linked to the limitation of the computational power of the classical PC's, workstation or supercomputers.
This paper presents how the new and revolutionary hardware as F.P.G.A. is (Field of Programmable Gates Arrays) can solve the simulation algorithms. The theoretical approach is based on the experimental results made by the author using QQ FPGA PCMCIA hardware.

Key words: *Petroleum Reservoir Simulation, Parallel programming, Reconfigurable computer, Hardware programming, FPGA.*

Introduction

Reservoir simulation has a history almost as old as the history of computers. Many of the basic numerical techniques for solving simple problems of flow through porous media developed in the 50's continue to be used. In the 60's, techniques started appearing for the solution of three-phase, three-component problems that form the basis of modern black-oil models. The next major shift occurred in the 70's and early 80's, as simulators became robust enough to move out of the research laboratories and onto the desktops of practicing reservoir engineers. Since the mid 80's, reservoir geostatistics has created a new opportunity in the science of modeling reservoir performance.

Now, the modern simulators working with millions of block-cells need huge computational resources as well very sophisticated algorithms.

Mainly, there are 2 ways to considerably increase the computational power of the existed computers and workstations:

i) Multi CPU (MCPU) powerful workstations try to solve the problem of the huge need of computation work by using many CPU installed on the same motherboard system. Using the parallel algorithms these powerful workstations have considerably reduced the required time for a simulator to complete the project. However the number of CPU's involved to solve the problem is strictly limited today by the technology (the powerful workstation has limited its CPU number from 16 to 64).

ii) Massively Parallel Processing (MPP) computer technology, employs hundreds or thousands of commodity CPU's, interconnected via a fast network, to solve a single complex problem simultaneously. This is in contrast to the conventional supercomputers where a single or few proprietary CPU's collaborate to solve the same problem. The MPP technology readily provides a path for growth for reservoir simulation at a superior price performance. Substantial increases in storage capacity and processing power are making very detailed reservoir descriptions a practical reality. Thus, a problem that may be so large that long run time leads to loss of engineering productivity can be readily addressed with additional processors.

The limitation of this technology (clustering technology) is mainly generated by the fact that each particular computer component of so call "clustering system" communicates with relatively low speed compared to the CPU's processing speed. So, most of the time saved by using hundreds of CPU is spent in the intercommunication network. Therefore, the final speed earning is no so large as as in theory.

Field Programmable Gates Arrays (F.P.G.A.) implementation to the modern simulators

FPGA is a hardware built by millions of unlinked logical gates and assisted by memory system and the time base. More or less FPGA is similar with the classical CPU but has its logical gates unlinked. In the computer community, the FPGA is known as "Reconfigurable Computers". The most powerful computer that has ever existed was recently built for the need of Johnson Space Center, US using FPGA technology. In 2000, it was reported for the first time by the author the advantage of using this technology in the field of Petroleum Reservoir Simulation. The power of the machine built based on this technology comes from the fact that the logical gates are linked so that they form an equivalent logical schema of the algorithm. This is the "hardware" programming technique. It is well known that the most rapid way to electronically solve an algorithm is to implement it into (hardware) logical schema.

One of the most computational consuming inside the simulator is the huge system of equations solving part. Fortunately this part can be massively paralleled so that many processes may run independently. Considering the following system of equation (m eq. with n unknowns):

$$\begin{bmatrix} a11 & a12 & \bullet & \bullet & a1n \\ a21 & a22 & \bullet & \bullet & a2n \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ an-1,1 & an-1,2 & \bullet & \bullet & an-1,m-1 \\ an,1 & an,2 & \bullet & \bullet & an,m \end{bmatrix} \times \begin{bmatrix} x1 \\ x2 \\ \bullet \\ xn-1 \\ xn \end{bmatrix} = \begin{bmatrix} b1 \\ b2 \\ \bullet \\ bn-1 \\ bn \end{bmatrix} \tag{1}$$

then the following iterative formula can be used in order to solve the system of equation:

$$x_i^{(\nu+1)} = \frac{1}{aii}\left[bi - \sum_{j=1}^{n} a_{i,j} \cdot x_j^{(\nu)}\right] \tag{2}$$

This iterative process can be massively paralleled in the following way:

- computational process of each unknown does not depend on the other (n-1) unknowns on the previous iterative level so this process can be considered as parallel;
- error verification process is a serial one, but it is a small computational resources consumer.

In other words, as much equations the system contains, as large parallel process can be identified. For one huge system of equation with one million of eq., theoretically, one million of parallel processes will result. Using the classical computer, all these parallel processes are treated serially, so the process is great time consuming.

The following schema shows the parallel processes identified in the iterative equation solving technique:

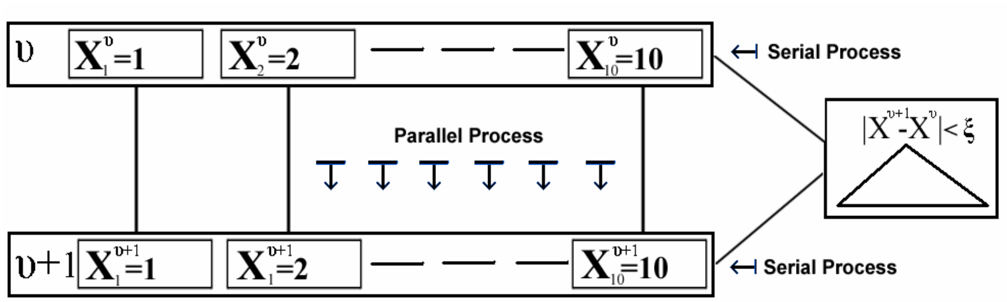

Fig. 1. The solving system of equation flowchart

Considering the simple case of 10 equations with 10 unknowns (as shown in figure 2), the iterative process will work as fellow:

- starting the process supposing any (randomize) data for unknowns (parallel process);
- correction the unknowns using the iterative formula 2) (parallel process);
- checking errors (serial process);
- if the error is under the accepted level, the iterative process is stopped;
- if not, then the iterative process starts again.

In this simple iterative process, the most of sub-units are independent so it can be implemented (each) as separated to one F.P.G.A logical block. So, for this simple case 10 F.P.G.A logical block have to be built so that the correction iterative process showed be run at the same time. This simple approach generates the hardware that solves the system of equation 10 times faster as compared to the regular computer having one CPU solving this process serially.

If we think that in the real simulators the system of equation has hundreds of thousands of unknowns, we understand better the benefits of using this new technology in Petroleum Reservoir Simulation. Today, the FPGA has millions of logical gates, so we can easily built thousands of separated logical blocks as in the simple example presented. So, the simulator built on this technology can easily reach computational power thousands times bigger as compared to the most powerful existing workstation.

Advantages of FPGA technology are:

- very high speed compared to the most powerful computer ever built using the classical technology (CPU) - 1000 times and more;
- high speed processing compared to the parallel machines - 100 times and more;
- real time reconfigurable hardware;
- acceptable cost.

The required steps for F.P.G.A project are as follows:

- identifying the processes which can be paralleled from the general algorithm;
- building the hardware object for these processes;
- implement the hardware object to FPGA;
- build the interface between FPGA and regular computer or workstation;
- run the project.

In the future, the Reconfigurable Computers (RCs) will combine the flexibility of traditional microprocessors with the power of Field Programmable Gate Arrays (FPGAs). The designers of powerful simulator will not be the only specialists in the Oil and Gas area, but also in electronics. Probably they have to have solid knowledge of Verilog, Xilinx ISE tools, VHDL, HSPICE, Synopsys Design Compiler, and so on.

Nevertheless, theoretically, the FPGA project for Petroleum Reservoir Simulation is now possible to be built, some obstacle remaining, such as the requirement of a large multidisciplinary team to work for understanding Petroleum Reservoir.

Nomenclature

a_{ij} - the unknowns coefficients;
b_i - the free term coefficients;
m, n - number of eq. and unknowns respectively
$\mathbf{X}_i^{\upsilon}$ - unknowns from X_1 to X_n at current iteration level;
$\mathbf{X}_i^{\upsilon+1}$ - unknowns from X to X at next iteration level;
ξ - level of the error.

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Beneficiile tehnologiei F.P.G.A pentru ingineria de zăcământ

Rezumat

Simularea exploatării zăcămintelor de petrol este instrumentul principal din cadrul categoriei multidisciplinare care a apărut relativ recent şi se numeşte " Managementul Zăcământului de Petrol".
Prin urmare acurateţea predicţiei evoluţiei unui zăcământ de petrol este dată de performanţele "Simulatoarelor" cu care se opearează iar acestea, la rândul lor, au performanţele strict legate de platforma hardware pe care funcţionează.
Această lucrare prezintă o nouă abordare a simulatoarelor utilizând, de data aceasta, tehnologia F.P.G.A (Field of Programmable Gates Arrays). Această abordare teoretică are la bază rezultatele experimentelor pe care autorul le-a efectuat pe carduri FPGA de tip QQ PCMCIA.