Parallel Reservoir Simulation Based on Domain Decomposition Techniques

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Abstract. We have studied parallelisation methods for the pressure equation in the reservoir simulator FRONTSIM *** for three-dimensional reservoirs. In order to obtain a faster simulator and finer resolution, we have studied the use of domain decomposition methods combined with the use of parallel processing. Both the additive and multiplicative Schwarz methods have been implemented together with coarse grid solver techniques. The code is parallelised using the PVM message passing library for communication and has been tested on a cluster of workstations as well as on a tightly coupled multiprocessor machine. This effort is part of the EC-ESPRIT III / EUROPORT2 project. Some implementational results are given.

1 Introduction

The reliability of a reservoir model depends on the level of details in critical areas. To be able to exploit oil fields with only marginal economics, more reliable results are needed. Therefore, for future planning of oil fields, larger models are needed. One would like to be able to run models with up to one million grid blocks. Currently, such large models can only be run in parallel on a number of processors. FRONTSIM, developed by Technical Software Consultants AS (TSC), is a software package for petroleum reservoir simulation. FRONTSIM is rather fast on a large class of reservoir problems, and therefore it has been natural to develop a parallel code for FRONTSIM in order to apply it on models with up to several million grid blocks. Acceptable simulation time for such problems is important for the planning of future oil fields.

2 Code Description

The simulator FRONTSIM [2, 5] handles compressible, two-phase, black-oil problems for two- or three-dimensional heterogeneous reservoirs. The problem is dis-

*** FRONTSIM is developed by TSC AS.

cretised using the finite element method. An important part of the simulator is the solution of the pressure equation of incompressible flow which reads

$$\nabla \cdot \mathbf{u}_T = Q$$

where $\mathbf{u}_T = -\lambda_T K(\nabla P - \rho_T g \nabla D)$, K is a permeability tensor, λ_T is the total mobility, ρ_T is the average density, g is the gravitational acceleration, D is the vertical distance in the reservoir, and Q is the source term for the wells.

Discretisation of the equation gives a symmetric and positive definite matrix so that e.g. the method of conjugate gradients (CG) can be used to solve the resulting system of linear equations. In order to obtain faster convergence, especially in the case of larger problem sizes, the general strategy is to use an effective preconditioner.

2.1 Code Structure Outline

The main parts of FRONTSIM are the pressure and the saturation solvers. For a three-dimensional case, the pressure solver in the serial version of FRONTSIM typically uses 50–90% of the total CPU time, most in the case of compressible flow. As the problem size increases, the pressure solver part is also increasing. The underlying reason for this is that the pressure solver uses a three-dimensional grid where the computational work is growing very rapidly as the problem size is increased. The computational work in the saturation solver, however, normally grows proportional to the surface of the oil/water interface. This is the unique feature of the FRONTSIM package, and leads to increased accuracy in describing the interface and to less computational work in the saturation part of the solution procedure.

More important than the growth of the computational work, is the growth of the memory requirements as the problems are refined. Again, this growth is more severe for the pressure solver than for the saturation solver. Hence, the memory requirements of the pressure solver together with the computational work are the major bottlenecks for simulating larger problems for the end-users of FRONTSIM. Hence, in porting this code to a parallel platform we have focused on parallelising the pressure solver, and we have limited ourselves to the incompressible cases.

The FRONTSIM code can be divided into four basic blocks in addition to the initialisation part as formulated in Algorithm 1.

Algorithm 1 (Main loop of the FRONTSIM code)

Initialisation (1)
for *each time step*
  Assemble the matrix of the linear system for solving the pressure equation (2)
  Solve the pressure equation (3)
  Compute the velocity field and other pressure dependent parameters (4)
  Solve the saturation equation (5)
end for