Development of Parallel Climate/Forecast Models on 100 GFLOPS PARAM Computing System

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ABSTRACT

The Climate Models T21 / T42 and Forecast Models T80 / T126 are ported on the Parallel Computing system PARAM10000. The global spectral models have been parallelised on the distributed memory parallel computer with a large number of Ultrasparc II processors. The accuracy / computational efficiency for the results is demonstrated and benefits of PARAM 10000 for Numerical Weather Prediction are emphasized.

1. Introduction

The Climate is usually defined as a set of averaged quantities that characterise the structure and behaviour of the atmosphere, hydrosphere and cryosphere over a period of time. One of the tools for understanding the climate and weather (the state of the atmosphere at an instant of time) is the mathematical model based on the observed physical processes and the laws governing them. A hierarchy of the mathematical models are now available in the literature[1,2], amongst them, the atmosphere and ocean General Circulation Model is widely used. This model is very general, includes adequate physics and is strongly linked to the radiation. The ground rules governing the climate and weather are similar and differ in the complex interaction between, as well as changes within, all the components of the climate system viz. the atmosphere, ocean, land, sea, ice, snow and terrestrial and marine biota.

Numerical Weather and climate Prediction involves solving a system of coupled nonlinear partial differential equations with appropriate boundary conditions. The predictions can range from short (up to three days) to long (up to a month). The climate modeling extends much beyond this limit.

Understanding the atmospheric variations and interpreting the continuing complex flow behavior has been now possible using present day computers. The capabilities for such predictions are strongly linked to socio-economic national growth and technological innovations. In order to reinforce the need to support thrust research areas, India has designed and developed a 100 GFLOPS High Performance Computing System, PARAM 10000, to tackle important scientific challenges on a priority basis and Numerical Weather Climate Prediction is one such task.

2. PARAM 10000

Centre for Development of Advanced Computing (CDAC) is a national initiative in supercomputing under the support and guidance from Department of Electronics, Government of India. At the end of two successfull missions, it has evolved to the open frame architecture for scalable and flexible High Performance Computing in the form of PARAM 10000 supercomputer with UltraSparc II as the processing nodes. Earlier, the processing nodes of PARAM have been Transputers, i860, SuperSparc, DEC Alpha and UltraSparc I. With the improved processing capabilities, the different PARAM models also led to a very stable compute environment and parallel processing protocols. The system is now fully operational at National PARAM Supercomputing Facility (NPSF), Pune, India (Figure 1).

In this distributed memory machine, parallel processing is supported by message passing communication software like MPI and PVM. For compute intensive applications like weather forecasting, seismic data processing, computational fluid dynamics, etc. an effective low latency, high bandwidth supported communication software KSHIPRA[3] is provided. PARAM 10000 is also equipped with HPF and Fortran 90 compilers.

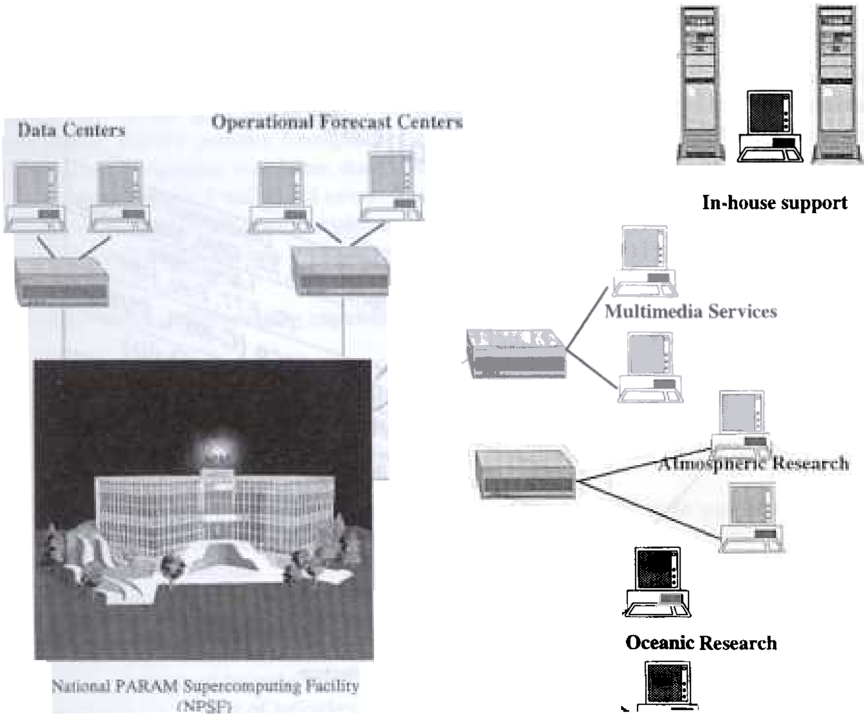

Figure 1 : National PARAM Supercomputing Facility (NPSF)

For high performance, CDAC provides lightweight communication protocols on the PARAM NET and MYRINET. The interfaces to these protocols have been developed in conformance to the Active Messages II specifications, provided by the University of California, Berkeley. The protocols through the efficient implementation provide very low latency and high bandwidth even for small messages. CDAC implementation of MPI, the emerging message passing interface standard has been highly optimized by layering it on light-weight protocols and by using collective algorithms tuned for the OpenFrame architecture (Figure 2). With this MPI, excellent performance has been achieved for the T80 weather code on the OpenFrame [4,5,6,7,8].

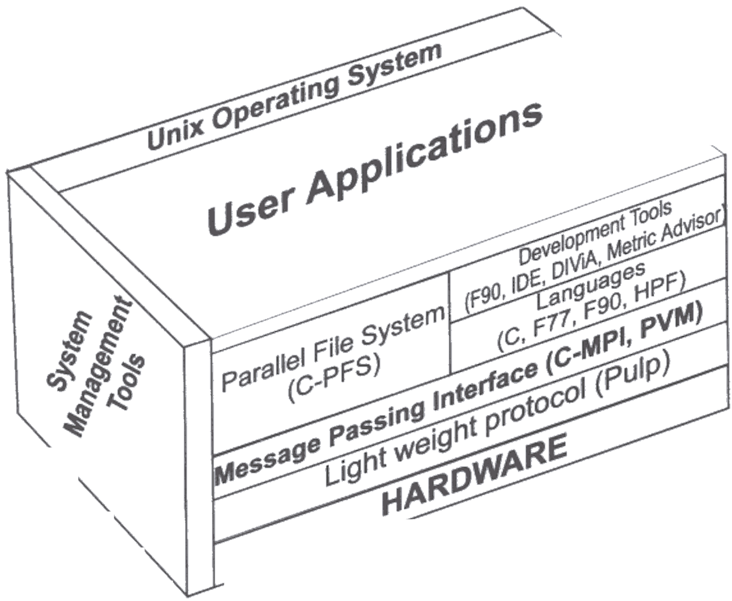

Figure 2: HPCC Software Architecture

Development of multidisciplinary applications software on parallel machines has been a major team exercise. With the capabilities of PVM and MPI and extension for data parallel programming, the usability of PARAM has considerably grown. The efforts have been continuing to use the PARAM computing system in many scientific research areas. One of the advantages being the portability of the software across various parallel systems without degradation in its performance and accuracy. In this paper, porting of codes like T21, T42, T80 and T126 and their efficiency using PARAM is described.

3. Climate Modeling

Governing equations for global spectral models are derived from the conservation laws of mass, momentum and energy. Vorticity, divergence, temperature, surface pressure and moisture equations are its main constituents. Expansion of the global field is done using the spherical harmonics. Finite difference operators are used to approximate the derivatives in the vertical directions and a semi-implicit time integration scheme is applied to the coupled equations. For the nonlinear terms calculations, a transformed method is used to convert the spectral quantities to the grid point values in the physical space which are transformed back to the spectral space after the computations.

The climate models T21L05 and T42L15 were ported on PARAM Open Frame considering only eight compute nodes[9]. The communication between nodes is achieved by message passing protocols through 100 BaseT fast ethernet using MPI. These models have a grid size of 600 km and 300 km respectively in the horizontal directions.

The codes were parallelised using the farm field approach. The input to the model was provided as the grid point values of temperature, horizontal velocity components, humidity, surface pressure / roughness / orography, etc. The GFDL scheme is used for radiation calculations which are done every 12 hours. This scheme includes long and short wave radiation and cloud cover. The dry and moist adiabatic adjustment and large scale condensation are also included in the model. Using data parallelism approach, the models were operational on PARAM system and reasonably good speedup was obtained.

4. The Weather Forecasting capabilities

The parallelisation of the codes T80L18 and T126L28 on PARAM 10000 were attempted. This work was carried out in continuation of optimising the compute resources on various versions of PARAM computing systems. These codes were provided by National Centre for Medium Range Weather Forecasting (NCMRWF).

The main task before deciding the parallelisation strategy of the code was to identify the nature of parallelism involved in the code and subsequent compute intensive parts and their data dependencies. There are many data independent variables namely latitudes, and longitudes for data decomposition. The most obvious and clear data independency, latitude wise parallelisation was implemented.

For this strategy of latitude wise data decomposition, data for latitude is available for each processor. A pair of latitudes is allocated on each processor. In the spectral models, major computations are done in Fourier and Legendre transform[10]. The transforms are performed twice for physics and dynamics part of the code. In order to minimise the communication traffic, these transforms should be performed on each processor sequentially. With latitude distribution, FFT can be performed independently without any communication on each processor, but this leads to parallel Legendre transform (the most time consuming) where partial sums are performed on each processor. This also ensures minimal changes in the original algorithm of the sequential code.

The parallelisation procedure was implemented for the code T80L18 and the computations were carried out for time steps of 15 minutes each. One day forecast was achieved by 96 iterations and the results were compared up to five days of forecast. Once the parallel T80 was tested for its results and repeatability, the code was ported on different versions of PARAM i.e. I860, SuperSparc, Alpha and UltraSparc I & II. A good speedup was registered with about 7 minutes on UltraSparc II (Figure 3).

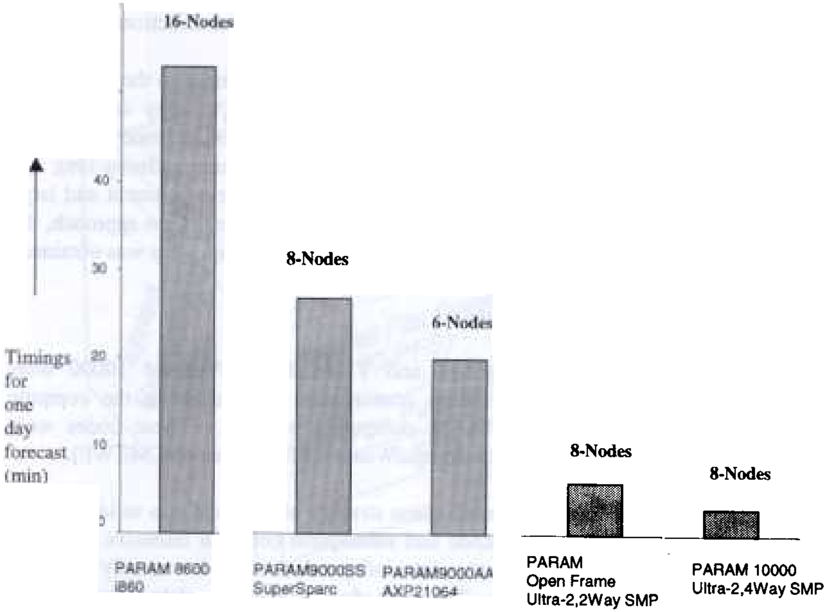

Figure 3 :T80 performance on different PARAMs

The code T126L28 was first optimised for good performance. The optimisation involved in reallocating the memory space and including the load balancing aspect more rigorously in view of the increased grid points and more time iterations[11]. In order to exploit the SMP architecture of the UltraSparc II nodes, a scheme involving hybrid network of shared memory processing within the nodes and MPI communication across different nodes is experimented. This scheme has further helped in reducing the communication delay amongst immediate neighbours of the PARAM nodes. The time step was of ten minutes each and the radiation calculations were performed six times. For a given set of data, the computations were performed and the results were well within the acceptable accuracy. A typical results for average rainfall is enclosed (Figure 4).

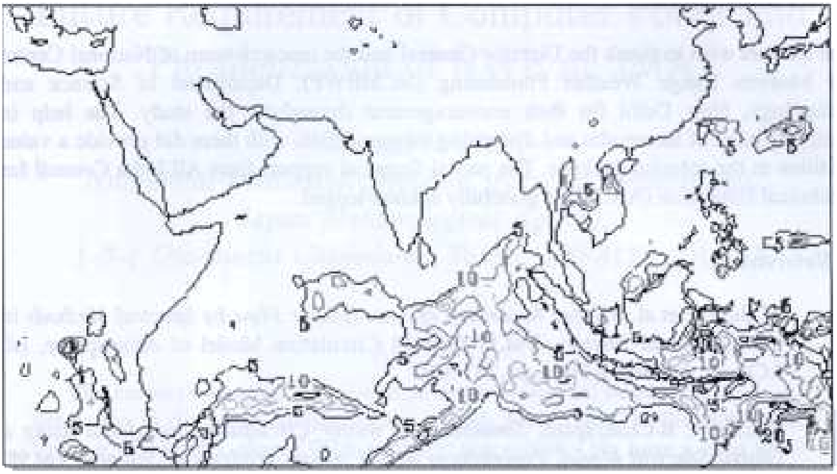

Figure 4 : T126 model forecast rainfall (mm/day) at 0000hrs 28th January, 1995

5. Future Directions

The next objective will be to minimize communications overheads in porting T126L28 across many nodes by combining active messages protocols (AM) with shared memory paradigm. Also parallelisation across the wave numbers will be attempted with transportation type communications.

6. Summary

Parallel Climate models T21/T42 and Forecast models T80/T126 on the SMP (Symmetric Multiprocessors) based PARAM have been developed. The computing nodes are UltraSparc II of 300Mhz equipped with 4 CPUs. Experiences with porting of spectral transform models to this distributed memory machine are discussed. It was observed that the parallel implementation effectively uses the shared memory computation for the SMPs and parallelism is optimal on message passing between the different SMP nodes. Overview of these models with respect to the parallelisation strategy, load balancing, communication, topology has been presented. Parallelisation issues for migration for forecast model T80 to T126 are also discussed. Experiments are carried out for the parallel radiation computations for T126. Feasibility of parallelisation for data analysis code are studied and timings for one day predictions are optimised along with effective visualisation interface.

7. Acknowledgement

The authors wish to thank the Director-General and the research team of National Centre for Medium Range Weather Forecasting (NCMRWF), Department of Science and technology, New Delhi for their encouragement throughout the study. The help in verifying most of the results and discussing minute details with them did provide a value addition to the solution package. The partial financial support from All India Council for Technical Education (AICTE) is gratefully acknowledged.

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