Scientific Report

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Nationality	PAKISTANI
Name of the *Host Organisation*	SICS SWEDISH ICT AB
First Name / family name of the *Scientific Coordinator*	MATS BRORSSON
Period of the fellowship	07/10/2013 to 06/10/2014

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

Performance analysis is central to ensuring performance-portability and predictability of target applications. In performance analysis, the composition and execution of target applications is mainly analyzed to derive guidelines usable by the middleware to provide portable and predictable performance. During the fellowship, my research activities were mainly focused on performance analysis of target applications and design of the scheduling algorithms in order to predict performance within the project PaPP (Portable and Predictable Performance on Heterogeneous Embedded Manycores). This project aims at making performance predictable for parallel applications on heterogeneous parallel platforms.
During the fellowship, my major research activities were as following:

1. **Design of Schedulers for PaPP Applications:**
   Design of schedulers for performance analysis and prediction of PaPP target applications was a major activity during my fellowship. I have proposed two scheduling heuristic algorithms for massively parallel applications (refer to publications [1], [2], and [4] in section-II). Parallel computing systems promise higher performance for computationally intensive applications. Since programs for parallel systems consist of tasks executed simultaneously, task scheduling becomes crucial for the performance of these applications. Given dependence constraints between tasks, their arbitrary sizes, and bounded resources available for execution, optimal task scheduling is considered as an NP- hard problem. Therefore, proposed scheduling algorithms are based on heuristics.
   My first contribution during fellowship is the proposition of a novel list scheduling heuristic, called the Noodle heuristic. Noodle is a simple yet effective scheduling heuristic that differs from the existing list scheduling techniques in the way it assigns task priorities. The priority mechanism of Noodle maintains a proportionate fairness among all ready tasks belonging to all paths within a task graph. We conduct an extensive experimental evaluation of Noodle heuristic with task graphs taken from Standard Task Graph (STG) and compared results with existing state-of-the-art algorithms. Results presented in paper [1] and [2] show that Noodle produces schedules that are within a maximum of 12% (in worst-case) of the optimal schedule for 2, 4, and 8 core systems.
   My second contribution was another scheduling algorithm, called the LeTS heuristic. In systems with complex many-core cache hierarchy, exploiting data locality can significantly reduce execution time and energy consumption of parallel applications. Failing to do so, on the other hand, can cause more cores stalled, thereby undermining the very viability of parallelism. Locality can be exploited at various hardware and software layers. For instance, by implementing private and shared caches in a multi-level fashion, recent hardware designs

are already optimized for locality. However, this would all be useless if the software scheduling does not cast the execution in a manner that promotes locality available in the programs themselves. This contribution presents a Locality-aware Task Scheduling (LeTS) heuristic algorithm for homogeneous multiprocessor systems. Details are published in publication [4] of section-II.
My third contribution during the fellowship period is the proposition of a regression-based modeling approach to predict task-based program performance for different scheduling parameters with variable input data size. Dynamic runtime behavior and contention on shared resources make it harder to predict the execution time of task-based programs on multicore systems. In order to get the highest performance and provide real-time guarantees, it is required to identify which runtime configuration is needed and how processor resources must be shared among tasks. Exploring design space for all possible scheduling and runtime options, especially for large input data, becomes infeasible and requires statistical modeling. Regression-based modeling determines the effects of multiple variables on a response variable, and makes predictions based on statistical analysis. In this work, we execute a set of task-based programs by varying runtime parameters, and conduct a systematic measurement for influencing factors on execution time. Our approach uses executions with different configurations for a set of input data, and derives different regression models to predict execution time for larger input data. Our results show that regression models provide accurate predictions for validation inputs with mean error rate as low as 6.3%, and 14% in average among four task-based programs.

2. **Professional Activities:**
   During this period, I was involved in a number of professional activities being undertaken in the CSL group at SICS and other places. Within the scope of the fellowship, I have participated in several project meetings and prepared some presentations and deliverables. I have also participated in many international events, details of which are provided in section-III.

II – PUBLICATION (S) DURING YOUR FELLOWSHIP

1. **M. K. Bhatti**, Isil Oz, Konstantin Popov, Ananya Muddukrishna, and Mats Brorsson. Noodle: A Heuristic Algorithm for Task Scheduling in Parallel Computing Systems. In the Proceedings of International Euromicro Conference on Digital System Design (DSD'14), August 2014, Verona, Italy.

2. **M. K. Bhatti**, Isil Oz, Konstantin Popov, Mats Brorsson. Proportionately Fair Task Scheduling for Parallel Computing Systems. Elsevier Journal of Systems Architecture (JSA), special issue on High Performance Computing (HPC) and Real-time Embedded (RTE) Systems. Under review since June 2014.

3. Isil Oz, **M. K. Bhatti**, Konstantin Popov, Mats Brorsson. Regression-Based Prediction for Task-Based Program Performance. Springer's journal of Real-Time Systems (RTS), Special Issue on Multicore Systems. Under review since July 2014.

4. **M. K. Bhatti**, Isil Oz, Konstantin Popov, Mats Brorsson. Locality-aware Task Scheduling for Homogeneous Parallel Computing Systems. PaPP project deliverable/ Scientific Report.

III – ATTENDED SEMINARS, WORKHOPs, CONFERENCES

1. ACACES-2014, HiPEAC Summer School on Advanced Computer Architecture and Compilation for High-Performance and Embedded Systems, July 13 -19, 2014, Fiuggi, Italy. Website: http://www.hipeac.net/acaces2014/

2. International Euromicro Conference on Digital System Design (DSD'14), August 2014, Verona, Italy.

3. SEMINAR-III, ERCIM ABCDE Program Annual Seminar for fellows, November 2013, Athens, Greece.

4. HiPEAC international conference, January 20-22 2014, Vienna, Austria.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

1. **REP-1:**
   Host Institution: INRIA Roquencourt, Paris, France
   Period: (25/05/2014 to 06/06/2014)
   Hosting scientific coordinator: Prof. Albert Cohen

   Summary of Activities:
   During this visit, I had presented research activities of the PaPP project under ERCIM program to the hosting team PARKAS (Parallélisme de Kahn Synchrone) at INRIA Paris - Rocquencourt, France. Moreover, I had briefly worked on another project of the hosting team and shared some ideas based on my expertise in ream-time systems. This visit resulted in an informal collaboration between my home and host teams.

2. **REP-2:**
   Host Institution: INRIA Sophia Antipolis, France
   Period: 02 weeks (25/05/2014 to 06/06/2014)
   Hosting scientific coordinator: Prof. Robert de Simone

   Summary of Activities:
   During this visit, I had presented my current research activities under ERCIM program to the hosting team AOSTE (Models and methods for the **A**nalysis and **O**ptimization of **S**ystems with Real-**T**ime and **E**mbedding constraints) at INRIA Sophia Antipolis, France. During the visit, I had the opportunity to interact and exchange ideas with researchers and PhD students who are working within AOSTE team.