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# An Integer Linear Programming Approach for the Analysis of DTM Strategies

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**Abstract**— As the number of cores in multicore processors and their operating frequency continue to grow, processor power consumption increases and leads to an escalation in chip temperatures. This escalation causes today's multicore processors' performance to be limited by chip thermal constraints rather than process technology or circuit design. As a result, Dynamic Thermal Management (DTM) has an increasingly significant role in the design of new microprocessors.

We propose a new way to design and quantitatively analyze DTM strategies. Using Integer Linear Programming, we compute optimal offline DTM strategies that achieve maximal performance and meet thermal constraints. By analyzing the optimal strategies, we are able to calculate the upper bound on DTM performance, to identify optimal strategy patterns and to compare the thermal limitations of several microprocessor layout designs.

We employ offline Optimal DTM analysis on the case of Multicore Task Scheduling DTM. We find that this analysis suggests that a layout of many small cores is more thermally efficient than a layout of several large cores. The analysis further suggests specific task scheduling algorithm guidelines that maximize performance under thermal constraints. In addition, we compute and analyze the optimal multicore task scheduling strategies for DVS/DFS-based mechanism and Stop&Go DTMs

## 1. Introduction

While multicore processors leverage the parallelism of multi-threaded applications to achieve higher performance, the increased on-chip parallelism results in greater power densities that may lead to a dangerous increase in chip temperatures [1]. As high temperatures can cause functional failures, reliability reduction and changes in circuit timing [5], today's multicore processors' performance is most often limited by thermal constraints rather than process technology or circuit design constraints [1].

In order to mitigate the thermal problem, computer architects design Dynamic Thermal Management (DTM) [3] mechanisms that monitor and dynamically reduce the chip's temperatures via regulation of the on-chip power distribution. Several DTM techniques had been proposed such as Stop&Go (global clock toggling) [3], local toggling [5], activity migration [4], thread migration, dynamic voltage/frequency scaling and multicore Temperature Aware Task Scheduling [11]. In most cases, the DTM design process is rather empirical and involves using 'trial and error' with various simulators to fine-tune algorithm parameters. In general, this design process does not achieve the optimum performance.

In this paper, we propose a new approach to design and quantitatively analyze DTM strategies and employ this approach on multicore task scheduling DTM. We use use Integer Linear Programming [23] to compute offline optimal DTM strategies that achieve maximal performance within chip temperature limits. We then analyze the behaviors of the optimal offline strategies and find specific strategy patterns that are desirable for DTM behavior. Finally, we use these patterns to formulize the on-line behavior of the DTM mechanism to be designed.

In addition to formulating the desired behavior of online task scheduling, we compute its upper bounds on performance and devise a method to compare and identify the thermal limitations of microprocessor layout designs. We find that the multicore layout has a crucial effect on the thermal limitation of the microprocessor, and by comparing several multicore layouts we are able to identify several simple layout design guidelines in the case of multicore task scheduling. Besides its application to multicore task scheduling DTM, we show that our approach also suggests important design guidelines for other DTMs such as multicore DVS/DFS-based mechanism and Stop&Go (global clock toggling) DTMs.

The rest of this paper is organized as follows: In section 2, we discuss previous work on DTM design and analysis, section 3 contains the formulation of the Thermal Multicore Task Scheduling DTM optimization problem and the model we use. In section 4, we describe the methods we use to compute the optimal solution while in section 5 our results for Multicore task scheduling, multicore DVS/DFS-based mechanism and Stop&Go DTM mechanisms are presented. Finally, in section 6, we discuss our conclusions and future research directions.

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## 2. Related Work

Brooks et al. introduced Dynamic Thermal Management (DTM) as a solution for microprocessor thermal problems [3]. Since then, several different DTM mechan-