Chapter 3
Energy–Aware Scheduling for Parallel Applications on Multicore Systems

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ABSTRACT
This chapter discusses energy-aware scheduling techniques for parallel applications on multicore computers. Key techniques for developing an energy-aware scheduler, such as estimation of power usage and performance features per application, are analyzed and evaluated. The authors first discuss the runtime profiling techniques for collecting detailed application-specific information to be used by the scheduler. Then they focus on the techniques that estimate power usage and performance features. Performance features such as speedup and CPU-intensiveness enable the scheduler to make the tradeoffs between power consumption and the performance of the application. Preliminary experimental results show that energy-aware scheduling could save a significant amount of energy by adopting novel scheduling policies based on the knowledge of performance features collected from the applications.

1. INTRODUCTION
Energy consumption has been a major concern for a long time in regards to portable consumer electronics such as smartphones and laptops. The explicit goal has been to extend the battery life of such devices, making them more useful. However, much focus has been recently shifted to improve the energy efficiency of large-scale systems such as servers, grids, and clusters due to the following two primary reasons: firstly, there is a traditional economic incentive of reducing the TCO (Total Cost of Ownership) by reducing the energy consumption. The cost of powering and
cooling a large-scale system could be in the order of millions of dollars, making it an increasingly important issue due to the continuously increasing deployment of such systems. Secondly, there is an increasing awareness from consumers of the environmental impact that occurs during energy production. In developed countries, about 70% of generated electricity comes from the burning of fossil fuels (Nordman & Christensen, 2009), which in turn produces greenhouse gas emissions that impact on the environment. This environmental problem is driving the increased demand for more energy efficient solutions.

Apart from these primary reasons for the study on energy efficiency of large-scale systems, other indirect benefits are attainable through improving energy efficiency, such as increased system stability and uptime. Since a system using less power generates less heat, its stability becomes better. According to Arrhenius’ Equation (which was first proposed by the Dutch chemist J. H. van ’t Hoff in 1884 and then proved by Swedish chemist Svante Arrhenius in 1889), for every increase of 10°C (18°F) in temperature, the failure rate of a system doubles, which could cause more system downtime. As can be seen in Table 1, the costs of system downtime can be quite significant to businesses (Hsu & Feng, 2005).

So far, energy efficient solutions are only incorporated into the deployments of large-scale systems through the use of newer, more energy efficient hardware. Relying on this approach alone has two key drawbacks. The first is the prohibitive cost of replacing the existing hardware with a more energy efficient alternative. Secondly, this approach could also bring about more waste of resources, because some of the hardware being replaced are still sufficient to complete the work, though in a less energy efficient way.

Moreover, relying solely on more energy efficient hardware to reduce the total energy consumption of the IT industry may not have its desired impact, because it may instead cause an increase in the total energy consumption. Due to the trend of improving energy efficiency and reducing operational cost, large-scale systems are more affordable, which may in turn lead to an increase in deployments (Tomlinson, Silberman, & White, 2011). However, software solutions do not suffer from this problem to the same extent because they help change the way in which the hardware is used and promote energy efficiency through their wider adoption in existing systems. Additionally, software solutions are more cost effective as they are able to leverage new technologies in commodity components, such as Dynamic Voltage and Frequency Scaling (DVFS) and multicore chips.

Because of these reasons, this chapter explores how scheduling software is able to make use of technologies in commodity processors to reduce the energy consumption of large-scale systems. The chapter is organized as follows. Section 2 discusses the motives and requirements of energy-aware scheduling. Then runtime profiling techniques are discussed in Section 3, followed by methods for estimating power usage of applications in Section 4. Section 5 discusses the performance features that can be utilized by scheduling software to save energy. Section 6 shows the effect of energy-aware scheduling through preliminary experimental results. Finally, Section 7 gives the conclusions and future work.

<table>
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<th>Service</th>
<th>Cost of One Hour of Downtime</th>
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<tr>
<td>Brokerage Operations</td>
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<td>Catalog Sales Center</td>
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Adapted from Hsu and Feng (2005)
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