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論文の内容の要旨

Real-time systems are playing an important role in our society. In the last two decades, there has been a dramatic rise in the number of real-time systems being used in our daily lives and in industry production. Representative examples include vehicle and flight control, chemical plant control, telecommunications, and multimedia systems. These systems all make use of real-time technologies.

The most important attribute that sets real-time systems apart from other systems is that the correctness of systems depends not only on the computed results but also on the time at which results are produced. In other words, a task in a real-time system is required to be completed before a specific time instant which is called deadlines. This sensitivity to timing is central feature of system behaviors. To satisfy this requirement, tasks need to be allocated sufficient resources (e.g., processor) so as to meet their deadlines (i.e., to be completed before their deadlines). Scientific community has made great efforts in developing scheduling polices for properly allocating resources to tasks. This field of study is referred to as real-time scheduling.

With decades of efforts, real-time scheduling on uniprocessor systems can be viewed as relatively mature. But there still remain many problems. For example, for a soft or firm real-time system, when the system is under overload condition, some tasks will miss dead- lines. It is important to minimize the degree of system performance degradation caused by the missed deadline tasks. For this problem, the performance of existing scheduling algorithms is not satisfactory.

Compared to uniprocessor systems, real-time scheduling on multiprocessor systems is far from well-studied. Even for the simpler problem of scheduling identical multiprocessor systems, there still remain many problems. For the harder problem of scheduling heterogeneous multiprocessor systems,

where we have to face an awkward reality that considering a relatively practical application scenario, there is still no solution to efficiently schedule heterogeneous multiprocessor systems. This becomes unfortunate since current progress in developing heterogeneous multiprocessor systems is a long way ahead of research efforts to determine the best scheduling policies.

These situations motive this research. The vision of this research is to help developers easily and efficiently design scheduling for real-time systems with low cost. To approach this vision, a Real-time scheduling methodology based on Satisfiability Modulo Theories (RSMT) is proposed. In RSMT, the problem of scheduling is treated as a satisfiability problem. The key work is to formalize the satisfiability problem using first-order logical formulas. Through formalization, a SAT model is constructed to represent the scheduling problem. This SAT model is a set of first-order logic formulas (within linear arithmetic in the formulas) which express all the scheduling constraints that a desired schedule should satisfy. After the SAT model is constructed, a SMT (satisfiability modulo theories) solver (e.g., Z3, Yices) is employed to solve the formalized problem. A desired schedule can be generated based on a solution model returned by the underlying SMT solver.

After RSMT is proposed, it is first applied to uniprocessor time-driven systems to solve the overload problem. Then, RSMT is exploited to design scheduling for multiprocessor time-driven systems. Heterogeneous real-time systems have been considered. At last, in order to apply RSMT to design scheduling for event-driven systems, a method of combining RSMT and online scheduling algorithm is given. Through these studies, RSMT shows capabilities to be applied to design scheduling for various kinds of scheduling targets and systems, from uniprocessor to multiprocessor, from time-driven to event-driven. In addition, many practical requirements that are considered in real-time scheduling domain can be dealt with, e.g., task dependency relation, tasks with different degrees of importance, task preemption, and task migration. Benefit from these capabilities, RSMT leads us one step closer to the vision. To the best of my knowledge, it is the first time systematically introducing SMT to solve a series of problems covering a wide scope in real-time scheduling domain.

keywords: real-time systems, satisfiability modulo theories, real-time scheduling, overload problem, heterogeneous multiprocessor systems

論文審査の結果の要旨

The Evaluation Committee recognizes that the research work presented in the dissertation is real-time scheduling, in the exploration of Satisfiability Modulo Theories (SMT) problem that is expressed in classical first-order logic formulas to help developers

easily and efficiently to design scheduling for real-time systems with low cost. The real-time scheduling methodology based on SMT (RSMT) that is proposed can be deployed to design and extract the offline scheduling table for both uniprocessor and multiprocessor heterogeneous real-time systems. In addition, RSMT can be combined with other scheduling algorithms, e.g., earliest deadline first (EDF) to deal with both time-driven systems and event-driven systems simultaneously. Cheng Zhuo focuses on the RSMT framework and has reached a very good competence with clear vision and objectives of his research work.

The dissertation divides into three main parts: design of RSMT scheduling framework, numerical evaluation of uniprocessor and multiprocessor real-time systems, and combination of offline and online scheduling. In the first part, the three-layer RSMT framework, task model and scheduling constraints are identified explicitly. In the second part, the function model, task model, processor model, network channel model are derived to further analyze the performance of RSMT framework. The issues of task dependency, migration and non-migration are well-examined with comprehensive results and discussions. In the final part, a running car with engine control, cruise control and radar systems is investigated using structured object-oriented formal language (SOFL) specification. The Evaluation Committee identifies that the dissertation contains the appropriateness of the given literature backgrounds, the wide-ranging related research works, and the methodologies for the numerical studies. Besides that, the simulation results are validated and extensively well-discussed to justify the correctness and effectiveness of the proposed RSMT framework. The dissertation also includes clear and specific conclusions and recommendations for future works. In addition, the references are appropriately presented in the dissertation.

The Evaluation Committee validates and confirms that the research works in each chapter of the dissertation have been disseminated to the 11 international conferences and two journals. The Evaluation Committee agrees that he did make very good achievements and momentous contributions to the scheduling domain of real-time systems, in particular the research topics of SMT and cyber-physical systems technique. The Evaluation Committee observes that he speaks frequently in English and his ability in oral presentation is excellent. In addition, this research work is a frontier step toward the scheduling problem in the real-time systems today. Hereby, the Evaluation Committee concludes that he with no doubts deserves to obtain the doctoral degree (Information Science).