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**Modular Performance Analysis
of Embedded Real-Time Systems:
Improving Modeling Scope and Accuracy**

A dissertation submitted to

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presented by

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Abstract

A fundamental aspect of the design of an embedded system is the prediction of its performance in terms of timing, memory, or energy early in the design process. The objective of this task, typically referred to as system-level performance evaluation, is twofold. On one hand, it is instrumental for pre-validating a system design before any resources are invested for the actual implementation and, on the other hand, the performance evaluation is a central driver for the exploration of the design space. For systems with strict performance requirements such as hard real-time systems the performance evaluation needs to be provably correct, that is, it has to cover the worst-case performance scenarios. Furthermore, the evaluation should be fast such that it can be employed for the exploration of large design spaces.

Recent research efforts have led to analytical and modular methods for worst-case performance evaluation at the system level. These methods ensure the correctness of the performance evaluation and are fast even for large-scale systems. However, they suffer from limited modelling scope and analysis accuracy. As a consequence, when applying these methods to complex systems, one often experiences considerable abstraction losses, which lead to overly pessimistic performance results.

This thesis introduces several formal models and methods that refine the modelling capabilities of analytical performance evaluation and prevent abstraction losses. The results build on the existing framework for Modular Performance Analysis (MPA), but apply also to other analytical formalisms. The main contributions of this thesis can be summarized as follows:

- The modelling scope of analytical performance evaluation is extended to systems with cyclic dependencies.
- New models and methods are introduced for handling structured event or data streams in analytical performance evaluation.
- A novel hybrid analysis methodology is presented that combines analytical and state-based system evaluation.
- New design methods for energy-efficient real-time systems are introduced.

Zusammenfassung

Ein wesentlicher Aspekt der Entwicklung von eingebetteten Systemen ist die Vorhersage deren Leistung bezüglich Zeitverhalten, Speicherbedarf oder Energieverbrauch in frühen Entwurfsphasen. Diese Leistungsbewertung, oft als *System-level Performance Evaluation* bezeichnet, dient zwei Zielen. Zum einen ermöglicht sie die Validierung von Systementwürfen vor der eigentlichen Implementierung des Systems. Zum anderen ist die Leistungsbewertung ein entscheidendes Element der Exploration des Entwurfsraumes. Für Systeme mit strengen Leistungsanforderungen wie zum Beispiel Echtzeitsystemen, muss die Leistungsbewertung nachweisbar korrekt sein, d.h. sie muss Worst-Case Szenarien erfassen. Weiterhin sollte die Leistungsbewertung möglichst schnell sein, damit sie für die Exploration von grossen Entwurfsräumen eingesetzt werden kann.

Die Forschungsbemühungen der letzten Jahre haben analytische, modulare Methoden zur Worst-Case Leistungsbewertung auf Systemebene hervorgebracht. Diese Methoden garantieren die Korrektheit der Leistungsbewertung und sind auch für grosse Systeme schnell. Allerdings zeichnen sich diese Verfahren auch durch einen eingeschränkten Anwendungsbereich und teilweise mangelnder Analysegenauigkeit aus. Aus diesem Grund kommt es bei der Analyse von komplexen Systemen häufig zu erheblichen Abstraktionsverlusten und folglich zu pessimistischen Leistungsbewertungen.

Die vorliegende Arbeit stellt formale Modelle und Methoden vor, die die Ausdrucks Kraft und Genauigkeit der analytischen Leistungsbewertung wesentlich verbessern. Die Arbeit baut auf den bestehenden Ansatz der *Modular Performance Analysis (MPA)* auf. Die Ergebnisse finden jedoch auch in weiteren analytischen Verfahren Anwendung. Die konkreten Beiträge dieser Arbeit können wie folgt zusammengefasst werden:

- Der Anwendungsbereich der analytischen Leistungsbewertung wird um Systeme mit zyklischen Abhängigkeiten erweitert.
- Modelle und Methoden zur Handhabung von strukturierten Datenströmen werden vorgestellt.
- Ein neuartiges hybrides Analyseverfahren wird eingeführt, welches analytische und zustandsbasierte Leistungsbewertung kombiniert.
- Neue Entwicklungsmethoden zum Entwurf von energieeffizienten Echtzeitsystemen werden vorgeschlagen.

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