QUALITY MANAGEMENT
OF REAL-TIME DATA
IN CYBER-PHYSICAL SYSTEMS

WANG JIANTAO

DOCTOR OF PHILOSOPHY
CITY UNIVERSITY OF HONG KONG
JUNE 2013
Abstract

This thesis investigates how to manage the quality of real-time data in a cyber-physical system. We present intensive theoretical analysis and extensive performance evaluation of the designed algorithms. The major work is outlined as follows.

Temporal data consistency is very important in cyber-physical systems. A cyber-physical system is a system featuring a tight combination of, and coordination between, the system’s computational and physical elements. In a cyber-physical system, the update tasks that aim at updating real-time data always have transmission delays or jitters from the sources to the destinations. In Chapter 2, we present how to maintain the temporal consistency of real-time data when different types of jitters are taken into consideration. We first present a novel algorithm to guarantee the temporal consistency of real-time data when the jitter of each update task has a limited bound. Based on the novel algorithm, an enhanced algorithm is presented to provide statistical temporal consistency of real-time data when the jitter of each update task is unbounded and unpredictable. Performance evaluation shows that both algorithms can provide good temporal data consistency when different kinds of jitters are considered.

Maintaining the temporal consistency of real-time data has a close relationship with meeting the deadlines of control tasks. Unfortunately, these two goals, maintaining temporal data consistency and meeting the control tasks’ deadlines, conflict with each other and are difficult to be achieved at the same time. To address the conflict, in Chapter 3, we present a fixed priority co-scheduling algorithm. It uses periodic update tasks to maintain the temporal consistency of real-time data. It judiciously decides the priority order among all the update tasks and control tasks.
so that the constructed co-scheduling can satisfy the deadline constraints of all the control tasks while maximizing the qualities of real-time data. However, the performance of the fixed priority co-scheduling algorithm decreases with the increase of the system workload. In chapter 4, instead of using a fixed priority co-scheduling, a dynamic co-scheduling algorithm with the purposes to meet the deadlines of the control tasks and maximize the quality of control offered by the control tasks are presented. Extensive simulation results show that the dynamic co-scheduling algorithm can effectively improve the system schedulability and the temporal consistency of real-time data.

In Chapter 5, we present a novel multi-version B\(^+\)-tree index structure for indexing multi-versions of data objects in an multi-version database over flash memory. The proposed multi-version index structure is divided into two levels. At the higher level, a multi-version index is maintained for keeping successive versions of each data object. These versions are allocated consecutively in a version block. Each version block consists of a pre-defined number of consecutive pages. At the lower level, a version array is used for searching a specific data version within a version block. Extensive simulation results show that the overhead for managing the index in processing update operations can be greatly reduced. At the same time, the number of accesses to the index in processing version-range queries is greatly reduced.
# Contents

Abstract i

Table of Contents v

List of Figures ix

List of Tables xii

1 Introduction 1

2 Maintain Temporal Data Consistency in Distributed Sensing and Control Systems 5

2.1 Related Work .......................... 8

2.2 Backgrounds and Preliminaries .................. 11

2.2.1 Temporal Consistency of Real-Time Data .......... 11

2.2.2 Maintaining Temporal Consistency with Jitter .......... 14

2.2.3 The More-Less Method and its Limitations .......... 16

2.3 Jitter-Based More-Less .......................... 18

2.3.1 Theoretical Preliminaries .................. 19

2.3.2 JB-ML Approach .......................... 21

2.3.3 Comparison of JB-ML with More-Less .................. 23

2.4 Statistical Jitter-Based More-Less .......................... 26

2.4.1 Statistical Guarantee in Temporal Consistency .......................... 27

2.4.2 Principles of SJB-ML .......................... 28

2.4.3 Algorithm Details .......................... 29
5 Block-based Multi-version B⁺-tree for Flash-based Database Systems

5.1 Related Work ................................. 103

5.2 Preliminaries ................................. 105
  5.2.1 Flash Memory Storage Systems .......... 105
  5.2.2 Multi-version B⁺-Tree (MVBT) ............ 107
  5.2.3 Problems and Motivation ................. 108

5.3 System Model and Operations .................. 110
  5.3.1 System Model and Assumptions .......... 110
  5.3.2 Write and Read Operations ............... 111

5.4 The Block-based MVBT (BbMVBT) ............... 113
  5.4.1 Principles of BbMVBT ..................... 113
  5.4.2 An Example of BbMVBT .................... 116
  5.4.3 Operations in BbMVBT .................... 119

5.5 Purging & Version Block Size .................. 121
  5.5.1 Purging of Data Versions and Index Nodes ... 121
  5.5.2 The Determination of Version Block Size .... 123

5.6 Analysis of BbMVBT .......................... 125
  5.6.1 Run-time Analysis of Update Transactions ... 126
  5.6.2 Run-time Analysis of User Queries ........ 127
  5.6.3 Space Analysis ........................... 129

5.7 Performance Evaluation ......................... 130
  5.7.1 System Model and Parameters ............. 130
  5.7.2 Experimental Results ...................... 135

5.8 Summary .................................... 138

6 Conclusions .................................. 141

6.1 Summary .................................... 141

6.2 Future Work ................................ 142
  6.2.1 Optimization of the Co-scheduling Problem ... 142
6.2.2 Multi-version R-tree for Spatial Temporal Data over Flash Memory
6.2.3 Implementation of the Complete System

References

List of Publications