AN INTELLIGENT MAINTENANCE BASED ON MACHINE LEARNING APPROACH FOR WIRELESS AND MOBILE SYSTEMS

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Abstract: To enhance wireless and mobile system dependability, audit operations are necessary, to periodically check the database consistency and recover in case of data corruption. Consequently, how to tune the database audit parameters and which operation order and frequency to apply becomes important aspects, to optimize performance and satisfy a certain degree of Quality of Service, over system life-cycle. The aim of this work is then to suggest an *intelligent* maintenance system based on reinforcement *Q-Learning* approach, built of a given audit operation set and an audit manager, in order to maximize the performance (performability and unreliability). For this purpose, a methodology, based on deterministic and stochastic Petri nets, to model and analyze the dependability attributes of different scheduled audit strategies is first developed. Afterwards, an intelligent (reinforcement *Q-Learning*) software agent approach is developed for planning and learning to derive optimal maintenance policies adaptively dealing with the highly dynamic evolution of the environmental conditions. This intelligent approach, is then implemented with feedforward artificial neural networks under the supervised gradient back-propagation learning to guarantee the success even with large state spaces, exploits intelligent behaviors traits (learning, adaptation, generalization, and robustness) to derive optimal actions in different system states in order to achieve an *intelligent* maintenance system.

1 INTRODUCTION

The problem of protecting data, stored in internal databases and used by a wide variety of systems during their execution, against run-time corruption has long been recognized to be a critical aspect highly impacting on the overall system reliability/availability. Wireless and mobile systems are typical examples of systems whose activities rely on databases, where the information is frequently accessed and updated. Indeed, these systems heavily rely on internal databases to keep trace of resource usage status and user data in order to correctly setting up and managing user calls. For this purpose, databases are included, where data are organized in such a way to capture the relationships existing among them. Unfortunately, these databases are subject to data corruption determined by a variety of hardware and/or software faults, such as the huge amount and the dynamic nature of data, internal bugs and transient hardware faults. The occurrences of such faults have the potential of yielding to service unavailability with (possibly heavy) consequences on Quality of Service (QoS). Thus, a self-checking maintenance software, using data audits with checks and recovery actions, has been successfully developed achieving a high availability in Lucent Technologies 5ESS switch system since quite long time (Haugk et al, 1985). More recently, a framework containing a database audit subsystem has been developed in (Bagchi et al, 2001) for database audit and control flow checking to maintain the structural and semantic integrity of the database and a preemptive control flow checking technique.

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In this work, the authors claimed the need of both database audit and control checking (mechanisms for detecting errors in the data flow of the client) to guarantee a high detection coverage. In general, off-the-shelf database systems are equipped with utilities to perform data audits, such as described in (Haugk et al, 1985), (Costa et al, 2000), (Bagchi et al, 2001), (Oracle8 Server Utilities).

Our research objective, in this work, is to investigate on such approach to derive optimal maintenance policies of database supports in such systems. It is noteworthy then to underline the specific characteristics possessed by such communication systems which have to be taken into account in devising approaches for their maintenance. The two main factors characterizing wireless communication systems are: 1) Short-persistence of most of the data stored in the database (typically, of the same duration of the user call). 2) The highly dynamic evolution of the environmental conditions (e.g., varying number of active calls) and the changes over time of the requirements and services offered from these communication systems. These two factors make maintenance difficult to achieve by traditional methods, and consequently approaches using *learning* and *adaptation* to replace missing or incorrect environment knowledge by the experimentation, observation, prediction, and generalization, come out to be very attractive.

The methodology using DEpendability Evaluation of Multiple phased systems (DEEM) tool to model and analyze the dependability attributes of different scheduled audit strategies is developed. This methodology, essentially based on Deterministic and Stochastic Petri Nets (DSPN) and supported by DEEM tool, aims to derive appropriate settings for the order and frequencies of database audits to optimize selected performance indicators. Afterwards, an intelligent software agent based on a reinforcement *Q-Learning* approach is developed for planning and learning to derive optimal maintenance policies adaptively and Artificial Neural Networks (ANN) for its implementation.

2 INTELLIGENT MAINTENANCE SYSTEM

Wireless and mobile systems include a database subsystem, storing system-related as well as clients-related information, and providing basic services to the application process, such as read, write and search operations. Data concerning the status, the access rights and features available to the users, routing information for dispatch calls, are all examples of data contained in such database, organized in appropriate data structures usually called tables (e.g., database tables A, B, and C). The database is subject to corruption determined by a variety of hardware and/or software faults, such as internal bugs and transient hardware faults. The occurrences of such faults have the potential of yielding to service unavailability. Because of the central role played by such database in ensuring a correct service to clients, means to pursue the integrity/correctness of data have to be carried out.

The synopsis, shown in Figure 1, of an intelligent database maintenance system, built of a given audit operation set, and an audit manager, is suggested in order to allow to select, in each time period, the optimal maintenance policy, *the optimal audit behavior*. The part, in Figure 1, labelled "Relevant Parameters" indicates those parameters of the wireless communication systems which determine the states space of these systems, mainly the time (the nature of the application under study imposes the time as relevant parameter), the mean number of user calls N_{call}, and the pointer failure rate λ_C.

2.1 Audit Operation Set

In this work, we are not interested in defining or analyzing audit operations from the point of view of the detection and/or correction capabilities offered by them. Instead, a given set of audit operations is assumed to be provided (as shown in Figure 1 e.g., Audit1_AB, Audit1_BC, Audit2_AB, Audit2_BC are audit operations dealing with database tables A, B, and C) to cope with data corruption, where each audit operation is characterized by a cost (in execution time) and coverage (as a measure of its ability to detect and/or correct wrong data).

2.2 Audit Manager (Decision-making)

The audit manager is responsible for applying a maintenance strategy to cope with database corruption and therefore preventing system unavailability; it activates different audit operations at different time intervals. To achieve this goal, it has to select the part of the database to check/recover, the detection/recovery scheme to apply, and the frequency with which each check/recovery operation has to be performed. It is implemented by a decision-making subsystem which integrates a methodology to model and analyze maintenance strategies (where e.g., Table Pointers are structured in homogeneous sets A, B, and C as

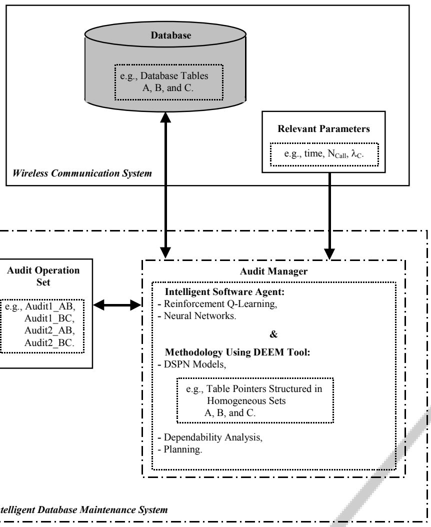

Figure 1: Synopsis of an intelligent maintenance system.

shown in Figure 1) and an intelligent software agent.

Current database maintenance systems are facing with less predictable and more complex environments such as the dynamic environment of wireless communication systems. For more QoS, database maintenance approaches must drop the assumption that perfect environment knowledge is available. They have to explore, check, recover from failures *autonomously* their environments in *real-time* (Kemme et al, 2011). More, if database maintenance systems lack knowledge about themselves and their environments, *learning* and *adaptation* become then inevitable to replace missing or incorrect environment knowledge by the experimentation, observation, prediction, and generalization. Indeed, the interest in complete (intelligent) database maintenance systems dealing with highly dynamic environments is becoming necessary from *embodied cognitive science* and *understanding natural intelligence* perspectives (Pfeifer and Scheier, 1999), (Chohra, 2001).

3 MODELING AND ANALYSIS OF DATABASE MAINTENANCE

In this phase, our goal is to identify a methodology to model and evaluate the relevant dependability attributes of scheduled audit strategies in order to derive optimal maintenance solutions for a given setting of the system and environment parameters: 1) the representation of the basic elements of the system and the ways to achieve composition of them; 2) the behavior of the system components under fault conditions and under audit operations to restore a correct state; 3) the representation of failure conditions for the entire system; 4) the interleaving of audits with on-going applications and their relationships; 5) the effects of (combinations of) basic audit operations on relevant indicators for the system performance, in accordance with applications requirements. Our approach is based on Deterministic and Stochastic Petri Nets (DSPN). Specifically, we defined general models which capture the behavior of the database and of the maintenance policy checking/recovering it, to be easily adapted to the implementation of database audits. This allows then analyzes which give a useful indication about the tuning of the major parameters involved in the database audit. The optimal trade-off between the audit frequency and the investment to improve the coverage of the audits can be found, to match the best performability and dependability constraints.

4 TOWARDS OPTIMAL MAINTENANCE

In this Section, a reinforcement *Q-Learning* approach is suggested for a dynamic (adaptive) selection of the maintenance policy at varying database and environmental parameter values leading to select, at each time period, the optimal maintenance policy, *the optimal audit behavior*. Indeed, this adaptive selection is very important and necessary to carry out the changes which could occur during the life-cycle system which are not foreseeable and react consequently by reinforcement learning during on-line learning. While the foreseeable changes are carried out using DEEM tool as environment model for planning during off-line learning. Thus, to dynamically adapt maintenance policies at varying database and environmental parameter values, reinforcement *Q-Learning* approach, in Figure 2, is suggested.

5 ANN IMPLEMENTATION

The utility (performance) network having multiple ANN under supervised gradient back-propagation learning with single output, illustrated in Figure 3, is suggested to implement the reinforcement *Q-Learning* approach.

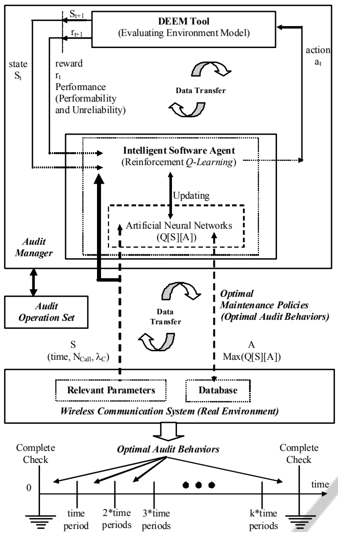

Figure 2: Q-Learning approach synopsis.

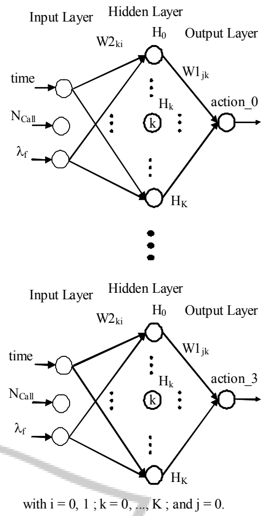

Figure 3: Feedforward ANN to implement the reinforcement *Q-Learning*.

6 CONCLUSIONS

From a given audit operation set, maintenance database approaches aim to make in use an efficient decision-making system to schedule these audit operations, which defines their order and frequencies in order to maximize the performance of a considered wireless communication system. The interest is then focalized on the database maintenance approaches devoted to how to optimally schedule a given audit operations and particularly in which order and frequencies. For this purpose, two audit optimization strategies based on *statistics* collected during system operation have been developed in (Bagchi et al, 2001) while we suggest in this work a reinforcement *Q-Learning* approach, i.e., *audit behavior learning*, implemented by ANN under supervised GBP learning. This approach exploits essential traits of intelligent behaviors such as the learning ability of *Q-Learning* paradigm to converge to the optimal actions and the generalization and robustness capabilities of ANN in order to achieve an *intelligent* database maintenance system. Then, one important issue to guarantee the success of the reinforcement *Q-Learning* approach is developed suggesting ANN implementation to derive an efficient state space representation.

An interesting alternative, for future research, is to extend the number of relevant actions considering: different time durations of the operational phases, different audit operations, and different combinations of the operational phases and audit operations.

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