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Reliability assessment and sensitivity analysis of software reliability growth modeling based on software module structure

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Abstract

Software reliability is an important characteristic for most systems. A number of reliability models have been developed to evaluate the reliability of a software system. The parameters in these software reliability models are usually directly obtained from the field failure data. Due to the dynamic properties of the system and the insufficiency of the failure data, the accurate values of the parameters are hard to determine. Therefore, the sensitivity analysis is often used in this stage to deal with this problem. Sensitivity analysis provides a way to analyzing the impact of the different parameters. In order to assess the reliability of a component-based software, we propose a new approach to analyzing the reliability of the system, based on the reliabilities of the individual components and the architecture of the system. Furthermore, we present the sensitivity analysis on the reliability of a component-based software in order to determine which of the components affects the reliability of the system most. Finally, three general examples are evaluated to validate and show the effectiveness of the proposed approach.

Keywords: Non-homogeneous Poisson process; Sensitivity analysis; Software reliability; Software reliability growth models

1. Introduction

Due to the recent rapid developments of computer and network technologies, the Internet and World Wide Web make it possible for users to access a variety of resources and applications distributed over the world. Since software is embedded in computer technologies and permeates our daily life, the correct performance of software systems becomes an important issue of many critical systems. Software designers are motivated to integrate commercial off-the-shelf (COTS) software components for rapid software development. To ensure high reliability for such applications using software components as their building blocks to construct a software system, dependable components have to be deployed to meet the reliability requirements. Therefore, it is necessary to assess the reliabilities of such systems by investigating the architectures, the testing strategies, and the component reliabilities (Lyu, 1996; Musa et al., 1987; Musa, 1998). For instance, Everett (1999) uses the extended execution time (EET) reliability growth model and several test cases to model the reliability growth of each component. Gokhale et al. (1998) and Gokhale and Trivedi (2002) assumes the failure behavior of each component is described by a

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time-dependent failure intensity. The total number of failures is obtained and the reliability is estimated via the enhanced non-homogeneous Poisson process (ENHPP). Krishnamurthy and Mathur (1999) evaluated a method, known as component based reliability estimation (CBRE), to estimate the reliability of a component-based software system using reliabilities of its components. Yacoub et al. (1999) proposed a reliability analysis technique called the scenario-based reliability analysis (SBRA), which is based on execution scenarios to derive a probabilistic model for the analysis of a component-based system. In the field of software reliability modeling, Musa (1994, 1998) and Musa et al. (1987) first investigated the validity of the execution time theory and operational profile. Recently, we (Huang et al., 2002; Lo et al., 2002, 2003) adopted the concept of testing-effort within an NHPP model to get a better description of the software fault phenomenon. The failure behavior of each component can be described by failure intensity. Thus, an appropriate software reliability growth model can be applied for estimating the component reliability from the failure data. However, due to the insufficiencyof failure data, sensitivity analysis of the reliability estimation has also been investigated in the context of black-box models (Musa, 1994; Chen et al., 1994; Pasquini et al., 1986). The parameters in these software reliability models are usually obtained from the failure data. Sensitivity analysis provides an approach to analyzing the impact of the parameters (Musa, 1993, 1994). In general, one difficulty in estimating the reliability of a system in the testing stage is the insufficiency of the failure data and therefore the accurate values of the parameters are hard to get. Sensitivity analysis is often used in this stage to deal with this problem. In this paper, we investigate the sensitivity analysis of the reliability for a component-based software system. The method is very useful in practice. For example, if we use the approach to determine that a parameter or a component in a system is the most sensitive, it is critical for the software testing-team to have this parameter estimated as accurately as possible or allocate more resources for this component. The organization of this paper is as follows. Section 2 presents an analytical approach to estimating the reliability of a system. Three different architecture styles are conducted in Section 3. Sensitivity analysis is discussed in Section 4. Experimental results of sensitivity analysis of system reliability are depicted in Section 5. Conclusions are presented in Section 6.

2. Reliability prediction for module software systems

2.1. Notations

Pr	probability function
$\text{pow}(x,y)$	power function, i.e. $\text{pow}(x,y)=x^y$
X_n	discrete-time Markov chain with some absorbing and some transient states
P_{ij}	probability of X_{n+1} being in state j given X_n is in state i, i.e. $Pr(X_{n+1}=j\|X_n=i)$
N_{ij}	number of visits to state j before entering an absorbing state given $X_0=i$
μ_{ij}	expected value of N_{ij}, $E(N_{ij})$
η_k	probability of absorption when a process terminates at an absorbing state k
θ_i	expected value of the number of visits to Component i
R_i	reliability of Component i
R_s	reliability of the system
T_{p,θ_i}	relative change of the system reliability as θ_i is changed by $100p\%$
S_{p,θ_i}	sensitivity of the relative change of the system reliability to θ_i when θ_i is changed by $100p\%$
T_{p,R_i}	relative change of the system reliability as R_i is changed by $100p\%$
S_{p,R_i}	sensitivity of the relative change of the system reliability to R_i as R_i is changed by $100p\%$
p_{ij}^{E}	erroneous transition probability with respect to the estimated software usage used in the test
p_{ij}^{T}	true transition probability regarding the true software usage
ε_{ij}	error corresponding to p_{ij}, i.e. $\varepsilon_{ij}=p_{ij}^{\mathrm{E}}-p_{ij}^{\mathrm{T}}$
ρ_{ij}	relative error, i.e. $\rho_{ij}=\varepsilon_{ij}/p_{ij}^{\mathrm{T}}$
ρ_i	relative error of transition probability in Component i, i.e. $\rho_i=-\rho_{ij}p_{ij}^{\mathrm{T}}/(1-p_{ij}^{\mathrm{T}})$
$T_{p,P_{ij}}$	relative change of the system reliability as p_{ij}^{T} is changed by $100p\%$
$S_{p,P_{ij}}$	sensitivity of the relative change of the system reliability to p_{ij}^{T} as p_{ij}^{T} is changed by $100p\%$
T_{p,ρ_i}	relative change of the system reliability as ρ_i is changed by $100p\%$
S_{p,ρ_i}	sensitivity of the relative change of the system reliability to ρ_i as ρ_i is changed by $100p\%$

2.2. Reliability assessment

To construct a component-based software, it involves assembling components together, allowing plug-and-play in a collection of self-contained and loosely coupled components, and interactions among these integrated components (Lyu, 1996; Musa, 1998). Such an approach facilitates software construction and has been increasingly adopted for software development. Due to the complex characteristics of a component-based software, the assessment of the reliability of a software system contains two major tasks: the estimation of the reliability of a component-based system and the estimation of the reliabilities of its individual components. The novelty of this integrated approach presented here lies in the fact that not only the failure behavior of each component