Measurement-Based Analysis of Networked System Availability

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1 Introduction

The dependability of a system can be experimentally evaluated at different phases of its life cycle. In the design phase, computer-aided design (CAD) environments are used to evaluate the design via simulation, including simulated fault injection. Such fault injection tests the effectiveness of fault-tolerant mechanisms and evaluates system dependability, providing timely feedback to system designers. Simulation, however, requires accurate input parameters and validation of output results. Although the parameter estimates can be obtained from past measurements, this is often complicated by design and technology changes. In the prototype phase, the system runs under controlled workload conditions. In this stage, controlled physical fault injection is used to evaluate the system behavior under faults, including the detection coverage and the recovery capability of various fault tolerance mechanisms. Fault injection on the real system can provide information about the failure process, from fault occurrence to system recovery, including error latency, propagation, detection, and recovery (which may involve reconfiguration). But this type of fault injection can only study artificial faults; it cannot provide certain important dependability measures, such as mean time between failures (MTBF) and availability. In the operational phase, a direct measurement-based approach can be used to measure systems in the field under real workloads. The collected data contain a large amount of information about naturally occurring errors/failures. Analysis of this data can provide understanding of actual error/failure characteristics and insight into analytical models. Although measurement-based analysis is useful for evaluating the real system, it is limited to detected errors. Further, conditions in the field can vary widely, casting doubt on the statistical validity of the results. Thus, all three approaches - simulated fault injection, physical fault injection, and measurement-based analysis - are required for accurate dependability analysis.

In the design phase, simulated fault injection can be conducted at different levels: the electrical level, the logic level, and the function level. The objectives of simulated fault injection are to determine dependability bottlenecks, the coverage of error detection/recovery mechanisms, the effectiveness of reconfiguration schemes, performance loss, and other dependability measures. The feedback from simulation can be extremely useful in cost-effective redesign of the system. For
thorough discussion of different techniques for simulated fault injection can be found in [15].

In the prototype phase, while the objectives of physical fault injection are similar to those of simulated fault injection, the methods differ radically because real fault injection and monitoring facilities are involved. Physical faults can be injected at the hardware level (logic or electrical faults) or at the software level (code or data corruption). Heavy-ion radiation techniques can also be used to inject faults and stress the system. The detailed treatment of the instrumentation involved in fault injection experiments using real examples, including several fault injection environments is given in [15].

In the operational phase, measurement-based analysis must address issues such as how to monitor computer errors and failures and how to analyze measured data to quantify system dependability characteristics. Although methods for the design and evaluation of fault-tolerant systems have been extensively researched, little is known about how well these strategies work in the field. A study of production systems is valuable not only for accurate evaluation but also for identifying reliability bottlenecks in system design. In [15] the measurement-based analysis is based on over 200 machine-years of data gathered from IBM, DEC, and Tandem systems (note that these are not networked systems).

In this chapter we discuss the current research in the area of experimental analysis of computer system dependability in the context of methodologies suited for measurement-based dependability analysis of networked systems. We use examples of LAN of UNIX-based workstations, LAN of Windows NT-based computers, and Internet to present methods for collecting and analyzing failure data to obtain dependability characterization of the network.

2 Measurement-Based Studies of Computer System Availability

There are many possible sources of errors, including untested manufacturing faults and software defects, transient errors induced by radiation, power surges, or other physical processes, operator errors, and environmental factors. The occurrence of errors is also highly dependent on the workload running on the system. A distribution of operational outages from various error sources for several major commercial systems are reported in [35].

There is no better way to understand dependability characteristics of computer systems (including networked systems) than by direct measurements and analysis. Here, measuring a real system means monitoring and recording naturally occurring errors and failures in the system while it is running under user workloads. Analysis of such measurements can provide valuable information on actual error/failure behavior, identify system bottlenecks, quantify dependability measures, and verify assumptions made in analytical models. Given field error-data collected from a real system, a measurement-based study consists of four steps, as shown in Fig. 1: 1) data processing, 2) model identification and