SELF-DIAGNOSIS FOR PARALLEL COMPUTERS

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Abstract

The growing importance of fault-tolerance for computing systems has made self-diagnosis a topic of considerable interest, since efficient self-diagnosis is a prerequisite for any fault-tolerant system behavior. In this paper, self-diagnosis of systems with multiple processing elements is considered where each element may enter into the diagnosis of other elements. We shall develop a formal model for self-diagnosis based on comparison testing. In particular, we consider tree machines suitable for VLSI-implementation.

1. Introduction

Technology has made possible the development of powerful computing systems as networks of many VLSI-components with the complexity of sophisticated processors [1]. It has been estimated that networks (parallel computers) comprising as many as $10^5$ interconnected modules will soon be technically feasible. Since reliability decreases with increasing system complexity it will then be necessary to provide for redundancy and to incorporate into the network modules the ability to test one another and to diagnose malfunctions. We shall assume that testing among modules is done by comparison. That is, two modules test one another by executing the same specific test program; a third module compares their outputs and signalizes an error if and only if these outputs disagree. We have, however, to make sure that from the begin of a test round up until the end of diagnosis no additional failures occur. Hence, tests and diagnosis must not be time consuming.

A (binary) tree structured network computer, the tree machine, efficiently implementable in VLSI-technology is described by Bentley and Kung [2]. The structure of the tree machine is illustrated by Figs. 1 and 2. It contains three types of modules: processing elements (PE, squares) which store and compute data, input elements (circles) which broadcast data (from the root to the PEs), and output elements (OE, triangles) which combine their inputs. The tree machine is controlled by a control unit CU. Bentley and Kung identified a large set of problems which can be solved efficiently by the tree machine. The tree machine can be si-
mulated by a set of conventional processors operating on a shared memory. It also provides a convenient model for understanding and analysing parallel algorithms. In the following we shall show how self-diagnosis can be efficiently implemented into parallel computers such as the tree machine.

![Tree Machine Structure](image1)

**Fig. 1** Structure of the tree machine

![Tree Machine Layout](image2)

**Fig. 2** A layout of the tree machine

### 2. Diagnostic model

Consider a system $S$ (a parallel computer) consisting of set $N$ of $n$ modules $u_1, u_2, \ldots, u_n$, and a test assignment $E = \{(u_i, u_j) | u_i$ and $u_j$ test one another by comparison$\}$. Thus, the test arrangement is given by the finite, undirected testing graph $G = (N, E)$. Without loss of generality we can assume that $G$ is connected. When units $u_i$ and $u_j$ test one another the test outcome $t_{ij}$ is 1 if both units are fault-free and 0 otherwise. Thus, $t_{ij} = 0$ indicates a malfunction of $u_i$ or $u_j$ or both. A complete set of test outcomes is called a syndrome. Given a syndrome $\text{SYN}$, the system $S$ has to identify its faulty modules from the knowledge of $\text{SYN}$ (diagnosis).

That is, $S$ has to partition $N$ into fault-set $F$ and its complement $H$ where $F$ is the set of all faulty modules. Each partition $(H, F)$ of $N$ determines a syndrome uniquely. A syndrome, however, can be generated by several partitions. In order to accomplish reliable self-diagnosis we have to limit the number of faulty modules in $S$. In practice, only a small fraction $t/n$ of all modules will be faulty. Further, in order to prevent congestion of the system by tests, it is reasonable to avoid unnecessary tests. Therefore, we define:

**Definition:** A self-diagnosing system $S$ and its testing graph $G$ are $t$-diagnosable ($t$-db) if for all syndromes of $S$ all faulty modules in $S$ can be identified, provided the number of faulty modules present does