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Fault Tolerant Datapath Synthesis Starting with Triple Algorithm Redundancy

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Today, integrated circuits are indispensable for our life. They exist everywhere, and play important roles in information technology (IT) infrastructures and personal IT services. Under the situation that we heavily depend on IT equipments and IT services, faults and breakdowns of large-scale integration (LSI) bring serious failures and disasters. Therefore, fault-tolerance is an important technology for LSIs. Error detection and retry for transient faults and triple modular redundancy for both transient and permanent faults are typical approaches to fault-tolerance. Triple modular redundancy is a simple technique and easy to apply, but its hardware overhead is high. To reduce the hardware overhead, isolating faulty parts and reconfiguring a system have been proposed. When we retry computations or reconfigure a system, services must be stopped temporarily. It is important to develop a fault-tolerant technique having low hardware overhead and high real-time-ness.

Algorithm based fault tolerance (ABFT) is known as a fault-tolerant technique having low hardware overhead and high real-time-ness. However, this technique can be applied to only a computational algorithm based on linear algebra. Aiming at a universal technique which can be applied to various computation algorithms, a basic concept of fault-tolerant datapath synthesis has been proposed. It is based on triple algorithm-level redundancy, and it tries to find a design point by optimizing the trade-off between the amount of hardware resources and execution time. For a synthesized datapath having a fault-tolerant property, hardware sharing (functional unit (FU) sharing by operations, and register sharing by data) is severely limited. This limitation makes the synthesis problem complicated. Arbitrariness of positions of vote operations make the problem more harder.

In this research, assuming that positions of vote operations are given, we investigate the problem to synthesize a fault-tolerant datapath from a triplicated computation algorithm. Major tasks of this datapath synthesis are scheduling and resource assignment (especially functional unit assignment), both of which are heavily constrained by the requirement of fault-tolerance. We propose two methods to do them, one is a method using integer linear programming (ILP) framework, and the other is a heuristic method. In the first part, we show that all of the schedule constrains, resource assignment constraints, and the other constrains relevant to fault-tolerance are written with the linear algebra, and we demonstrate that a small size problem can be solved in a practical computation time. In the second part, we develop a heuristic algorithm to find a schedule and an FU assignment, which satisfy schedule constraints, resource sharing constraints and fault-tolerant constraints. The method partitions an input algorithm into sub-computations named "cones." In our method, scheduling and FU assignment are done for one cone while considering its related cones. Once a cone is selected to be processed, at first, FU assignment is performed so that fault-tolerant constraints are met and loads of FUs are balanced. After that, a list scheduling technique is applied to operations in the cone. The experimental results show that our heuristic algorithm terminates quickly even for medium and large size problems, and outputs a comparable solution to the ILP-based method, or a reasonable solution which is sufficiently near the lower bound.

The proposed datapath synthesis method enables us to design a cost efficient fault-tolerant datpath with a reasonable design time. Fault-tolerant register assignment and overall synthesis method including the optimization of the positions of vote operations are future problems.