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Assignment-Driven Pipeline Scheduling and Its Application to Data-Path Synthesis

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In Computer Aided Design(CAD) and Design Automation(DA) of VLSI(Very Large Scale Integarted Circuit)s, top-down transformation technology is widely used, which transforms the system level discription located at the highest hierarchical level to register transfer(RT)level discription and logic level discription. Data-path synthesis is the task to synthesize the RT level structure which consists of functional units, registers and the other interconnection resources such as nets, buses, and multiplexors, and RT level behavioral description from a given algorithm in the behavioral domain. Data-path synthesis includes three major interdependent sub-problems, such as functional unit and register allocation, operation scheduling, and assignment of operations and data to functional units and registers. The RT level structural and behavioral discriptions are synthesized by using solutions of there three major sub-problems. Unfortunately, it is known that each sub-problem belongs to $\mathcal{NP}$-complete class, and it will be difficult to find the optimum solution for instances with middle or larger sizes.

Most of the conventional data-path synthesis assumes VLSIs whose area and performance are dominated by the number and performance of functional units, and aims mainly to minimize the number of control steps and the number of functional units. Then they adopt resource constraint schduling or time constraint scheduling first to decide scheduling and the number of functional units, which is followed by resource assignments, generation of connectivity, generation of floorplan sequentially. However, by the development of VLSI submicron-technology, the minimum feature size becomes smaller under 0.25 micro meters. In such deep submicron VLSIs, the signal transmission delay induced by wires becomes a dominant factor for the total computation time, and it cannot be ignored anymore for evaluating system performance. Hence, it is indispensable to develop a data-path synthesis method which can respect the signal transmission delay induced by wires and hence the connectivity or floorplan optimality throughout the synthesis process.

In this research, we studied pipeline scheduling problems under given oparation to functional unit and data to register assignments, which is one of the key tasks in data-path synthesis based on the assignment solution space exploration, and we proposed an approach using parametric scheduling graph with disjunctive arcs generated from the specified assignment information.

At first, we show that the lifetime collison between oprations o_a and o_b or data(d_a and d_b) which are assigned to a same resource in the pipeline scheduling can be avoided if and only if there exists such an integer $K_{ab}(R_{ab})$ that the lifetime of the operation o_a executed in i th iteration(the data d_a generated in i th iteration) precedes the lifetime of the operation o_b executed in $i - K_{ab}$ th iteration(the data d_b generated in $i - R_{ab}$ th iteration), and at the same time the lifetime of the operation o_b executed in $i - K_{ab}$ th iteration(the data d_b generated in $i - R_{ab}$ th iteration) precedes the lifetime of the operation o_a executed in $i + 1$ th iteration(the data d_a generated in $i + 1$ th iteration). To represent these constraints explicitly, we introduce a parametric scheduling graph which is derived from the initial scheduling graph by adding disjunctive arcs with a function of integer variable $K_{ab}(R_{ab})$ as its delay factor. As a result, the pipeline schduling problems is now reduced to the problem to find integer values for variables $K_{ab}(R_{ab})$ for all pair of operations(data)assigned to a same resource.

Next we show that the range of possible values for each unknown variable K_{ab} can be given using the longest path length on the scheduling graph from one operation to the other which shares a same resource with the former, and the one for R_{ab} can be given also in a similar way. Based on the above considerations, we derive an efficient scheduling method based on branch-and-bound exploration of the parameter space together with range computation whose results are used for branching solution space. Moreover, we developed a heuristic range reduction technique which always reduces a range of possible values for one variable into a single integer.

Finally, as an application of the proposed scheduling method, it is incorporated with SA based exploration of assignment solution space, and data-paths of the 5th order elliptic wave filter are synthesized. As the result, the data-path with fewer number of point-to-point connections than ever under a given iteration period is obtained within a reasonable computation time.

In this research, we limited input dependence graph to a strongly connected graph, and scheduling(especially the decision of ranges of possible values for K_{ab}, R_{ab})for non-strongly connected input dependence graphs is left for a future problem. Development of better heuristics is also important for applying SA based exploration of assignment space to larger and practical problem instances.