Lower Bounds on the Power Consumption in Scheduled Data Flow Graphs with Resource Constraints†

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Abstract

The problem of estimating lower bounds on the power consumption in scheduled data flow graphs with a fixed number of allocated resources prior to binding is addressed. The estimated bound takes into account the effects of resource sharing. It is shown that by introducing Lagrangian multipliers and relaxing the low power binding problem to the Assignment Problem, which can be solved in $O(n^3)$, a tight and fast computable bound is achievable. Experimental results show the good quality of the bound. In most cases, deviations smaller than 5% from the optimal binding were observed. The proposed technique can for example be applied in branch and bound high-level synthesis algorithms for efficient pruning of the design space.

1. Introduction

This paper addresses the problem of lower bound estimates for low power HLS and related applications. In particular, a lower bound estimation procedure for the power consumption of datapath resources, i.e. registers and functional units (FUs) like adders and multipliers, in scheduled data flow graphs (DFGs) with resource constraints for a given input data stream is given. In the assumed design flow the binding of operations and variables to functional units and registers respectively follows allocation and scheduling. Different bindings produce most probably different datapath activities due to the varying data multiplexing schemes if resources are shared.

Due to the given schedule, a square power cost matrix *PCM* as defined in [1] suffices to store all required cost information.

2. Problem Formulation and Results

The ILP $z = \min \sum_{i,j=1}^{n} PCM_{ij} x_{ij}$ subject to $x_{ij} \in \{0, 1\}$ and the cyclic constraints:

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1, \ldots, n$$

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad j = 1, \ldots, n$$

$$\sum_{i \geq j} x_{ij} = m$$

provides a lower bound on the power consumption for m resources by discarding the precedence constraints resulting from the given schedule. $x_{ij} = 1$ iff operation/variable i precedes directly operation/variable j in the binding on the same ressource.

The solution of the ILP is approximated from below by relaxing the constraint $\sum_{i \geq j} x_{ij} = m$ with Lagrange multipliers [2] and iteratively solving the resulting ILP with the Hungarian method [3]. Table 1 shows the good quality of the bound for an image low pass filter (LPF), a FDCT (both transforming images), and the EWF HLS benchmark (speech input signal). Two different cost functions are applied: The avg. Hamming distance at the ressources inputs and a RTL power model. At most 10 Lagrange iterations were needed to produce these results. It took about 8 s for a 200 operation problem instance.

Table 1. Deviation of lower bound from best binding in %, averaged over all possible resource constraints.

benchmark	ressource type	Hamming distance	power model
LPF	add	0.2	0.4
FDCT	add	0.3	0.4
	mul	4.9	0.6
EWF	add	0.6	0.5
	mul	1.7	0.3

3. References

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[3] C.H. Papadimitriou, K. Steiglitz, "Combinatorial Optimization, Algorithms and Complexity", Prentice Hall, Inc., 1982

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