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Heuristics For Backplane Ordering*

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Abstract—**The Board Permutation Problem, a backplane ordering problem, has been previously shown to be NP-hard. We develop here several heuristics for the Board Permutation Problem. These heuristics produce solutions that are locally optimal with respect to some nontrivial transforms. The heuristics are analytically shown to be $m/3$-approximate, where m is the number of nets in a problem instance. The heuristics have been shown experimentally to have quite acceptable behavior. Several of the heuristics make use of a statistical mechanics technique (simulated annealing) for thermal equilibrium analysis in producing their solution.**
Keywords and Phrases: **board permutation, backplane wiring, design automation, heuristics, local optimality, transforms, statistical mechanics, and thermal equilibrium.**

1. INTRODUCTION

Complex digital systems are often decomposed into functional units, which are individually designed and implemented. The result is a collection of boards, that when properly interconnected, serve as the desired digital system. Prior to wiring the interconnections, the boards are arranged in some linear arrangement or permutation. Besides the interconnections required to directly implement the nets, other interconnections are then introduced. For example, if a connection must cross a board or boards that are not involved in the net, then a terminal must be placed on each of these intermediary boards to allow the signal to pass through.

The permutation of boards together with all their interconnections is a *backplane*. The size of the backplane is a function of both the size of the individual boards and the interconnections between the boards. If the boards themselves have been constructed to minimize their size, then the backplane area may be minimized by minimizing the space required for the interconnections. The goal of the *Board Permutation Problem,* or *BP,* is to determine a permutation of the boards that minimizes the backplane area. The input to the BP problem is a hypergraph (B,L), where B is set of n boards $\{b_1, \ldots, b_n\}$ and L is a set of m nets $L=\{N_1, \ldots, N_m\}$ on B. In Figure 1a, a BP instance is given. There are eight

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boards and five nets in the example. In Figure 1b a permutation π of B is given. The arcs in the figure are graphic representations of the nets in L.

There are several methods for minimizing the backplane area. One method is to find a permutation that minimizes the maximum number of interconnections among the boards. The premise for this method is that each interconnection requires space, and by minimizing the total number of interconnections, the backplane area is minimized [1, 9, 10, 11].

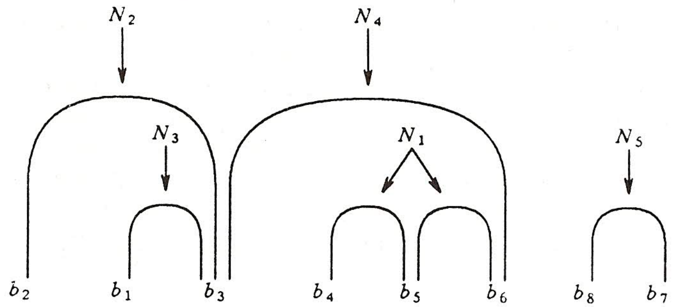
Another method of minimizing the backplane area is explored here. Before proceeding a definition must be given. The *density*(π), where π is a permutation of B, is

$$\max_{1 \leq i \leq n-1} \left(\left| \left(\bigcup_{j=1}^{i} S_{\pi_j} \right) \cup \left(\bigcup_{j=i+1}^{n} S_{\pi_j} \right) \right| \right)$$

where $S_i = \{a | a \in L, b_i \in a\}$, $1 \leq i \leq n$. Informally, the *density*(π) is the maximum number of interconnections between any two adjacent boards in π. Cederbaum [2] showed that minimizing the interconnection density is equivalent to minimizing the backplane area.

$B = \{b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8\}$
$L = \{N_1, N_2, N_3, N_4, N_5\}$
$N_1 = \{b_4, b_5, b_6\}$
$N_2 = \{b_2, b_3\}$
$N_3 = \{b_1, b_3\}$
$N_4 = \{b_3, b_6\}$
$N_5 = \{b_7, b_8\}$

(*a*) - BP Instance



(*b*) - Permutation For Above BP Instance

Figure 1 Sample instance and solution.

Therefore, to minimize the backplane area it suffices to choose a permutation π from Π whose density is minimal (Π is the set of all permutations of B). This method of minimizing the backplane area has also been previously examined by Goto et al. [5] and it is the subject of further exploration here.

Given the above terminology and remarks, the BP problem may be formally expressed:

Input: A set of boards $B = \{b_1, \ldots, b_n\}$; a set of nets $L = \{N_1, \ldots N_m\}$ on B such that $N_i \subseteq B$, $1 \leq i \leq m$ and $\bigcup_{i=1}^{m} N_i = B$.

Output: A permutation π of B such that $density(\pi) = \min_{\omega \in \Pi} \left(density(\omega) \right)$.

In Figure 1b the permutation has density 2. The density of 2 occurs in several places in the permutation, for example between boards b_4 and b_5. An examination of the problem instance shows that this permutation has optimal density.

The algorithms, which are developed here and elsewhere to minimize the backplane area by minimizing the maximum density of interconnection, have a variety of other applications. One application is in the *Gate Array Layout problem* or *GAL* [12]. In the GAL problem the input is a set of cells, where a cell is some basic electrical and logical unit. The cells are to be laid out and interconnected in a regular fashion, typically in a matrix-like form. This structure, a *gate array,* may be built both economically and with fast turnaround. The gate array has both interconnections among the columns of cells and intraconnections within a column of cells. A part of the output solution is a gate array whose size is minimal. Algorithms for the BP problem may be applied to each individual column to order the column's cells in a manner that minimizes the impact of intracolumn connections. The BP algorithms can then be applied on a higher hierarchical level to order the columns themselves in a manner that minimizes the impact of intercolumn connections.

The BP problem is a generalization of the NP-Hard *Minimum Cut Linear Arrangement problem* or *MCLA* [4]. MCLA restricts the size of the N_i's in L such that $|N_i| = 2$, $1 \leq i \leq n$. Such a restriction reduces the input from a hypergraph to a graph. As any alogrithm for BP is also an algorithm for MCLA, BP is NP-hard. Contemporary analysis strongly suggests that there is no deterministic, polynomial-time algorithm for any NP-hard problem. So, alternative methods of dealing with BP must then be explored. One alternative is to develop low-order, polynomial-time algorithms for special cases of BP problem. For example, we have developed two algorithms *Bpd1* and *Bpd2,* which determine whether the optimal density is 1 or 2 respectively [3]. Another special case that can be considered is the reduced BP problem, MCLA. Though MCLA as stated earlier