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Author(s)	小川，真一
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Description	Supervisor:金子　峰雄，情報科学研究科，修士

Auxiliary Objective Function Approach to Simulated Annealing Based Rectangle Packing

Shinichi Ogawa (210015)

School of Information Science,,
Japan Advanced Institute of Science and Technology

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Placement is the problem to find coordinates of modules on a plane, and is one of major subtasks in the layout design of VLSIs. While the size of the solution space for the placement is originally $\mathbb{R}^{2n}$ where n is the number of modules, Murata, et al, proposed a finite size of solution space for the placement by using a coding scheme called "sequence pair". Sequence pair is a pair of permutations of module names. Murata, et al, found the rule to connect the positional relation of modules in the sequence pair and the spatial relation of modules on a plane, and they also proposed encoding algorithm (that is, conversion from a given placement to a sequence pair) and decoding algorithm (that is, conversion from a sequence pair to a placement).

Since many of the placement problems with different objectives are known to be in NP-hard, Simulated Annealing is often used to find sub-optimal solution within a reasonable computation time. However, as the size of a circuit integrated on a chip becomes larger, the computation time of the simulated annealing also becomes longer. As a result, how to reduce the computation time while keeping the quality of solution becomes a serious problem in these days.

When we focus our attention on rectangle packing problem and simulated annealing for it, a lot of neighbor solutions may have a same cost value. It is because each solution is evaluated by the size of the smallest rectangle enclosing all rectangles to be packed (we call it Bounding-Box). According to a nature of SA, any neighbor solution having the same cost value with the current solution will be accepted unconditionally. However, to reduce the size of Bounding-Box, it is necessary to cancel lines of modules (critical paths) which decide the width or the height of the Bounding-Box. If we can distinguish solutions whose critical paths are easily canceled, and suppress the acceptance of the other solutions, it is expected that a solution will be improved within a smaller moving steps in SA.

In this research, we have introduced an auxiliary objective function called "cut degree", which reflects easiness/hardness of the cancellation of critical paths, and have proposed selective acceptance of neighbor solution, while its major cost (that is, area of the Bounding-Box) is the same with the current solution, by this cut degree for improving convergency property of SA based rectangle packing.

Cut degree is now defined as the minimum number of modules which are requested to move from their current position for canceling all critical paths in either horizontal-direction or in vertical-direction. Since a neighbor solution is now generated from a current solution by applying either (1)move one rectangle, (2) exchange two rectangles or (3) rotate one rectangle, the cut degree is identical to the minimum number of steps (that is, visited solutions) until the major cost is improved. An algorithm to compute the cut degree is outlined as follows. First we construct a critical path graph, whose vertices are the left side (denote it as s) and the right side (denote it as t) (or the upper side (s) and the lower side (t)) of the Bounding-Box and rectangles on critical paths in horizontal (vertical) direction, and whose edges are left-right (above-below) relations on critical paths. On this critical path graph, we will compute maximum flow from s to t under the constraint that vertex flow capacitance equals to 1. Then, from Maximum Flow Minimum Cut theorem, the computed maximum flow is the exact cut degree.

By evaluating cut degree of a placement, we can suppress the acceptance of neighbor solutions having comparable main cost value and larger cut degree, all of which were accepted unconditionally in the conventional SA. As a result, it is expected that the number of steps needed to reach an improved solution will be reduced and hence the convergency of SA will be improved.

The proposed system is implemented using C language, and various experiments have been done. In our proposed system, there are several options and parameters, such as (1)way to incorporate cut degree with the main objective; (1-a) decision of acceptance will be made in two steps, the first using the main objective followed by the second using cut degree, or (1-b) decision will be made using a single generic objective function composed of the original main objective and the cut degree, (2) how to arrange the cut degree for horizontal critical paths and the one for vertical critical paths; (2-a) the sum of them, or (2-b) the minimum of two, (3) temperature annealing schedule, etc. Through experiments, the performances using different options and different parameters are compared to find best choice of options and parameters.

In this research, we have focused our attention on the rectangle packing problem whose objective is to minimize the area of Bounding-Box. However, in a practical placement problem, not only the layout area but also wire relevant metric, such as total wire length and wire congestion become objective to be optimized. A choice of an auxiliary objective function to improve convergency of SA for placement problem considering both layout area and wire length is left as a future work.