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SIMULATED ANNEALING - AN EXCELLENT METAHEURISTIC FOR COMBINATORIAL OPTIMIZATION

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ABSTRACT

Effective and flawless solution for the combinatorial advancement issues in distinctive streams have been a territory of exploration from long time. Designing, Industrial, Economical and Scientific issues, for example, Transportation, Bioinformatics, Logistics, Scheduling, Timetabling, Vehicle Routing, Resource Allocation and numerous other are handled with different methodologies, for example, Simulated Annealing, Tabu Search, Genetic Algorithms, Ant Colony Optimization, Harmony Search, Scatter Search or Iterated Local Search. These strategies referred to as metaheuristics presents itself as exceedingly guaranteeing decision for about ideal arrangements in sensible time where careful methodologies are not appropriate because of amazingly vast running times or different constraints. Metaheuristic is an amazing methodology that aides and alters different heuristics to create arrangements past those that are typically produced in a mission for neighborhood optimality. This paper highlights the productivity of a metaheuristic methodology, Simulated Annealing, which is continuously utilized by the specialists now days in a few Engineering, Scientific, Business and Industrial applications.

KEYWORDS - Simulated Annealing, Metaheuristics, Combinatorial Optimization, Engineering and Industrial Automation, Heuristics, VLSI Floorplanning

1. INTRODUCTION

Metaheuristics are used to solve Combinatorial Optimization Problems*,* like Bin Packing, Network Routing, Network Design, Assignment Problem, Scheduling, or Time-Tabling Problems, Continuous Parameter Optimization Problems*,* or Optimization of Non-Linear Structures like Neural Networks or Tree Structures as they often appear in Computational Intelligence.

Metaheuristics are generally applied to problems for which there is no satisfactory problem-specific algorithm or heuristic; or when it is not practical to implement such a method. Most commonly used Metaheuristics are focused to combinatorial optimization problems, but obviously can handle any problem that can be recast in that form, such as solving Boolean equations.

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2. HEURISTICS AND METAHEURISTICS

Heuristic refers to “discover”. A Heuristic is used when

1. Exact method are not on any help, due to execution time
2. There are errors in input data or is unreliable
3. Improvement in the performance of exact methods is required
4. There is need of a solution after a limited period of time.
5. We have to choose between addressing a more realistic model and provide an approximate solution instead of a simpler, unrealistic model that we can prove that can solve to optimality.
6. There is need of good starting points for an exact method.

3. DISADVANTAGES OF USING HEURISTICS

1. In many cases, convergence is generally guaranteed
2. Optimality may be achieved but it is not proved
3. In many cases, they may not be able to generate a feasible solution.

Metaheuristics are said to be high level procedures which coordinate simple heuristics such as local search, to find solutions that are of better quality than those found by simple heuristics done.

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4. COMMONLY USED METAHEURISTICS

- Tabu search [Glover, 89 et 90]
- Simulated Annealing [Kirckpatrick, 83]
- Threshold accepting [Deuck, Scheuer, 90]
- Variable neighborhood [Hansen, Mladenovi´c, 98]
- Iterated local search [Loren¸co et al, 2000]
- Genetic Algorithm, Holland 1975 – Goldberg 1989
- Memetic Algorithm, Moscatto 1989
- Ant Colony Optimization, Dorigo 1991
- Scatter search, Laguna, Glover, Marty 2000

Countless variants and hybrids of these techniques have been proposed, and many more applications of Metaheuristics to specific problems have been reported. This is one of the active fields of research, with a considerable literature, a large community of researchers and users, and a wide range of applications.

Traditional methods of search and optimization are too slow in finding a solution in a very complex search space, even implemented in supercomputers. Metaheuristics consist of number of methods and theories having robust search method requiring little information to search effectively in a large or poorly-understood search space. There exists an extensive range of problems which can be formulated as obtaining the values for a vector of variables

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subject to some restrictions. The elements of this vector are denominated decision-variables, and their nature determines a classification of this kind of problems. Specifically, if decision-variables are required to be discrete, the problem is said to be combinatorial. The process of finding optimal solutions (maximizing or minimizing an objective function) for such a problem is called combinatorial optimization.

Combinatorial optimization problems have been traditionally approached using exact techniques such as Branch and Bound (Lawler and Wood, 1966). Finding the optimal solution is ensured with these techniques but, unfortunately, they are seriously limited in their application due to the so-called combinatorial explosion. As an example, consider the Traveling Salesman Problem (TSP). This problem (obtaining a minimal Hamiltonian tour through a complete graph of n nodes) is a classical example of NP-complexity: the work-area to be explored grows exponentially according with the number of nodes in the graph, and so does the complexity of every know algorithm to solve this problem. It is not only a good example of a combinatorial optimization problem, but also an approach to real problems like VLSI-design or X-ray Crystallography.

5. SIMULATED ANNEALING – A METAHEURISTIC TECHNIQUE

Simulated Annealing is commonly said to be the oldest among the metaheuristics and surely one of the first algorithms that had an explicit strategy to avoid local minima. The fundamental idea is to allow moves resulting in solutions of worse quality than the current solution (uphill moves) in order to escape from local minima. The probability of doing such a move is decreased during the search.

The name Simulated Annealing (SA) is taken from annealing in metallurgy, a well known technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. The heat makes the atoms become unstuck from their initial positions (a local minimum of the internal energy) and stroll randomly through states of elevated energy; the slow cooling gives more chances of finding configurations with lower internal energy than the initial one.

Each step in the SA algorithm replaces the current solution by an arbitrary "nearby" solution, chosen with a probability which depends on the difference between the corresponding function values and on a global parameter T (called the temperature), that is gradually decreased during the process. The dependency is such that the current solution changes almost randomly when T is large, but increasingly "downhill" as T goes to zero.

The method was independently described by Scott Kirkpatrick, C. Daniel Gelatt and Mario P. Vecchi in 1983, and by Vlado Černý in 1985. The method is an adaptation of the Metropolis-

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Hastings algorithm, a Monte Carlo method to generate sample states of a thermodynamic system, invented by N. Metropolis et al. in 1953.

The table below shows the mapping of physical annealing to Simulated Annealing.

Thermodynamic Simulation	**Combinatorial Optimization**
System States	Feasible Solutions
Energy	Cost
Change of State	Neighboring Solutions
Temperature	Control Parameter
Frozen State	Heuristic Solution

Table 1: Relationship between physical annealing and Simulated Annealing

Using these mappings, any combinatorial optimization problem can be converted into an annealing algorithm.

The major advantage of SA over other methods is an ability to evade becoming trapped at local minima. This algorithm employs a random search, which not only accepts changes that decrease objective function, f, but also some changes that increase it. The latter are accepted with a probability

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$$p = \exp(-\delta f/T)$$

where δf is the increase in f and T is a control parameter.

The algorithm starts by generating an initial solution and by initializing the temperature parameter T. Then the following is repeated until the termination condition is satisfied: A solution s' from the neighborhood N(s) of the solution s is randomly sampled and it is accepted as new current solution depending on f(s), f(s') and T. s' replaces s if f(s') < f(s) or, in case f(s') >= f(s), with a probability which is a function of T and f(s') - f(s). The probability is generally computed following the Boltzmann distribution exp(-(f(s') - f(s))/T).

The temperature T is decreased during the search process, thus at the beginning of the search the probability of accepting uphill moves is high and it gradually decreases, converging to a simple iterative improvement algorithm. This process is analogous to the annealing process of metals and glass, which assume a low energy configuration when cooled with an appropriate cooling schedule. Regarding the search process, this means that the algorithm is the result of two combined strategies: random walk and iterative improvement. In the first phase of the search, the bias toward improvements is low and it permits the exploration of the search space; this erratic component is slowly decreased thus leading the search to converge to a (local) minimum. The probability of accepting uphill moves is controlled by two factors: the difference of the objective functions and the temperature. On the one hand, at fixed

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temperature, the higher the difference f(s')- f(s), the lower the probability to accept a move from s to s'. On the other hand, the higher T, the higher the probability of uphill moves.

5.1 COMPONENTS IN SIMULATED ANNEALING

- Solution space
- Cost function
    - Determines how "good" a particular solution is
- Perturbation rules

  (Transforming a solution to a new one)
- Simulated Annealing engine
    - A variable T, analogous to temperature
    - An initial temperature T_0 (T_0 = 40,000)
    - A freezing temperature Tempfreezing (Tempfreezing = 0.1)
    - A cooling schedule (T = 0.95 * T)

Another variant of Simulated Annealing also exists with the name Adaptive simulated annealing (ASA), in which the algorithm parameters that control temperature schedule and random step selection are automatically adjusted with the advancement of algorithm. It makes the algorithm more efficient and less sensitive to user defined parameters than canonical Simulated Annealing.

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5.2 VLSI FLOORPLANNING USING SIMULATED ANNEALING

VLSI design is a method used to build electronic components - microprocessors and memory chips comprising millions of transistors. VLSI design is basically divided into number of phases. The first stage generates a set of indivisible rectangular blocks called cells. In the second stage, interconnection information is used to determine the relative placements of these cells. In the third stage, the goal of optimizing the total area is achieved using various techniques. This is the stage called Floorplan Optimization or simply floorplanning which is considered in this paper using a metaheuristic technique Simulated Annealing. Floorplanning is an important part of the design process, since its area usually dominates the cost of a chip. This paper highlights the the potential of a metaheuristic technique, Simulated Annealing to solve this optimization problem called VLSI floorplanning.

Floorplanning is important in VLSI (Very Large Scale Integrated circuit) design automation. VLSI is the process of creating integrated circuits by combining thousands of transistor-based circuits into a single chip. The VLSI design automation is one of the most computational expensive and complicated processes with significant impact into computer chips manufacturing. The floorplanning problem aims to arrange a set of rectangular modules on a rectangular chip area so as to optimize an appropriate measure of performance. This problem is known to be NP-hard, and is particularly challenging if the chip dimensions are fixed.

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5.2.1 FLOORPLAN PROBLEM

For a set of blocks $B = \{b_1, b_2,\ldots, b_n\}$, block b_i is rectangular and having fixed width and height. The goals of floorplan optimization problem are to minimize the area of B and reduce wire lengths of interconnects subject to the constraints that no pair of blocks overlaps. Floorplanning minimizes a specified cost metric such as a combination of the area A_{total} and wire length W_{total} induced by the assignment of b_i's, where A_{total} is measured by the final enclosing rectangle of P and W_{total} the summation of half the bounding box of pins for each net.

$$Cost = \square * A_{total} + \square * W_{total}$$

Where,

A_{total} = Total area of the packing.

W_{total} = Total wire length of packing.

$\square$ and $\square$ = User specified constant.

CONCLUSION

A great deal of headways are continuously sought after by the analysts in discovering definite answers for the combinatorial enhancement issues utilizing strategies, for example, integer programming, dynamic programming, cutting planes, and branch and cut methods. Still there are a lot of people hard combinatorial issues which are unsolved and needs great heuristic routines. The arrangements acquired as Optimal Solutions is by and large are not according to the prerequisites. The objective and target of utilizing a metaheuristics methodology is to create effective arrangements. The metaheuristics, for example, Simulated Annealing is a standout amongst the most mainstream methodologies to investigate in the field of enhancement and it will bring miracle to the universe of calculations in future.

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