Feasibility Restoration
for Iterative Meta-heuristics Search Algorithms

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Abstract. Many combinatorial optimisation problems have constraints that are difficult for meta-heuristic search algorithms to process. One approach is that of feasibility restoration. This technique allows the feasibility of the constraints of a problem to be broken and then brought back to a feasible state. The advantage of this is that the search can proceed over infeasible regions, thus potentially exploring difficult to reach parts of the state space. In this paper, a generic feasibility restoration scheme is proposed for use with the neighbourhood search algorithm simulated annealing. Some improved solutions to standard test problems are recorded.

Keywords: Meta-heuristic, Combinatorial optimisation problems, Feasibility restoration, simulated annealing

1 Introduction

Iterative meta-heuristic search algorithms such as simulated annealing (SA) and tabu search (TS) are often implemented to solve combinatorial optimisation problems (COPs) using simple neighbourhood operators such as 2-opt, move and inversion [12]. In many cases, infeasible space is ignored, yet it could lead to other regions of the space in which higher quality solutions reside. One way to traverse this space is by the process of feasibility restoration. This technique allows the feasibility of the constraints of a problem to be broken and then brought back to a feasible state, thus traversing infeasible regions.

Feasibility restoration algorithms have typically been designed for specific problems [1,4,5,6,8,9]. A few examples will be detailed here. Chu and Beasley [5] use a heuristic to repair solutions generated by a genetic algorithm to solve generalised assignment problems (GAPs). It simply reassigns jobs from overcapacitated agents to agents that have some spare capacity. Kämpke [9] uses a similar approach in solving bin packing problems. After two items from different bins have been swapped, the capacity restriction of either of the bins may be violated. Therefore, another function is used to assign the largest item in the overfilled bin to the bin with the most spare capacity. Hertz, Laporte and Mit-taz [8] use augmented local search operators on a variant of the vehicle routing problem (VRP) known as the capacitated arc routing problem. Hertz et al. [8] employ the PASTE operator which merges various vehicle routes. Often the feasibility (in the form of vehicle capacity) of the solution is violated so as such
a new heuristic operator, known as SHORTEN, replaces portions of the route with shorter paths while still maintaining the required edge set.

Abramson, Dang and Krishnamoorthy [1] use an entirely different approach to any of the above. They use the general 0-1 integer linear programme (ILP feasibility restoration method of Connolly [7] (explained in Section 2), but tailor it to suit the set partitioning problem.

The characterisation of the aforementioned feasibility restoration schemes is that they are all tailored to solve specific optimisation problems. As such, if a problem definition changes or a new problem is required to be solved, new feasibility restoration algorithms would need to be developed. This paper presents the opposite approach by investigating a new generic feasibility restoration algorithm. This paper is organised as follows. Section 2 describes how feasibility restoration can be achieved in a generic manner. This is given in the context of a general modelling system for combinatorial optimisation problems (COPs) based on linked lists. Section 3 details the experiments and results of feasibility restoration using SA. Section 4 gives the conclusions.

2 Generic Feasibility Restoration

One of the first attempts at generic feasibility restoration was by Connolly [7] in a programme called GPSIMAN. GPSIMAN is a general purpose SA solver that accepts 0-1 ILPs. It incorporates a general mechanism for restoring feasibility of the system after each transition.

The feasibility restoration technique flips variables (other than the original variable changed by the SA process, called the primary transition) in order to obtain a new feasible solution. The scheme employed by Connolly [7] is a heuristic technique whereby a score is computed for each of the variables based on how helpful a change in the variable value would be for feasibility restoration. The most helpful variable (the one with the highest score) is flipped and the resulting feasibility/infeasibility is recalculated. If feasibility has been restored, the procedure is terminated. However, in many instances, particularly for 0-1 problems which have many related constraints, this is not the case. The algorithm proceeds to calculate the next most helpful variable. This progresses as a depth wise tree search, in which the algorithm can backtrack, should it find that the current sequence of flips cannot restore feasibility. This procedure is only useful if feasibility is relatively easy to restore, else the search for feasibility can quickly degenerate. If the process cannot restore feasibility after a fixed number of searches, then the primary transition is rejected.

According to Abramson and Randall [2], this algorithm is very slow and only effective for very small problems (such as a 5 city travelling salesman problem). In fact, they report that typically the restoration part of the algorithm takes 30% of the runtime. As such, in order for feasibility restoration to be usable, a new approach needs to be developed. The rest of this section outlines possible algorithms based on the linked list modelling system (explained next) and local neighbourhood search operators.