Advances in Local Search for Satisfiability

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Abstract. In this paper we describe a stochastic local search (SLS) procedure for finding satisfying models of satisfiable propositional formulae. This new algorithm, gNovelty$^+$, draws on the features of two other WalkSAT family algorithms: R+AdaptNovelty$^+$ and G^{2}WSAT, while also successfully employing a dynamic local search (DLS) clause weighting heuristic to further improve performance.
gNovelty$^+$ was a Gold Medal winner in the random category of the 2007 SAT competition. In this paper we present a detailed description of the algorithm and extend the SAT competition results via an empirical study of the effects of problem structure and parameter tuning on the performance of gNovelty$^+$. The study also compares gNovelty$^+$ with two of the most representative WalkSAT-based solvers: G^{2}WSAT, AdaptNovelty$^+$, and two of the most representative DLS solvers: RSAPS and PAWS. Our new results augment the SAT competition results and show that gNovelty$^+$ is also highly competitive in the domain of solving *structured* satisfiability problems in comparison with other SLS techniques.

1 Introduction

The satisfiability (SAT) problem is one of the best known and well-studied problems in computer science, with many practical applications in domains such as theorem proving, hardware verification and planning. The techniques used to solve SAT problems can be divided into two main areas: complete search techniques based on the well-known Davis-Putnam-Logemann-Loveland (DPLL) algorithm [1] and stochastic local search (SLS) techniques evolving out of Selman and Kautz's 1992 GSAT algorithm [2]. As for SLS techniques, there have been two successful but distinct avenues of development: the WalkSAT family of algorithms [3] and the various dynamic local search (DLS) clause weighting approaches (e.g. [4]).

Since the early 1990s, the state-of-the-art in SAT solving has moved forward from only being able to solve problems containing hundreds of variables to the routine solution of problems with millions of variables. One of the key reasons for this success has been the keen competition between researchers and the public availability of the source code of the best techniques. Nowadays the SAT community organises regular competitions on large sets of benchmark problems

and awards prizes to the best performing algorithms in different problem categories. In this paper we introduce the current 2007 SAT competition[1] Gold Medal winner in the satisfiable random problem category: gNovelty$^+$.

gNovelty$^+$ draws on the strengths of two WalkSAT variants which respectively came first and second in the random category of the 2005 SAT competition: R+AdaptNovelty$^+$ [5] and G^{2}WSAT [6]. In addition, gNovelty$^+$ connects the two branches of SLS (WalkSAT and DLS) by successfully employing a clause weighting heuristic to gain more efficiency.

In the remainder of the paper we describe in more detail the G^{2}WSAT and R+AdaptNovelty$^+$ techniques upon which gNovelty$^+$ is based. We then provide a full explanation of the execution of gNovelty$^+$ followed by a previously unpublished empirical evaluation of the algorithm. This evaluation examines the performance of gNovelty$^+$ on a range of structured problems and reports the effects of parameter tuning in comparison with two of the most representative WalkSAT based solvers: G^{2}WSAT and AdaptNovelty$^+$, and two of the most representative clause weighting solvers: RSAPS and PAWS. Finally we discuss these results and present our conclusions.

2 Existing Techniques

2.1 G^{2}WSAT

During the mid-1990s, Novelty [3] was considered to be one of the most competitive techniques in the WalkSAT family and was able to solve many hard problems faster than the best complete search techniques of that time. However, one key problem with Novelty is its deterministic variable selection,[2] which can cause it to loop indefinitely and fail to return a solution even where one existed [6, 7]. The first practical solution to this problem was to add a random walk behaviour with a probability *wp* to the Novelty procedure [7]. More recently Li and Huang [6] revisited this problem and proposed a more diversified heuristic to weaken the determinism in Novelty. This new Novelty^{++} solver selects the least recently flipped variable for the next move with a *diversification probability dp*, otherwise it performs as Novelty. Li and Huang [6] further improved Novelty^{++} by integrating it with a new gradient-based greedy heuristic based on the count of current false clauses. The resulting G^{2}WSAT solver (depicted in the left hand side of Figure 1) always selects the most promising variable that, if flipped, will reduce the number of false clauses the most. If there is more than one variable with the best score, G^{2}WSAT selects the least recently flipped one, and if the search hits a local minimum, G^{2}WSAT performs as Novelty^{++} until it escapes.

[1] http://www.satcompetition.org

[2] Novelty deterministically selects the next move from the two best variables of a randomly selected false clause [3].