Satisfiability
Conflict clause afterburner

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Abstract

In this report we investigate ways to improve the conflict-driven satisfiability solving architecture by postprocessing conflict clauses before learning them using look-ahead as a (expensive) conflict clause minimization technique. We investigate the effects of reducing the conflict clause size as well as the effects of improving the backjump level by searching for and removing literals from the conflict clause that are not essential to the conflict. We have implemented an extension within MiniSAT and by experimenting we find that our solver is slower than MiniSAT in most of the cases. This appears mainly to be caused by the amount of extra reasoning during clause reduction.

1 Introduction

The satisfiability (SAT) problem is the problem of finding an assignment to the variables of a Boolean formula that satisfies the formula. SAT is known to be an NP-complete problem. A trivial algorithm tries all 2^n assignments to the n variables, no polynomial time algorithm is known and current SAT solvers use heuristics to find a solution.

Because many problems can be encoded as SAT instances, much research goes into SAT solving and solvers. Two main classes of solvers exist: *complete* solvers, which can prove satisfiability as well as unsatisfiability, and *incomplete* solvers, which can prove only satisfiability. The realm of complete solvers can further be subdivided into *conflict-driven* solvers and *look-ahead* solvers.

In this report we investigate some heuristics for reducing conflict clause size in conflict-driven SAT solvers, with the goal of decreasing the amount of work needed to solve an instance. MiniSAT is a compact conflict-driven SAT solver and we use MiniSAT version 1.14/C++ as a basis for our implementations. In addition, we will experiment with this implementation and compare our results to those of MiniSAT.

This report is structured as follows. The remainder of this section will give a description of complete solvers. The next section will state the research problem. Section 3 describes several ways in which we have tried to reduce the conflict clauses efficiently and how we have implemented this in MiniSAT. Section 4 discusses our experiments and Section 5 their results. The last two sections contain an evaluation and a conclusion. Finally, an appendix is added to the report that contains detailed test results of test runs we performed with MiniSAT and our altered versions.

1.1 Complete solvers

Complete SAT solvers come in two main flavours: *conflict-driven* and *look-ahead*. Both are based on the *Davis-Putnam-Logemann-Loveland (DPLL)* search method ([DLL62]). The DPLL search method starts each step by simplifying the current formula and checking whether it has been satisfied. If not, it picks a free variable and assigns it to true and false and recursively examines both branches. DPLL returns `unsatisfiable` only when all possible assignments have been examined and no solution has been found.

Before we explain the conflict-driven and look-ahead SAT solving techniques, we discuss *unit propagation*. Unit propagation is a process for dealing with *unit clauses*. Unit clauses are clauses, where all literals except one are assigned to their opposite value. The clause can only be satisfied by assigning the remaining literal true, extending the current assignment. During unit propagation, other clauses could become unit clauses and propagation stops when no unit clauses exist in the current formula or when the formula becomes empty (satisfied).

1.1.1 Conflict-driven SAT solving

While searching, a SAT solver picks variables and assigns them a *true* or *false* value. These variables are called *decision variables* and with every decision made, the *decision level* is incremented by one. At some point in the DPLL search tree, the algorithm may assign a truth value to a decision variable that renders the resulting formula unsatisfiable. Such a situation is called a conflict. A straight-forward, simple DPLL solver would at this point backtrack one step and try the other truth assignment for the last assigned decision variable. A conflict-driven solver instead attempts to constrain the search space before backtracking by learning from the conflict.

A conflict can be analysed with an *implication graph*. By taking suitable cuts from this graph, *conflict clauses* can be found. A conflict clause describes a sufficient condition for a conflict to occur and is added to the formula (thereby constraining the search space). The conflict clause is therefore also called the *learnt clause*. From the conflict clause, the *backtrack level* can be determined, which is the depth in the tree where the conflict clause becomes a unit clause. A conflict-driven solver then jumps back to that level and continues searching from there.

The following list shows some features that modern conflict-driven solvers use to improve their performance according to [Heu08]. Also see [Heu08] for more information on SAT solving and different types of SAT solvers.

- **2-literal watch pointers data-structure**: Conflict-driven SAT solvers are interested in when a clause becomes unit. It is therefore not necessary to watch all the literals of a clause; watching just two literals suffices. When one of the two literals becomes falsified, we look for a literal in the clause that is not falsified. If we can not find one, the clause is either falsified or a unit clause.

- **Restarts**: Restarting the DPLL procedure while keeping the conflict clauses can sometimes 'rescue' the solver from bad areas of the search space and help it make better decisions [KH$^+$02].

Because conflict-driven solvers do not spend much time on reasoning, they can be seen as brute force solvers. One of the most popular solvers is MiniSAT [ES03], which we will use as a basis for our implementation.

1.1.2 Look-ahead SAT solving

Where a conflict-driven solver does not reason much on variable selection, a look-ahead SAT solver branches on the most effective decision variable it can find. A decision variable is called *effective* if it results in a relatively large reduction of the formula both when it is assigned true and when it is assigned false.

Deciding which variable is most effective, is done by 'looking ahead'. Look-ahead SAT solvers use heuristics for deciding which variables must be picked and which branch to take on this variable. Look-ahead solvers use additional reasoning to improve their performance. A small list is given here. See [Heu08] for more information.

- **Local learning**: Variables forcibly assigned by other clauses are called *indirect implications*. If a variable y is assigned by look-ahead on a variable x by indirect implication, a *locally learnt* binary clause $\neg x \vee y$ (or $\neg x \vee \neg y$, respectively) can be added. Adding only a subset of these locally learnt clauses will increase performance [HDvZvM05].

- **Autarky detection**: An autarky is a partial assignment that satisfies all clauses in which the variables of the autarky occur. Clauses satisfied by and variables in autarkies can be removed from the original problem while preserving satisfiability equivalence.

- **Double look-ahead**: If during look-ahead many binary clauses are created, the reduced formula is more likely to be unsatisfiable than satisfiable [Li99]. By performing additional look-ahead on the resulting formula, this can be detected faster.

2 Problem statement

Conflict-driven SAT solvers learn conflict clauses while searching, but do not reason much about them, although some solvers (for instance MiniSAT) employ a basic and cheap mechanism for conflict clause minimization. Using a more expensive mechanism could potentially speed up the search as noted by Van Gelder in [vG09]. Therefore, we will investigate the following question:

Can we improve a conflict-driven SAT solver by using search as a conflict clause minimization technique, before adding the conflict clauses to the clause database, thereby cutting off larger parts of the search space in order to hopefully converge to a solution more quickly?

Note that searching is potentially much more costly than the basic minimization techniques used by for instance MiniSAT. By reducing the size of the conflict clauses, more information about the search space is captured and hopefully that will speed up traversions of this space.

3 Conflict Clause Afterburner

MiniSAT [ES03] is a small and popular conflict-driven SAT solver. We have added additional reasoning to MiniSAT in order to shorten the conflict clauses by trying to eliminate literals. We call this process of literal elimination 'afterburning'.

In Section 3.1 we discuss the changes we made to existing MiniSAT code and in Section 3.2 and 3.3 we discuss our additions.

3.1 Changes to MiniSAT

When the current assignment in MiniSAT falsifies a clause, we say that MiniSAT is in a conflicting state. A clause that is falsified is called a conflicting clause. From a conflicting clause, MiniSAT generates a conflict clause which is added to the clause database. The assignments are now undone until the conflict clause is unit. The single remaining unassigned literal in that clause, called the *asserting literal*, is then assumed and the search continues.

We have inserted code directly after the generation of the conflict clause which starts the afterburner. To ease implementation, we created an `Afterburner` class. These changes are discussed in the following two subsections.

3.1.1 `search()` method

MiniSAT's `search()` method is a continuous loop of propagating and assuming literals, sometimes interrupted by a backjump because of a conflict. We have added a few lines of code that calls the afterburn method at appropriate times according to a heuristic (see 3.3 for details), as shown in Algorithm 1. Note that the solver restarts after a bound on the number of conflicts is reached and that the code for restarting has not been included in the listing.

Algorithm 1 Search

```
procedure SEARCH
    while true do
        if !propagate() then                                        ▷ conflict!
            learnt_clause, backjump_level ← analyze_conflict()
            if root level conflict then
                return UNSATISFIABLE
            end if

            if start_afterburn_heuristic() then                     ▷ start afterburn
                sort learnt_clause on descending decision_level
                learnt_clause, backjump_level ← afterburn(learnt_clause)
            end if                                                  ▷ end afterburn

            cancelUntil(backjump_level)
            newClause(learnt_clause)
        else                                                        ▷ no conflict
            if all variables assigned then
                return SATISFIABLE
            else
                assume(decision_variable)
            end if
        end if
    end while
end procedure
```

Remark that the `learnt_clause` is sorted before it is passed to the `afterburn` method. Sorting the `learnt_clause` is necessary for a certain `stop_afterburn_heuristic`, but it is performed regardless of which `stop_afterburn_heuristic` is actually used. See Section 6 for comments.

3.2 `Afterburner` class

The `Afterburner` class is similar to the `Solver` class of MiniSAT, but many redundant methods and attributes have been removed and a few added, most notably the `afterburn()` method (see 3.3).

The `Afterburner`'s job requires it to be able to propagate, a lot. In order to prevent messing up the state of the original `Solver`, especially the current assignments to variables and the watch pointers on each clause in the clause database, the `Afterburner` contains its own clause database. This database is linked to that of the original `Solver`; whenever a clause is added or removed from the original `Solver`'s clause database, it is also done in the database of the `Afterburner`.

The `Afterburner` also collects statistics of its `afterburn()` method (e.g. the number of method calls, the number of reductions, the improvement in backjump level) that are used in heuristics for its performance. For certain heuristics, values indexed by two parameters need to be stored (see 3.3 for details). In these cases, only nonzero entries are stored using stdlib's `map`.

A small remark: when afterburning, the `Afterburner` might stumble upon a satisfying assignment, but currently does not report this. The chances of this happening though are very slim.

3.3 The `afterburn()` method

3.3.1 General outline

The `afterburn()` method tries to shorten a given conflict clause by finding literals from that clause that are redundant to the conflict and removing those. Testing whether or not a literal from the conflict clause is redundant, is done as follows. We know that the conflict literals are assigned to `false` in the original solver. If we pick a certain conflict literal and assign it to `true` in the `Afterburner` together with `false` assignments to all the remaining conflict literals, then we can remove the chosen conflict literal if the assignment again results in a conflict. Note that non-conflict clause literals remain unassigned in the `Afterburner` (except for unit facts), otherwise the conclusion of redundancy of the chosen conflict literal holds under the assumption of the particular assignment to these literals. See Algorithm 2 for an overview of the `afterburn()` method in pseudocode.

Note that the conflict clause found in `Solver` and passed on to `afterburn()` is immediately conflicting, i.e., only assuming the literals from the conflict clause results in a conflict. However, after the `afterburn()` method has done its work, the returned conflict clause is *not* necessarily immediately conflicting (but it is a conflict clause nonetheless).

It is apparent that quite a few propagations are performed multiple times in the pseudocode above and improvement is certainly possible. The authors of MiniSAT mention in [ES03] that MiniSAT spends about 80% of its time propagating, so there is also a good reason to investigate this matter. Preliminary tests revealed that the `Afterburner` without any heuristics for early abortion incurred upto 10 times as many propagations as MiniSAT. Even with abortion heuristics the majority of the propagations was carried out in the `Afterburner`, albeit with a factor of about 5. Therefore, we altered the `afterburn()` method to the pseudocode shown in Algorithm 3.

In words, the way Algorithm 3 handles the assuming and propagating of conflict clause literals is as follows. It starts with assuming and immediately propagating each literal from the conflict clause in reverse order. Then it processes in regular order the conflict clause literals scheduled for burning by undoing all propagations up to and including the candidate literal, flipping the assignment to the candidate literal and assuming and propagating the already processed literals that could not be marked as redundant. The advantage of this approach is that each time a conflict literal is up for burning, the propagations of the conflict literals that are further down in the regular ordering need not be performed again. Of course this advantage is diminishing the more literals are processed.

The smarter way of propagating as shown in Algorithm 3 can still be improved upon. By cutting the conflict clause in two pieces, it is possible to assume all conflict clause literals in reverse order before dealing with the first piece and similarly (after undoing all propagations) to assume all conflict clause literals in *regular* order before dealing with the second piece. Ideally, the cut would be dynamically determined and when all conflict clause literals are considered anyway, this

Algorithm 2 afterburn

```
procedure AFTERBURN(conflict_clause)
    propagate()                                   ▷ propagate possibly learnt unit facts

    for all literals L ∈ conflict_clause do
        if stop_afterburn_heuristic() then
            break
        end if

        for all literals K ∈ conflict_clause do   ▷ assume assumptions
            if K = L then
                assume(K)                         ▷ flip assignment to L
            else
                assume(¬ K)
            end if
        end for

        if !propagate() then
            conflict_clause ← conflict_clause \ L ▷ L is redundant
        end if

        cancelUntil(0)                            ▷ undo all propagations not on root level
    end for

    return conflict_clause
end procedure
```

would imply cutting when the size of `kept_literals` exceeds the number of remaining literals. However, the `stop_afterburn_heuristic()` complicates matters. The candidates we consider for this particular heuristic rarely, if ever, result in considering more than half of the conflict clause literals, not taking into account the benchmark heuristic that never decides to stop. Since the gain is little compared to Algorithm 3, we have not implemented this improvement.

In the following sections, various heuristics are mentioned that affect the way the afterburning is performed.

3.3.2 Implemented heuristics

There are several aspects of afterburning that we can control. We can decide whether or not to invoke the `afterburn()` method, choose the candidate literals to burn and pick a stopping criterion.

Note that you could conceptually merge the decision to afterburn with the decision to stop afterburning, but there are start-up costs involved that you incur before the stopping criterion is checked. Therefore it is better to separate the two.

Starting criterion To determine whether or not the afterburner should fire, we created a simple heuristic based on preliminary observations from gathered data. The data showed a cloud of activity with different shapes and positions for different instances (see figures in Appendix A), which led us to believe a dynamic heuristic based on data from previous `afterburn()` calls might prove effective.

We designed the `start_afterburn_heuristic` as follows. After each `afterburn()` call for a conflict clause, we record the amount of literals reduced, indexed by conflict clause size and current decision level. Since we first need to have a sufficient amount of data before we can put the heuristic to work, initially the afterburner is started without consulting the `start_afterburn_heuristic` for some fixed number of conflicts. Thereafter, the afterburner only fires when the expected number of literals reduced relative to conflict clause size is greater than some threshold value.

Literal selection From the conflict clause, it is possible to select either a single literal or a larger group of literals. In order to prove redundancy of a subset of literals, the afterburner has to check a number of assignments exponential in the size of this subset. Moreover, the number of possible subsets of a given size k in a conflict clause of size n is $\mathcal{O}(n^{\min(k,n-k)})$, a polynomial with a fairly

Algorithm 3 afterburn

```
procedure AFTERBURN(conflict_clause)
    propagate()                                          ▷ propagate possibly learnt unit facts
    for all literals L ∈ conflict_clause in reverse order do
        assume(¬L)
        propagate()
    end for
    kept_literals ← ∅
    for all literals L in conflict_clause do
        if stop_afterburn_heuristic() then
            break
        end if
        cancelUntil(level[L])                            ▷ flip literal currently last assumed
        conflict ← ( !assume(L) ∨ !propagate() )
        for all literals K ∈ kept_literals do            ▷ assume kept literals
            if !conflict then
                conflict ← ( !assume(¬K) ∨ !propagate() )
            else
                break
            end if
        end for
        if conflict then
            conflict_clause ← conflict_clause \ L        ▷ conflict regardless; L redundant
        else
            kept_literals ← kept_literals ∪ L            ▷ redundancy unknown; keep L
        end if
    end for
    cancelUntil(0)                                       ▷ undo all propagations not on root level
    return conflict_clause
end procedure
```

high order. Of course, both these arguments strongly discourage selecting large subsets. However, it is easy to see that a subset of literals is redundant if and only if each literal in the subset is redundant. Therefore it is sufficient to consider one literal at a time.

Another subject of choice is the order in which the conflict clause literals are selected. We opted to process literals in descending order of decision level. The reason for this is that it eases the determination of the backjump level after afterburning a conflict clause up to a point that it is completely trivial.

Lastly, we made a distinction between either or not processing the asserting literal, the literal that was last assumed before the conflict surfaced. This distinction resulted from the realization that in case the asserting literal is successfully burnt, more analysis is required afterwards in order to find the new asserting literal. This analysis features expansion of the reason clauses for implied literals of the highest decision level occuring in the conflict clause (if any), which counteracts the goal and effort of reducing the conflict clause. Therefore, perhaps it is better to avoid it (together with its cost in effort).

Note that the variant that skips the asserting literal is more aimed at reducing the backjump level, such that the SAT solver is more strongly diverted from an infeasible subspace of the search space. This notice is based on the observation that successfully burning a literal implies burning another literal successfully is likely harder.

Stopping criterion In order to determine when the afterburner should stop, we used two different heuristics. The first is a non-stopping criterion, allowing the processing of each literal in the conflict clause. This heuristic is called the 'full burn' heuristic and served more or less as a benchmark. The second criterion aims at avoiding redundant processing of literals with respect to backjump level; it decides that the afterburner should terminate as soon as the backjump level cannot be improved anymore. We call this heuristic the 'backjump burn' heuristic. Note that it is equivalent to stopping on the first or second failure to burn when either disregarding the asserting literal or not respectively.

3.3.3 Other possible heuristics

This section discusses a few other possible heuristics that we have not implemented.

Starting criterion Of course the simple heuristic we use that only fires when the expected gain is greater than some threshold can easily be extended. For example, you could allow the afterburner to start with small probability, even though the expected gain shows no promise. This probability does not have to be fixed beforehand, it might vary depending on the number of conflicts that has passed since the last `afterburn` call. Or instead of considering all data since the start of execution, restrict the heuristic to use recent data only (e.g. up to a certain number of conflicts ago).

Literal selection The implemented heuristic regarding the order of processing conflict clause literals that disregards the asserting literal could be adapted to reduce backjump level even more. In the adaptation, the literals should be selected as follows.

1. Skip the asserting literal and burn the literals in order of descending decision level.
2. Upon the first failure to burn, try the asserting literal and continue with the remaining literals.

The backjump level is determined by the literals with the second highest decision level. Thus, when the first failure occurs when using the literal selection procedure outlined in this paragraph, the only way to improve the backjump level is by trying to burn the asserting literal. Note, however, that when the asserting literal is burnt, the clause has to be reanalyzed to find a new asserting literal and that reanalyzing the clause might introduce new literals due to reason clause expansion as outlined in the 'literal selection' paragraph in Section 3.3.2, possibly influencing the backjump level.

Another possible heuristic could be to put in extra effort to burn literals that do not seem redundant by involving a few non-conflict clause literals. Candidates for these literals could be the first few variables with the current highest activity. Taking this to the extreme, it is possible to start an entire new solver on the current formula and assume the literals in the conflict clause with one flipped. It is, however, easy to do too much.

Stopping criterion The heuristics we considered to determine when the afterburner should stop, namely processing every conflict clause literal or stopping when the backjump level cannot be improved anymore, can be generalized to the following heuristic. Stop burning after an absolute or relative number of successful reductions. This number can be fixed beforehand or determined dynamically from collected statistics, e.g. similar to what we did with the starting criterion discussed in 3.3.2.

4 Experiments

We have tested our afterburner on several instances and compared all of our proposed heuristics to MiniSAT using several metrics. All instances were run on a computer with two quad core Intel Xeon processors[1] clocked at 2.33GHz and 16GB of internal memory running Fedora 8 Linux.

4.1 Instances

MiniSAT performs well on *crafted* and *industrial* instances, which are two of the three types of instances used at international SAT competitions. Crafted instances are usually among the hardest to solve. For example, counting, ordering and pebbling problems formulated as SAT formulas are crafted problems. Industrial instances are problems in the field of hardware verification problems, formulated as SAT problems.

We picked instances from the crafted and the industrial categories, dividing them into satisfiable and unsatisfiable instances. All our instances were taken from the SAT 2007 competition [satcomp].

Although we ran some very hard instances, we focus on instances that can be solved within a reasonable timeframe (about 30 minutes) for the purpose of this investigation. Table 4.1 gives an overview the instances used. The names of the instances are the same as in the SAT 2007 competition.

Family	**SAT/UNSAT**	**Type**	**# instances**
frb	SAT	crafted	2
gensys	SAT	crafted	2
mod2	SAT	crafted	2
clause	SAT	industrial	4
vmpc	SAT	industrial	10
counting	UNSAT	crafted	2
gensys	UNSAT	crafted	2
lksat	UNSAT	crafted	4
sgen	UNSAT	crafted	4
dated	UNSAT	industrial	2
eq	UNSAT	industrial	4

Table 1: Overview of instances used

4.2 Solvers

In Section 3.3.2 we have discussed various heuristics that dictate the behaviour of the afterburner. For the starting criterion we used threshold values of 0, 0.025, 0.04 and 0.06. The higher the threshold, the less often the afterburner will start and the more it will behave like MiniSAT. A value of 0 means the afterburner will start every time whereas 0.06 has shown to be a fairly high threshold based on findings from some small test runs. On the first 100 conflicts the afterburner always starts while data is gathered for the heuristic. After the first 100 conflicts, the heuristic starts working.

We tested 16 possible combinations of the heuristics (4 possibilities for start criteria, 2 for stopping criteria and 2 for burning the asserting literal) plus the original MiniSAT. To differentiate between the 16 different afterburners we devised a solver naming scheme.

A solver with afterburner is named as **'ab-X-Y-Z'**, where **X** denotes the threshold value. **Y** should be *f* or empty and denotes that the afterburner uses the *full burn* heuristic or, when empty, the *backjump burn* heuristic. **Z** should be either *w-a* or *wo-a*, where *w-a* stands for *with asserting* and *wo-a* stands for *without asserting*. Details on these heuristics can be found in Section 3.3.2.

[1] Note that the solver is single-threaded and as such does not take significant advantage of the availability of multiple cores.

We have run all of the 16 afterburner variants and MiniSAT on all instances listed above. In Appendix B, the results are listed for every family of instances and in the next section we will discuss the results of the experiments.

4.3 Metrics

We measured the following data from the solvers. These metrics correspond to the column headers for the tables in Appendix B.

- *Restarts*: number of solver restarts
- *Decisions*: number of decisions taken
- *Conflicts*: number of conflicts incurred
- *Conflict Literals*: total number of literals in all conflict clauses combined[2]
- *Propagations*: amount of unit propagations in the main solver
- *Afterburner propagations*: amount of unit propagations in the afterburner[3]
- *Time spent*: runtime in minutes

5 Results

This section is divided into four parts. Firstly we will make some general observations. Secondly we will evaluate the performance of the implemented heuristics, followed by a more detailed investigation into the starting heuristic. Lastly we have included the results of a small extra investigation into the effect of using different seeds.

5.1 General observations

In Table 2 we counted the number of times a solver equipped with an afterburner does not perform worse than MiniSAT on various statistics. For all types of instances we tested the solvers equipped with an afterburner need slightly less restarts as well as less decisions, run into less conflicts, learn smaller conflict clauses on average and do less unit propagations. This looks promising, but unfortunately the cost of running the afterburner is high: the afterburner does a lot of unit propagation which pushes the number of propagations for the main solver and the afterburner combined far over the number of propagations MiniSAT uses to accomplish the same goal, sometimes by a factor 10 or more.

Statistic	Restarts	Decisions	Conflicts	Conflict Literals	Avg. Conflict Clause Size	Propagations
Afterburner	538	375	486	476	433	450
MiniSAT	70	233	122	132	175	158

Table 2: Afterburner versus MiniSAT performance on various statistics.

5.2 Evaluation of heuristics

5.2.1 Thresholds

Table 3 lists the number of times an afterburner variant with the given threshold finished in first, second, third or last place. Note that we tested four possible values for the thresholds, being 0, 0.025, 0.04 and 0.06. Keeping all other variables the same, we can construct this scoring list by taking for instance all four of the solvers that use the *full burn* and *with asserting* heuristics, the only thing different between the four being the threshold values used.

Table 3 shows that the higher the threshold, meaning the afterburner will start less often, the more often a variant is fastest. This is evidence that running the afterburner is (too) expensive.

Note that on a few instances there are multiple rows in the result tables that contain identical data, see 31, 32 and 33 for the VMPC instances in Appendix B for an extreme case. In each such

[2]Note that the number is skewed, see appendix B for details.

[3]Note that MiniSAT does not have an afterburner, so it has no *afterburner propagations* listed.

threshold	1^{st}	2^{nd}	3^{rd}	4^{th}
0	21	28	53	50
0.025	29	31	46	46
0.04	43	50	37	22
0.06	59	43	16	34

Table 3: Scores over all tested instances grouped by threshold value.

case, the rows correspond to the same type of solvers with increasing thresholds, starting from the threshold 0. This shows that on such instances the average number of reduced literals relative to clause size given the current decision level and conflict clause size always surpasses the threshold after the initial 100 mandatory starts (if 100 is ever reached at all). So either the threshold has been set too low to be of any effect, or the number of mandatory starts is too high.

5.2.2 Burning the asserting literal

To evaluate the effects of the literal selection criterion, we looked at how often a solver that does or does not try to burn the asserting literal was faster than the other. We also split up the results by the stopping criterion as the stopping and literal selection criteria have effects on eachother. So, for example, in the first two rows of Table 7 in Appendix B the solver that does try to burn the asserting literal (the first row) is fastest of the two and gets a point under *full burn*.

	full burn	backjump burn
with asserting	66	56
without asserting	86	96

Table 4: Number of times being the fastest solver over all tested instances grouped by literal selection and stopping criterion.

Because the stopping criterion behaves differently for the two variants of this heuristic, care must be taken when comparing the numbers in Table 4. Effectively, the *backjump burn* stopping criterion stops the afterburner on the second failure to burn a conflict clause literal when the *with asserting* heuristic is used. When the *without asserting* heuristic is used the afterburner stops on the first failure. This implies that, given the same solver state before the afterburner was started, the *with asserting* heuristic always does more work than the *without asserting* heuristic, which can be an explanation for the fact that is is slower on our testset as can be seen in Table 4.

In the case of the *full burn* stopping criterion a possible reason for the fact that the *with asserting* heuristic is slower may be that the *with asserting* heuristic does some extra work. This extra work consists of trying to burn the asserting literal, and when the asserting literal is successfully burnt, the analyze method needs to find a new asserting literal by expanding reason clauses.

5.2.3 Full burn versus backjump burn

The last heuristic we evaluate constitutes the stopping criterion. Two criteria were implemented: the *full burn* and *backjump burn*. The first tries to burn every single literal, the second is aimed at stopping when the backjump level can no longer be improved. Table 5 shows the number of times each criterion was faster than the other.

The number of unit propagations in the *full burn* variants is mostly larger, sometimes ten times as large as in the *backjump burn* variants. Also runtime is larger, often by a factor greater than 2. On the other hand, the *full burn* reaches a solution in less decisions, typically about 50% of the *backjump burn* keeping all other variables (starting and literal selection heuristics) the same.

stopping criterion	# times fastest
full burn	68
backjump burn	236

Table 5: Number of times being the fastest solver over all tested instances grouped by stopping criterion.

5.3 Graphical results

Appendix A contains graphs that give insights into when the afterburners start and when they are most effective. An explanation of the graphs can be found at the beginning of appendix A. A couple of things are interesting about the graphs. We will briefly discuss them and describe how they can be used to improve the starting heuristic.

5.3.1 Hotspots

The graphs show hotspots, areas in the graph where the afterburners were relatively more successful than in other areas. Figure 4 clearly shows a large hotspot below the diagonal suggesting that the afterburner should perhaps focus on that region. But Figure 5 shows that the bottom left part of the visible cloud is the most effective region, given that the afterburner starts. For another instance, see Figure 22 and Figure 23, it would appear that running the afterburner on smaller clauses is most effective.

Because of these hotspots, we experimented with targeting the focus of the afterburner on specific ranges of decision levels and conflict clause sizes, using the graphs for guidance. We have tried targeting the area below the diagonal, the area around the diagonal and also targeting small clauses (relatively small for a given instance). This was not an improvement. We suspect this is due to a considerable amount of clauses that should not be ignored but remain in the larger, untouched conflict clause space. Due to the time span of our research we did not conduct a more detailed research in this direction.

Note that the collected data is still used in the starting heuristic. See Section 3.3.2 for more information.

5.3.2 Diagonal

One striking peculiarity, visible in almost all graphs we generated, is the behaviour around the diagonal, where conflict clause size equals decision level. The diagonal appears to be an area of great activity in most instances, with lots of conflicts as can be seen in Figure 2 – 7. In other instances, the diagonal is an area of remarkably low activity considering the surrounding area. An example of the latter can be seen in Figure 14 – 19. We have no explanation for this phenomenon.

5.4 The effect of the seed

Complete SAT solvers often use randomness, for instance, in MiniSAT, when selecting the next decision variable. The source of the random data is usually a software pseudorandom number generator (PRNG). As the name implies a PRNG does not supply truly random data but tries to supply data that has properties of random data.

The next number in the sequence of a PRNG is dependent on the state of the generator. If the state is completely described by an integer seed (which is often the case), then a useful property of such a PRNG is that when it is initialized with the same seed, it will reproduce the exact same sequence. This enables other people to easily verify your results. On the other hand, when you have a bad seed, your solver may take a long time to solve a particular SAT instance. We investigate the influence of the seed on the running time of MiniSAT and one variant of our Afterburner by running both with a number of seeds generated by reading from */dev/random* which takes entropy from hardware components, such as network packet arrival times and disk i/o measurements among others to try to provide truly random data.

As can be seen in Table 6 both MiniSat's and the Afterburner variant's runtime vary greatly depending on the seed. The instance used was the 'UF250.1065.100/uf250-020' from [satlib]. It is a small instance but for larger instances the same behavior was observed. This variance suggests that frequent restarting with new seeds might improve overall runtimes.

6 Evaluation

We have taken a long time to complete this course and gone through several periods of inactivity. Often when we started working again, we had to get back into the material. Revisiting earlier work has on occasion made us wonder 'why did we do this?'. Unfortunately, sometimes this was followed by the realization that we had done work based on a wrong or off-target assumption or belief. In this section we will criticize our work on some points where we feel that we could have done better.

Seed (hex.)	Runtime (seconds)	
	minisat	afterburner
581556e4	1.144070	7.41646
7fb82cd6	2.00413	5.58835
74a799f3	0.96006	8.0365
7fddd296	0.616038	7.62448
83ba2ab7	0.264016	4.67629
210378e7	0.044002	3.2562
c5393db3	1.92412	11.6407
aa94abed	0.380023	7.6404
mean	0.9171	6.9849
standard deviation	0.7384	2.5352

Table 6: Runtimes for MiniSAT and an Afterburner variant for instance 'UF250.1065.100/uf250-020' (see [satlib]) with various seeds.

Problem statement We only really formalized the problem statement until long after the summer of 2008, in which we did most of the work. As a consequence, we sometimes focussed on the wrong things. For instance, after we had gotten our first changes into MiniSAT, we realized that runtimes were extremely large and started focussing on decreasing the amount of extra propagations (which we felt was the main cause of the long runtimes) and on improving backjump level instead of staying focussed on the main goal, to generate smaller conflict clauses.

Stopping criterion We were initially convinced that backjumping as far as possible would be most beneficial because we felt it allowed to escape a large part of the search space. We are now no longer convinced that backjumping as far as possible is necessarily a good thing. It is possible that jumping back too far will mean that it will take longer before a new conflict is encountered and perhaps it is even advantageous to stay in the same part of the search space to try and learn more.

Because we focussed on backjump level we introduced a stopping criterion (see 3.3.2). To efficiently evaluate the criterion we sorted the conflict clause literals on decision level before it is fed into the afterburner. However, the sorting always takes place, also in the full burn in which it is unnecessary. Although the sorting time is negligible, there may be other side-effects which cause the solver to proceed in a different manner, for instance when assigning watch pointers further down in the search tree.

7 Conclusion

In this research we have tried to improve a conflict-driven SAT solver by shortening learnt clauses in order to more quickly converge to a solution. We have managed, through the use of various heuristics and an afterburner, to lower the average conflict clause size, thus cutting off larger parts of the search space. This leads to improvements over MiniSAT in terms of the number of restarts and conflicts incurred and decisions taken before reaching a solution. The cost of the additional reasoning that made this possible however, was quite large, resulting in greater overall runtimes.

Of all afterburner variants tested, the higher the threshold, the faster the solver is; the higher the threshold, the more the afterburners behave like MiniSAT.

From our experiments it appears that trying to burn the asserting literal is not beneficial to the solving process. Also, the usage of a stopping criterion that does not process all conflict literals speeds up the search for a solution.

Based on our research and observations we recommend not using a starting criterion, not burning the asserting literal and to stop burning on the first failure to burn a literal (the backjump burn) when applying reasoning to shorten a conflict clause in a conflict-driven SAT solver. Of course, our research has only taken into account a few possible heuristics and there may very well be better options available. For any practical purpose MiniSAT without an afterburning extension currently outperforms MiniSAT with such an extension by a fairly wide margin, but perhaps with further tweaking and investigation it is possible to turn the odds. Some directions can be found in Section 3.3.3.

Lastly, we have been able to find patterns (see the graphs in Appendix A) but have not been able to exploit these using for instance starting criteria.

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A Plots

The graphs in this section are heatmaps and show hot regions for the plotted property. Graphs are included for four instances. The title of the graphs shows the afterburner type (see Section 4.2 for details), what is measured and the instance. For each instance six graphs are included.

1. Number of afterburner starts
2. Number of successful afterburner starts (at least one literal was reduced)
3. Average number of reduced literals, relative to clause size and afterburner starts
4. Average number of reduced literals, relative to clause size and successful afterburner starts
5. Average number of backjump level reductions, relative to clause size and afterburner starts
6. Average number of backjump level reductions, relative to clause size and successful afterburner starts

To interpret the colors used in the graphs, a legend is included in Figure 1. Red areas indicate relatively high values, blue values indicate relatively low values. Note that the colors within a graph are relative, so colors cannot be compared between graphs. As an example, for a graph that shows the amount of reduced literals, the areas that are marked red, are areas where afterburning was relatively successful as opposed to more blue areas.

Note that the values in the graphs are normalized. The graphs on the top half of a page show the averages of the reductions relative to clause size over all afterburner starts. Those on the bottom half show the same but only take into account those datapoints that correspond to a successful afterburner start (meaning that the conflict clause was reduced).

Figure 1: Legend for interpreting the graphs

All instances were taken from the 2007 SAT competitions, see [satcomp]. The four instances used are, in order of appearance in this appendix:

1. crafted/SAT/frb65-12-2.used-as.sat04-874.cnf
2. industrial/SAT/clauses-4.shuffled-as.sat05-1967.cnf
3. industrial/UNSAT/eq.atree.braun.11.unsat.cnf
4. crafted/UNSAT/counting-easier-fphp-012-010.sat05-1214.reshuffled-07.cnf

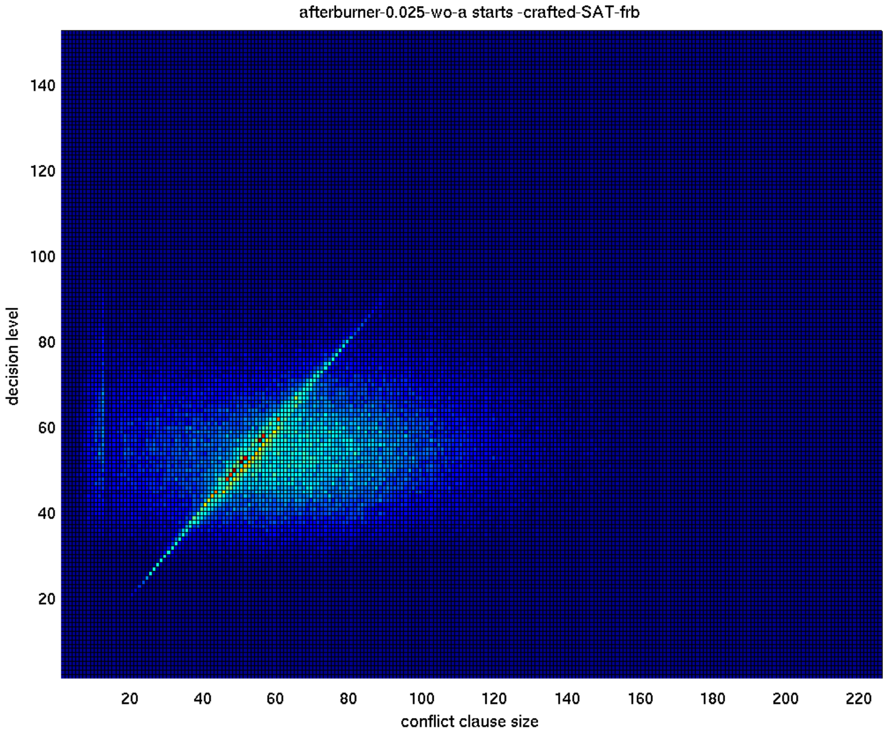

Figure 2: Heatmap of number of afterburner starts

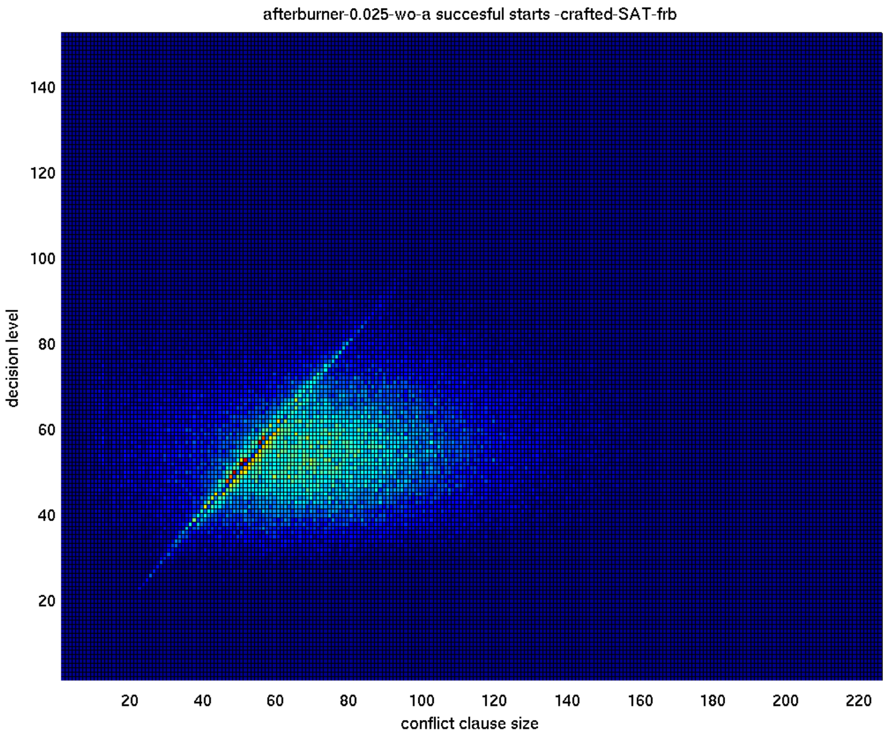

Figure 3: Heatmap of number of successful afterburner starts

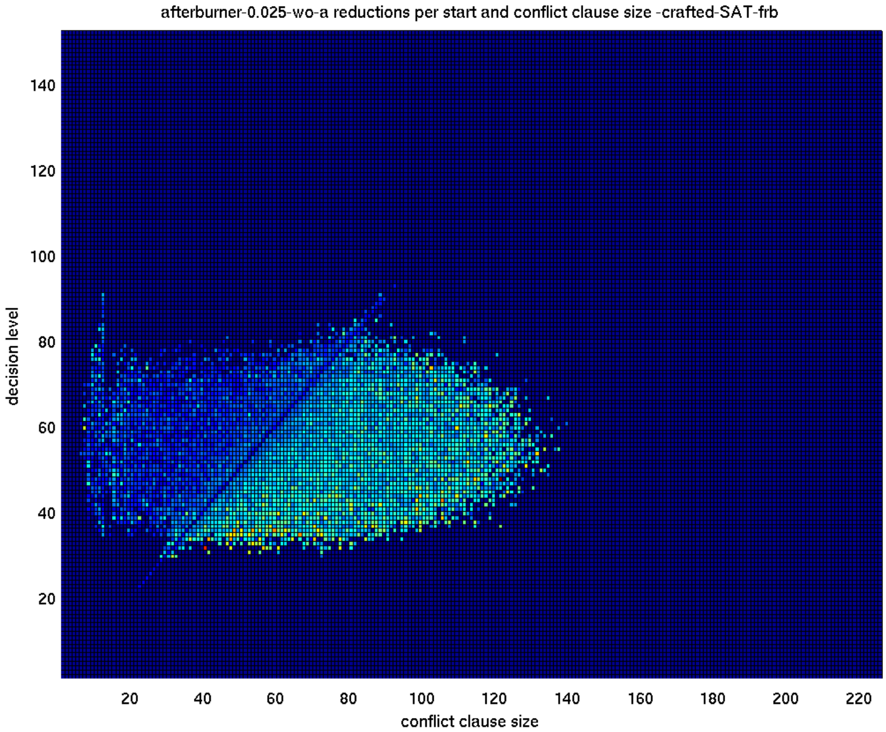

Figure 4: Heatmap of average number of reduced literals relative to clause size

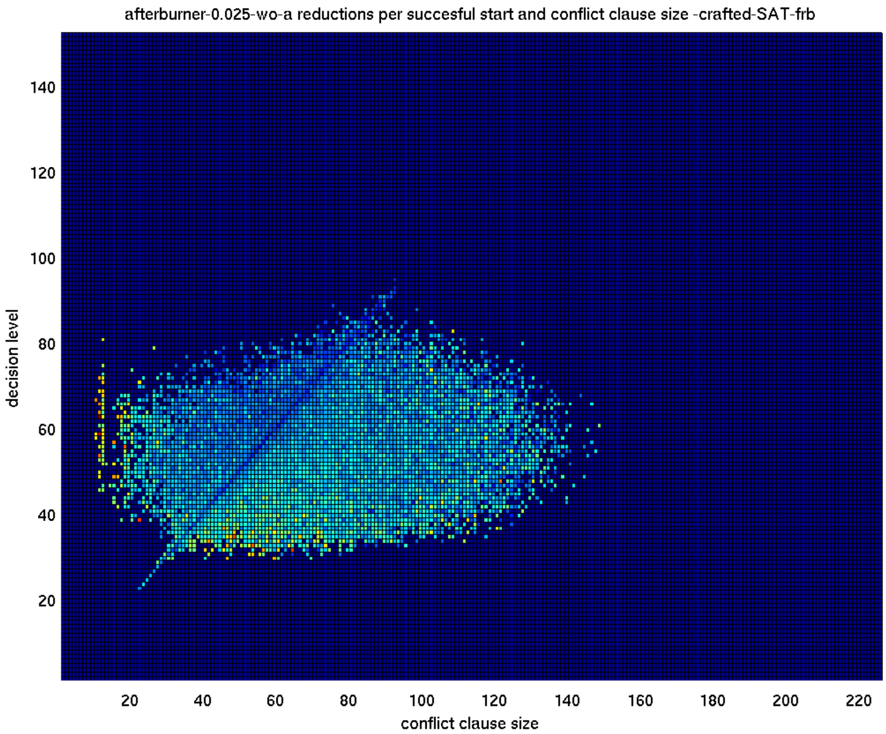

Figure 5: Heatmap of average number of reduced literals relative to clause size for successful starts

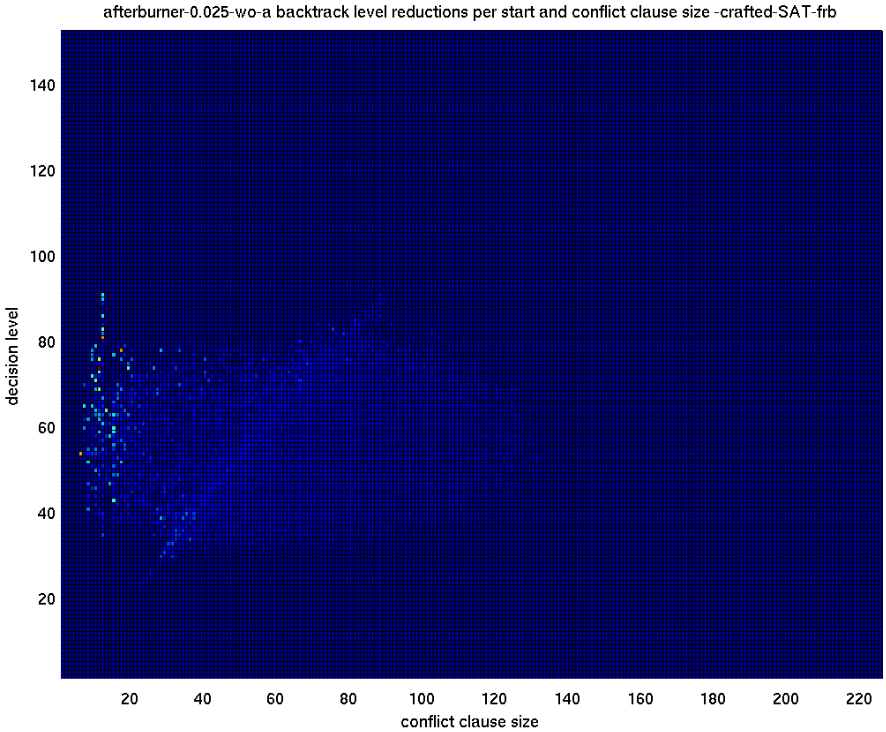

Figure 6: Heatmap of average number of reductions in backjump level relative to clause size

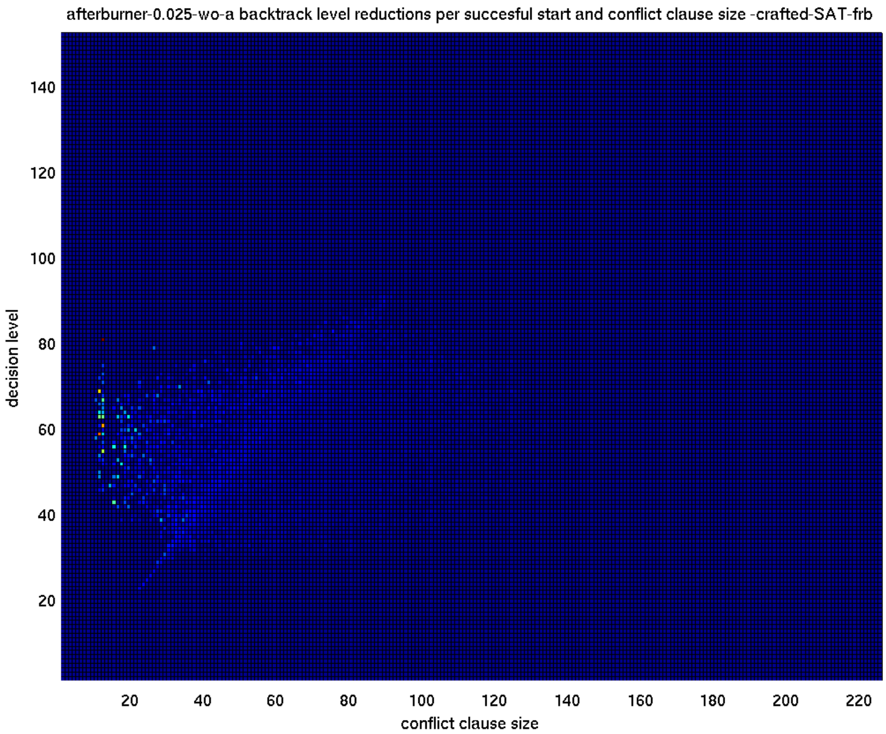

Figure 7: Heatmap of average number of reductions in backjump level relative to clause size for successful starts

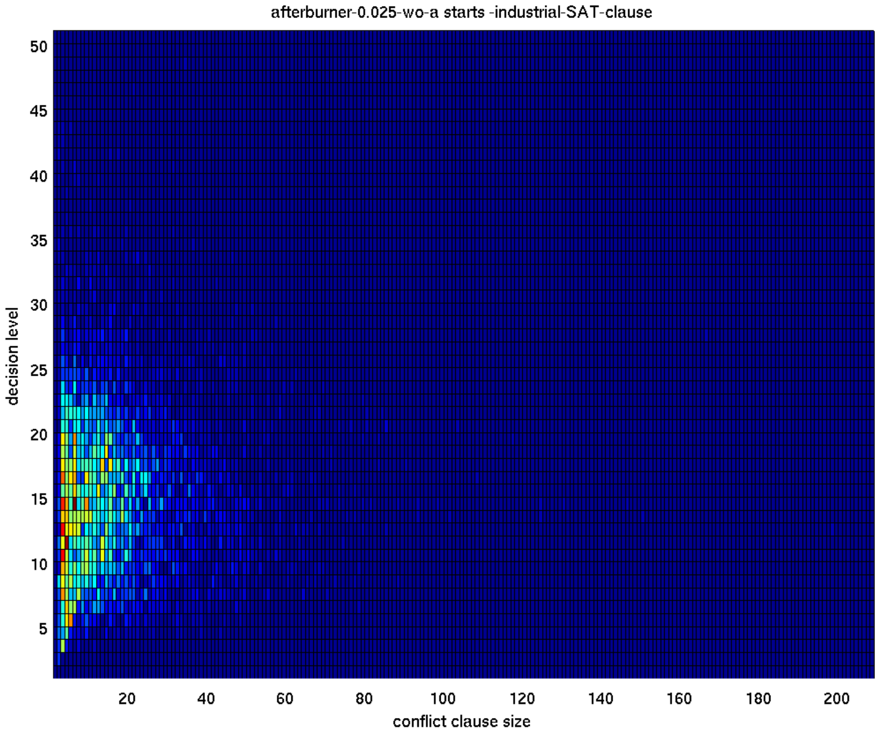

Figure 8: Heatmap of number of afterburner starts

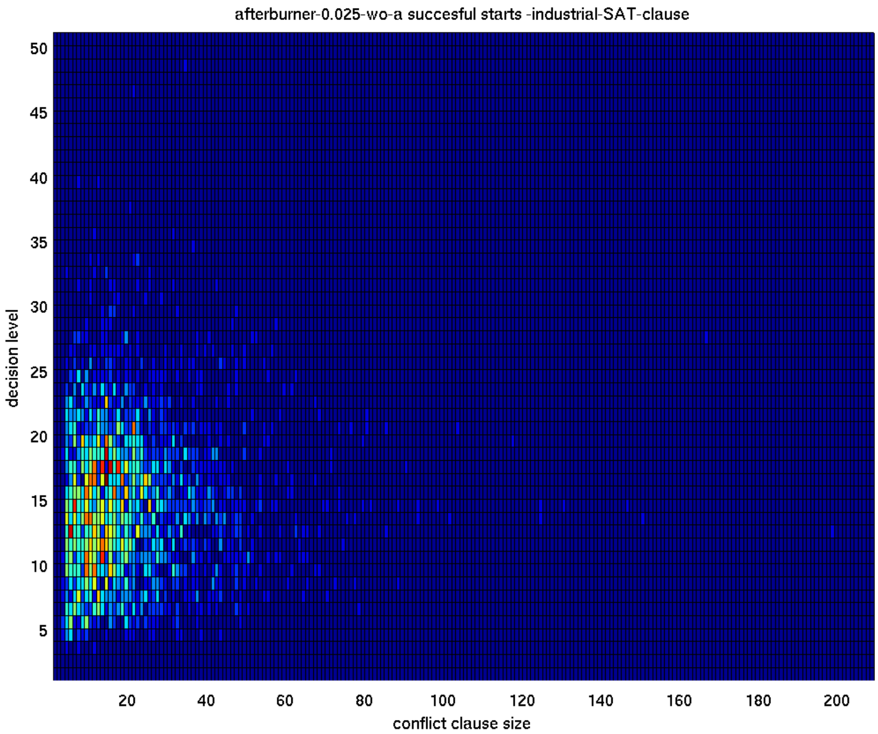

Figure 9: Heatmap of number of successful afterburner starts

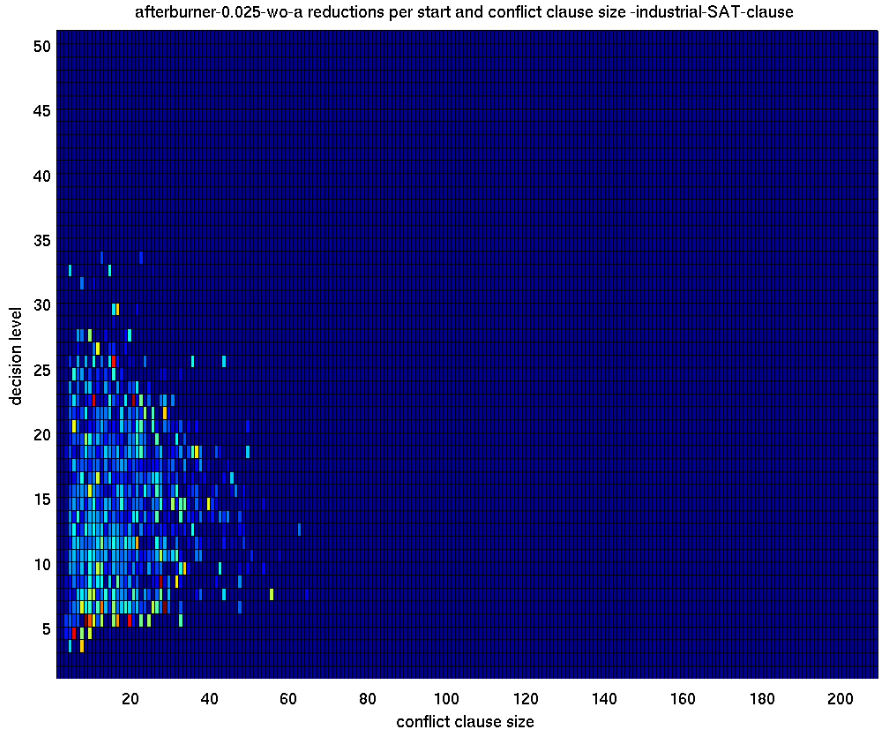

Figure 10: Heatmap of average number of reduced literals relative to clause size

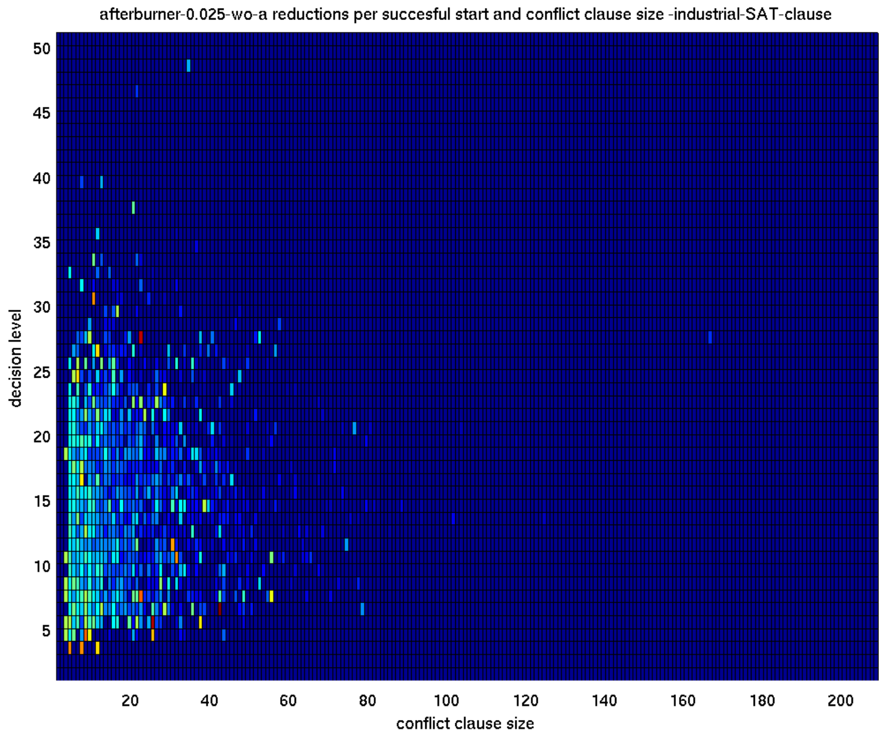

Figure 11: Heatmap of average number of reduced literals relative to clause size for successful starts

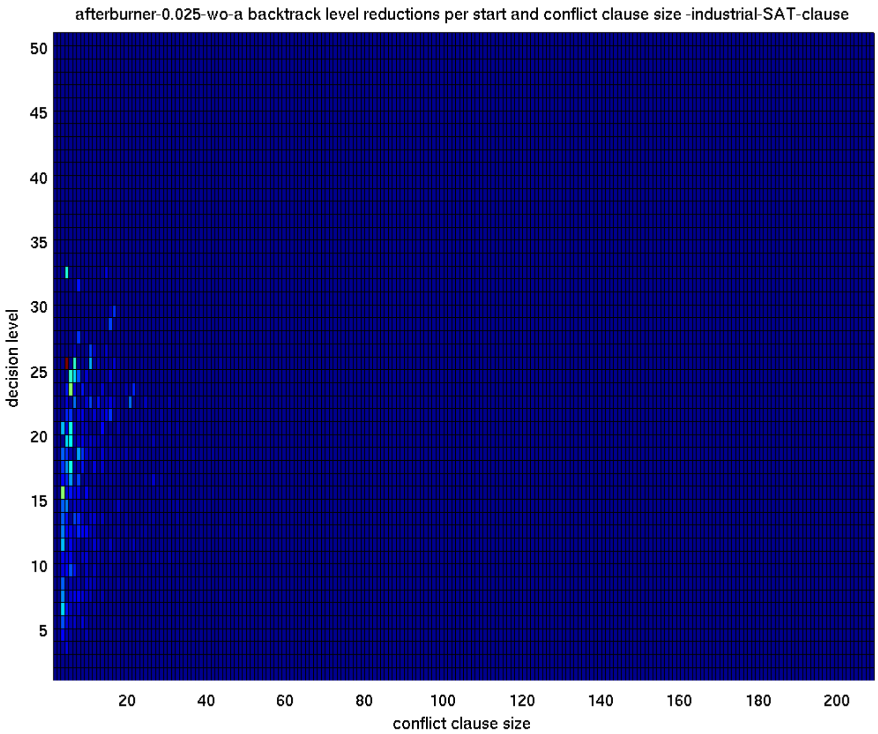

Figure 12: Heatmap of average number of reductions in backjump level relative to clause size

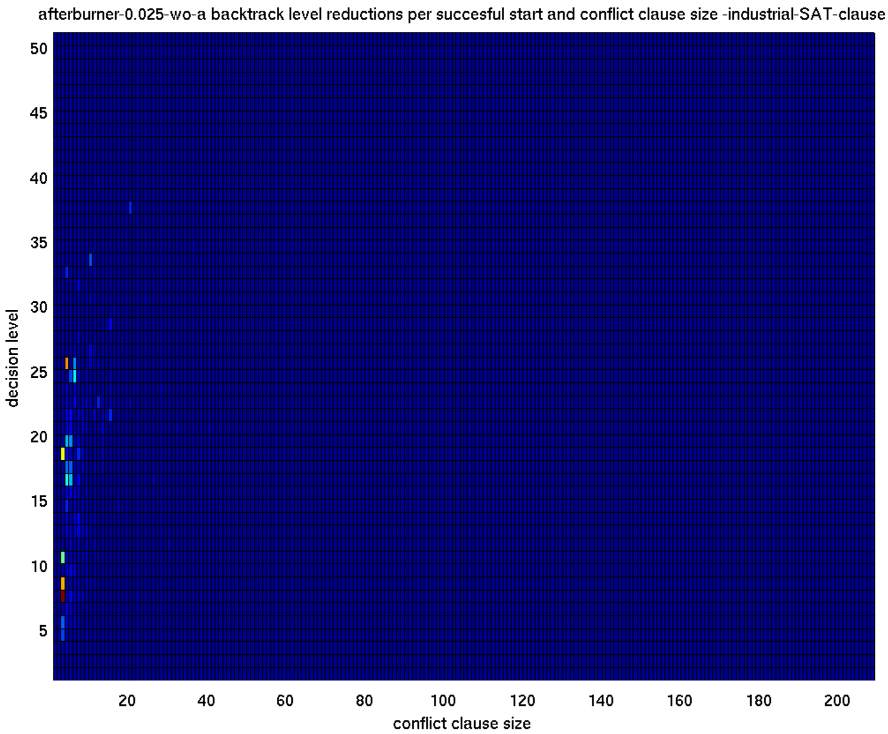

Figure 13: Heatmap of average number of reductions in backjump level relative to clause size for successful starts

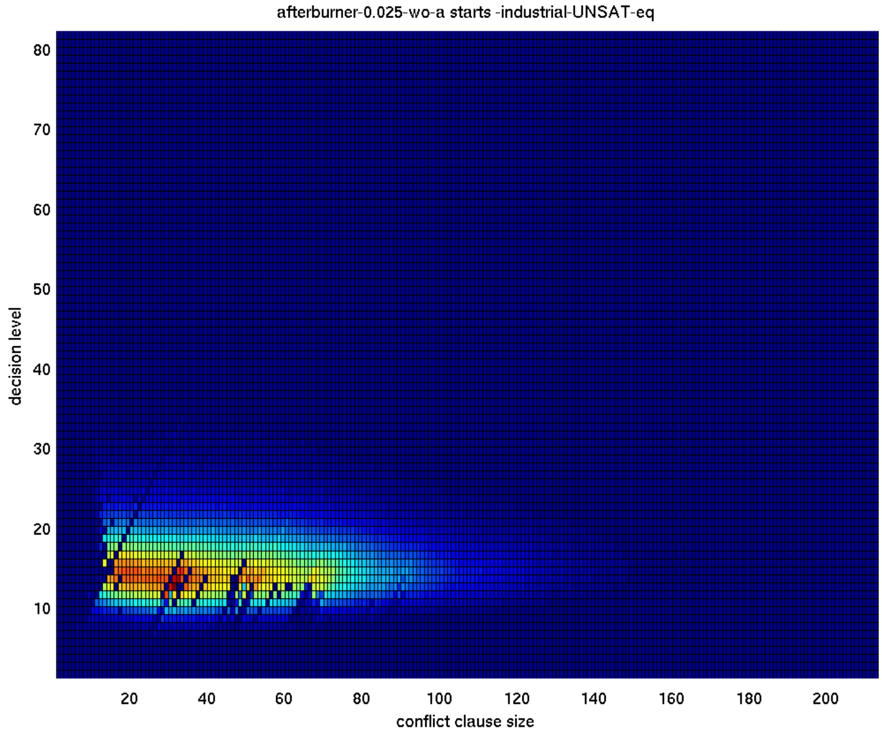

Figure 14: Heatmap of number of afterburner starts

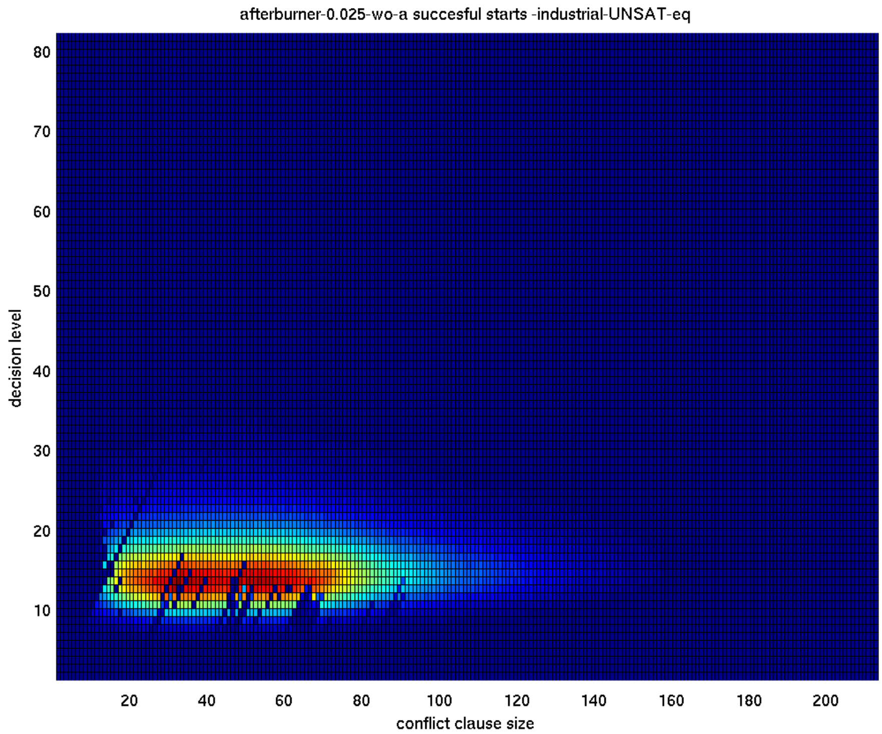

Figure 15: Heatmap of number of successful afterburner starts

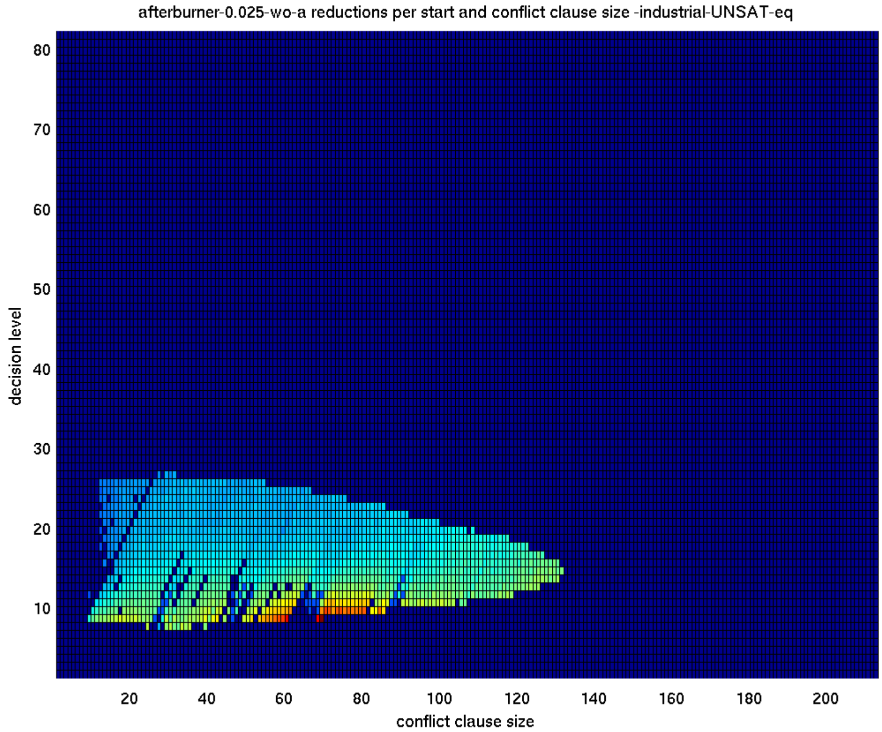

Figure 16: Heatmap of average number of reduced literals relative to clause size

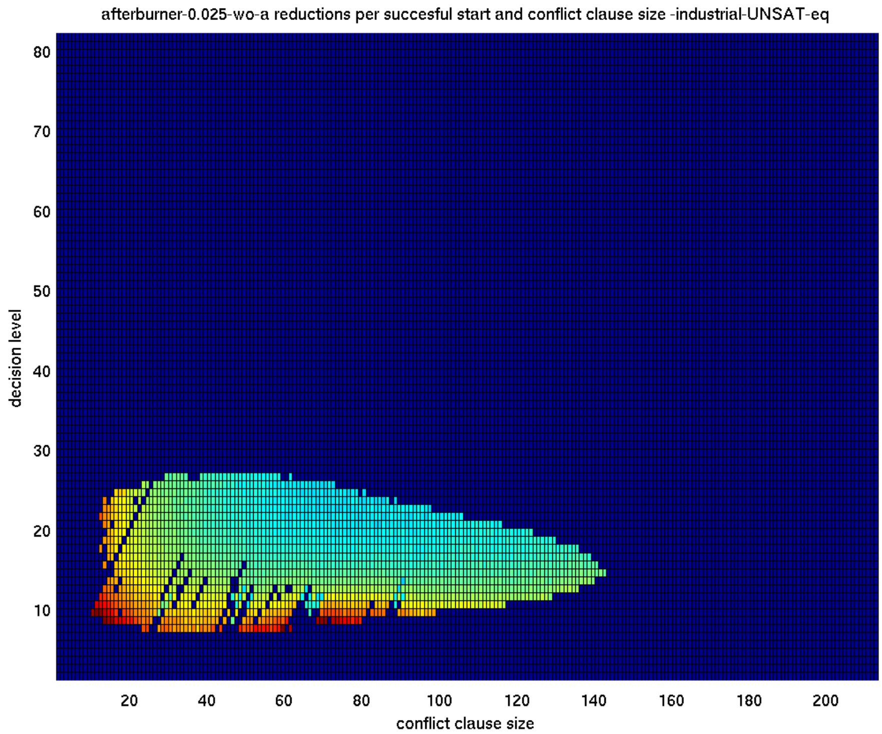

Figure 17: Heatmap of average number of reduced literals relative to clause size for successful starts

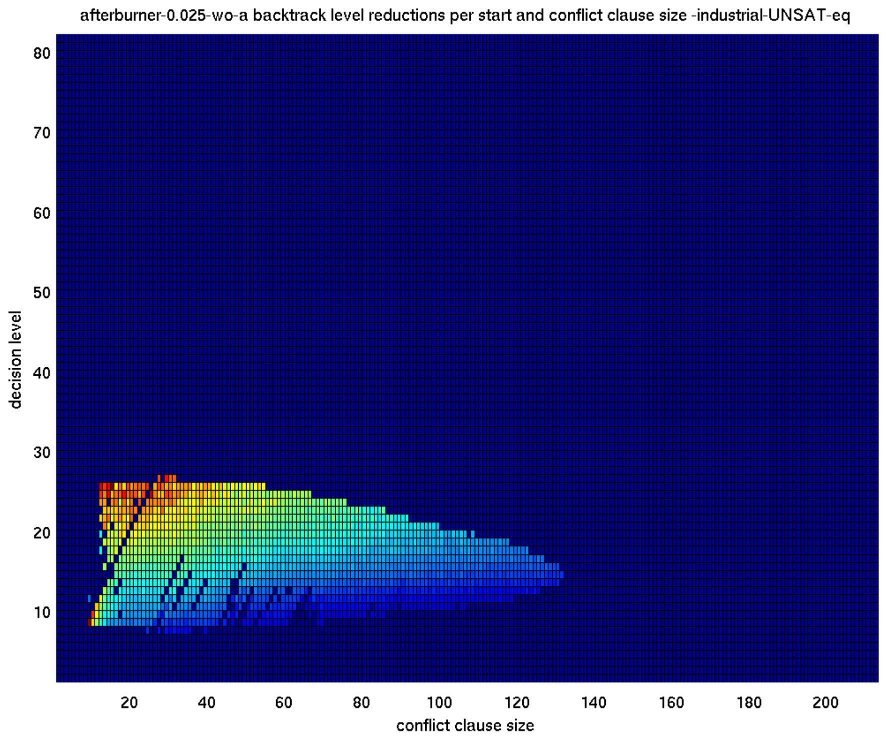

Figure 18: Heatmap of average number of reductions in backjump level relative to clause size

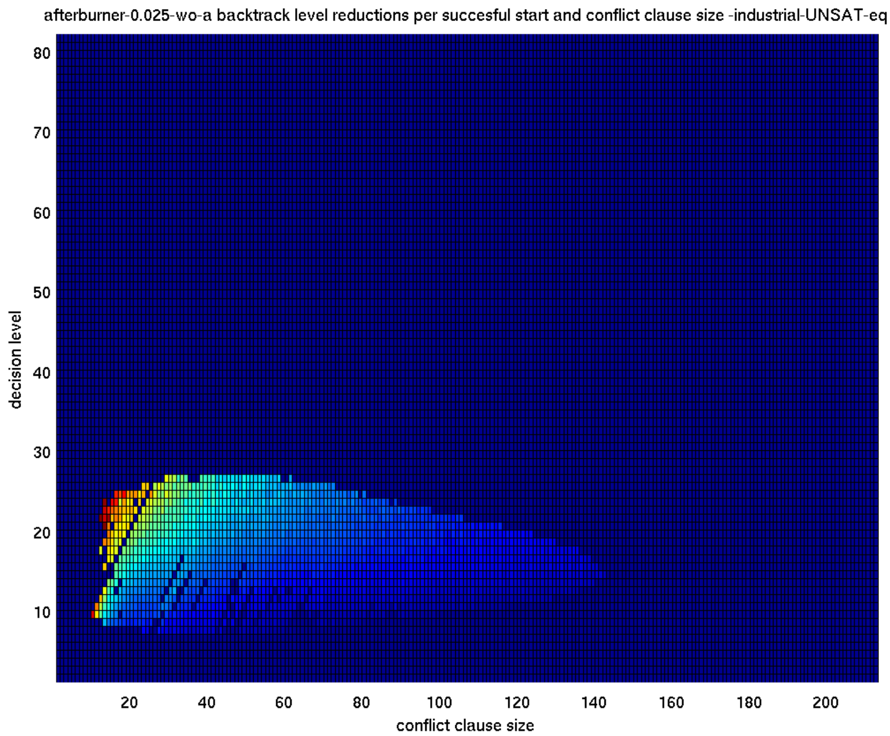

Figure 19: Heatmap of average number of reductions in backjump level relative to clause size for successful starts

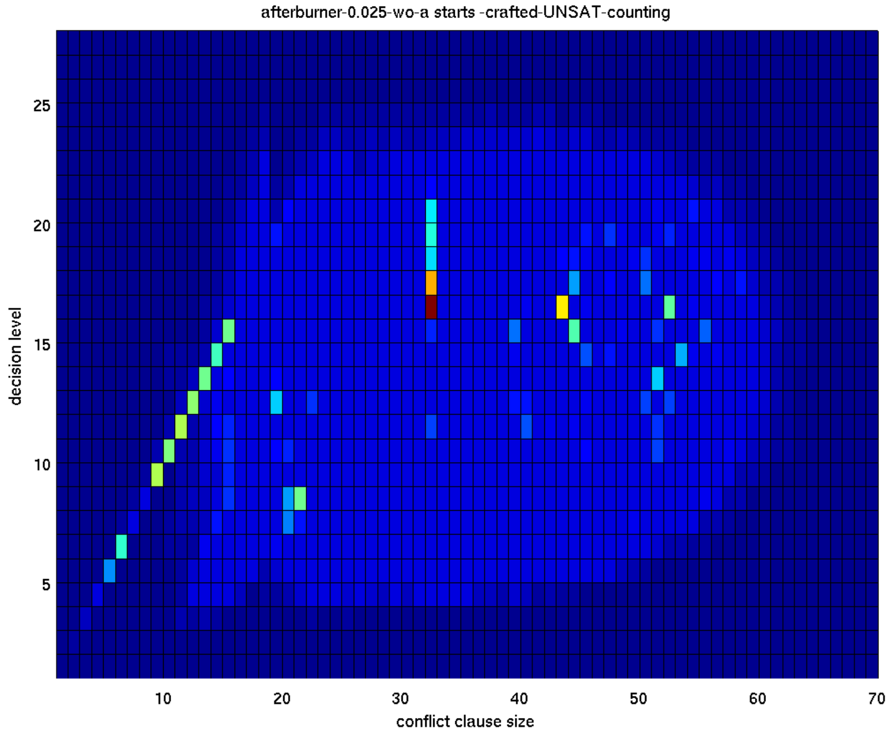

Figure 20: Heatmap of number of afterburner starts

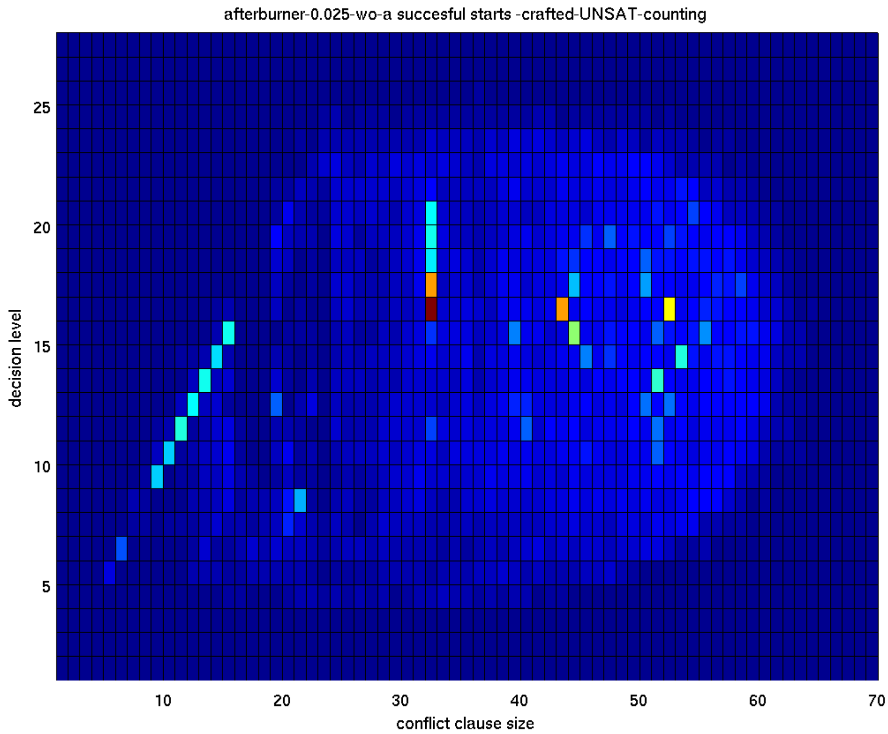

Figure 21: Heatmap of number of successful afterburner starts

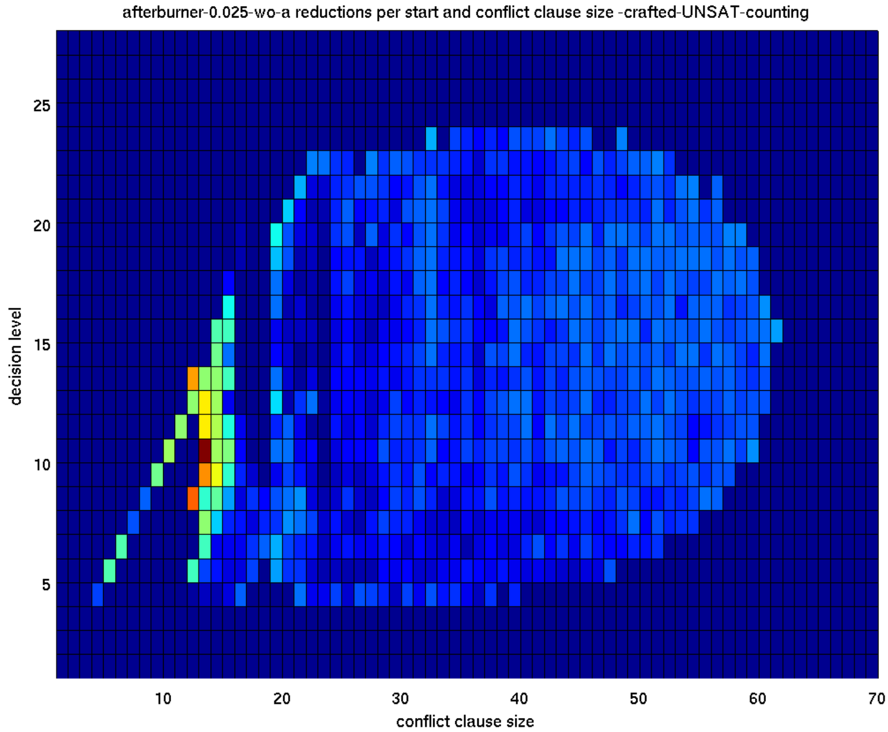

Figure 22: Heatmap of average number of reduced literals relative to clause size

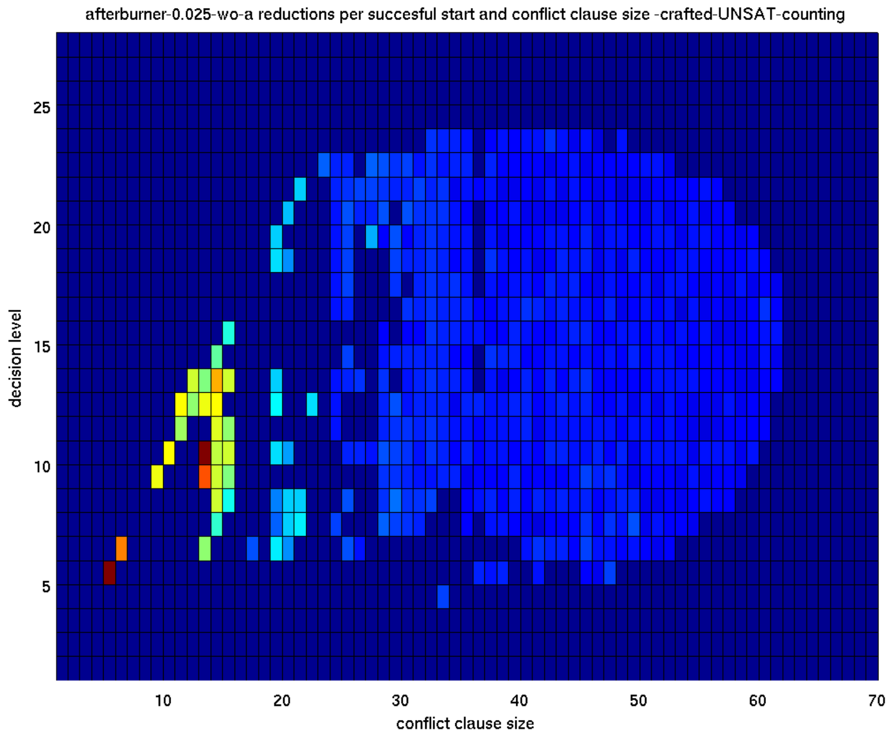

Figure 23: Heatmap of average number of reduced literals relative to clause size for successful starts

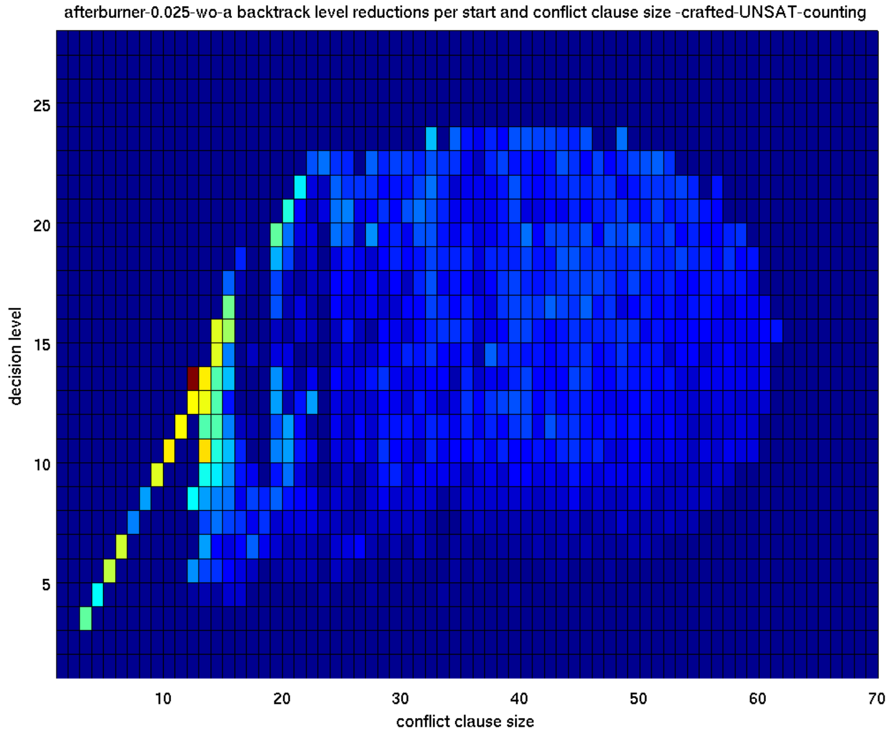

Figure 24: Heatmap of average number of reductions in backjump level relative to clause size

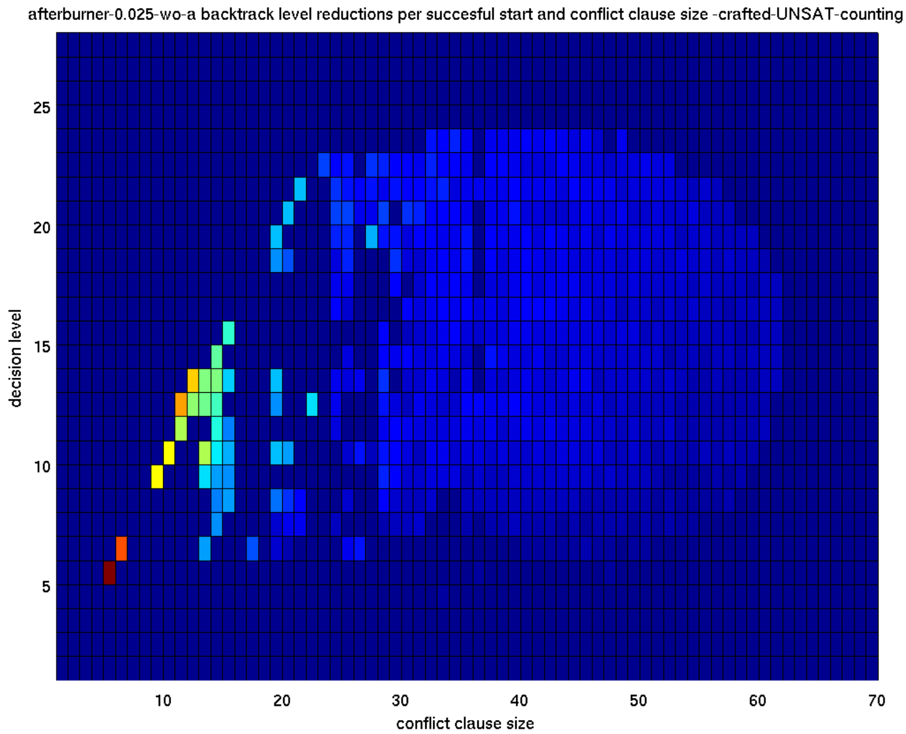

Figure 25: Heatmap of average number of reductions in backjump level relative to clause size for successful starts

B Tables

This appendix contains tables that show statistics collected from testruns of the various afterburner variants as mentioned in Section 4 as well as plain MiniSAT. Unfortunately there is a problem with the 'conflict literals' statistic. The number is increased in the `analyze` method and if during an afterburner start the asserting literal was burnt, the analyze method will be called again, causing some literals to be counted twice.

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	19	785111	392667	≤19623139	≤49	50721605	2810627266	2861348871	154.491000
ab-0-f-wo-a	18	547347	289035	15153277	52	36794235	2179596631	2216390866	184.176667
ab-0-w-a	17	404299	159803	≤12508980	≤78	22144780	127032401	149177181	14.168933
ab-0-wo-a	19	724828	332561	21188740	63	41767076	167680216	209447292	25.898500
ab-0.025-f-w-a	19	648066	324315	≤16546169	≤51	41875168	2368137840	2410013008	253.763333
ab-0.025-f-wo-a	18	457426	243308	12912252	53	30900489	1840143649	1871044138	201.116667
ab-0.025-w-a	17	397700	167209	≤13318000	≤79	22701729	121847230	144548959	17.916500
ab-0.025-wo-a	19	887084	437977	27979781	63	55413100	183813552	239226652	41.263500
ab-0.04-f-w-a	19	850680	427638	≤22104303	≤51	54702740	3192675690	3247378430	364.145000
ab-0.04-f-wo-a	19	787986	429520	21545683	50	54169532	3006711648	3060881180	367.955000
ab-0.04-w-a	20	1329687	578816	≤43457560	≤75	76948536	396439184	473387720	79.581667
ab-0.04-wo-a	19	634603	309932	19653650	63	39276474	128897909	168174383	24.893000
ab-0.06-f-w-a	19	766500	389421	≤18683417	≤47	50470555	2621473310	2671943865	249.173333
ab-0.06-f-wo-a	17	280104	149536	8028996	53	19477823	1127959693	1147437516	94.089167
ab-0.06-w-a	19	752206	320045	≤24256511	≤75	43515891	226890701	270406592	37.025000
ab-0.06-wo-a	19	665325	325615	20523023	63	41344116	135112486	176456602	28.481500
minisat	21	1300144	947810	64454034	68	105902376	0	105902376	11.417617

Table 7: Statistics of crafted_SAT_frb65-12-1.used-as.sat04-873 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	16	173765	89963	≤4610732	≤51	12317822	708099177	720416999	30.104667
ab-0-f-wo-a	19	776918	420575	21754775	51	54961642	3284539436	3339501078	244.531667
ab-0-w-a	22	2427045	1002857	≤83235226	≤82	132522919	819405823	951928742	96.290667
ab-0-wo-a	20	1016337	476234	33005618	69	61663324	250916577	312579901	36.547500
ab-0.025-f-w-a	16	173765	89963	≤4610732	≤51	12317822	708099177	720416999	34.671833
ab-0.025-f-wo-a	19	708633	382722	18970806	49	50730664	2789920039	2840650703	272.075000
ab-0.025-w-a	20	1227835	545334	≤43629306	≤80	73210689	393609336	466820025	63.687333
ab-0.025-wo-a	18	567386	279655	17655150	63	36490223	121916651	158406874	21.466000
ab-0.04-f-w-a	16	173765	89963	≤4610732	≤51	12317822	708099177	720416999	33.440333
ab-0.04-f-wo-a	18	448622	242309	12603183	52	32422947	1883497131	1915920078	163.474000
ab-0.04-w-a	18	623101	266924	≤19392631	≤72	35947651	191018922	226966573	27.095167
ab-0.04-wo-a	20	874744	446811	29517946	66	56700761	184487011	241187772	32.759333
ab-0.06-f-w-a	19	704349	373513	≤19883661	≤53	50297876	2994030873	3044328749	263.735000
ab-0.06-f-wo-a	19	666131	371260	19591288	52	49550247	2873061464	2922611711	279.970000
ab-0.06-w-a	20	1129003	511499	≤38997068	≤76	68043066	333420976	401464042	52.702500
ab-0.06-wo-a	19	700416	351072	23301606	66	44503571	146984438	191488009	28.036833
minisat	22	1507006	1076207	77416885	71	121988176	0	121988176	12.568300

Table 8: Statistics of crafted_SAT_frb65-12-2.used-as.sat04-874 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	15	343042	72818	≤1703189	≤23	3549045	78277639	81826684	1.860633
ab-0-f-wo-a	16	405069	105882	2978380	28	6573121	166078375	172651496	4.251200
ab-0-w-a	18	761570	228409	≤7057574	≤30	10970854	35324780	46295634	2.798000
ab-0-wo-a	19	1111337	350898	9548577	27	16751945	43313768	60065713	3.886083
ab-0.025-f-w-a	15	343042	72818	≤1703189	≤23	3549045	78277639	81826684	2.043567
ab-0.025-f-wo-a	16	405069	105882	2978380	28	6573121	166078375	172651496	5.319100
ab-0.025-w-a	18	864090	263334	≤7767557	≤29	12140188	38699093	50839281	3.255450
ab-0.025-wo-a	18	914337	282187	8292225	29	14198454	36130618	50329072	4.414867
ab-0.04-f-w-a	15	343042	72818	≤1703189	≤23	3549045	78277639	81826684	2.041967
ab-0.04-f-wo-a	16	405069	105882	2978380	28	6573121	166078375	172651496	5.522250
ab-0.04-w-a	18	960857	294498	≤9166891	≤31	14424126	42381510	56805636	4.209467
ab-0.04-wo-a	19	1075519	363719	9553240	26	17083596	34249775	51333371	4.146983
ab-0.06-f-w-a	15	336262	75905	≤1755919	≤23	3919916	81138448	85058364	2.228433
ab-0.06-f-wo-a	16	405069	105882	2978380	28	6573121	166078375	172651496	5.357400
ab-0.06-w-a	20	1425945	472794	≤15069802	≤31	22092341	44460288	66552629	5.526783
ab-0.06-wo-a	19	1042305	363912	9944647	27	15035093	23967762	39002855	3.286833
minisat	20	1258486	526553	14863149	28	18738752	0	18738752	1.439248

Table 9: Statistics of crafted_SAT_QG7a-gensys-brn004.sat05-3669.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	16	531246	100766	≤2627276	≤26	4852667	136380917	141233584	3.674917
ab-0-f-wo-a	16	633665	129958	3346952	25	7178703	180883920	188062623	4.656983
ab-0-w-a	19	1711585	407250	≤11855887	≤29	18827182	62304462	81131644	5.523150
ab-0-wo-a	19	1567855	379718	10329828	27	17330523	46219709	63550232	4.555800
ab-0.025-f-w-a	16	531246	100766	≤2627276	≤26	4852667	136380917	141233584	3.734617
ab-0.025-f-wo-a	16	633665	129958	3346952	25	7178703	180883920	188062623	6.438000
ab-0.025-w-a	20	2136562	528675	≤16489349	≤31	25985963	86661166	112647129	9.756833
ab-0.025-wo-a	20	1888567	483181	14039768	29	21627181	56242279	77869460	6.928200
ab-0.04-f-w-a	16	643504	107259	≤2770302	≤25	5580397	149604126	155184523	4.471300
ab-0.04-f-wo-a	17	803495	160263	4485680	27	9057916	256504946	265562862	10.629617
ab-0.04-w-a	20	2387192	645030	≤20106295	≤31	30998270	71958965	102957235	10.105617
ab-0.04-wo-a	19	1520648	441964	11983800	27	17842358	36113774	53956132	5.038183
ab-0.06-f-w-a	16	606117	119038	≤3214721	≤27	6089815	166704188	172794003	5.180117
ab-0.06-f-wo-a	16	632785	111649	2954119	26	6666813	163308988	169975801	5.126867
ab-0.06-w-a	20	1602744	445497	≤13012715	≤29	18984792	40425717	59410509	5.150967
ab-0.06-wo-a	20	1961504	564623	16632093	29	23747032	31756768	55503800	4.794417
minisat	19	1141357	357830	10488810	29	11753610	0	11753610	0.773115

Table 10: Statistics of crafted_SAT_QG7a-gensys-brn100.sat05-3765.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	23	2314687	1660056	≤30664359	≤18	115642425	733280208	848922633	6.300350
ab-0-f-wo-a	24	3495728	2880303	44333530	15	182381233	952759930	1135141163	9.330250
ab-0-w-a	21	1510205	924240	≤23096330	≤24	65559550	127416515	192976065	1.467577
ab-0-wo-a	22	1585917	1334849	21207154	15	81040624	97717267	178757891	1.613055
ab-0.025-f-w-a	23	2179289	1611494	≤29886697	≤18	112304213	688834235	801138448	5.900883
ab-0.025-f-wo-a	22	1168546	1014117	16418388	16	62465374	274372822	336838196	2.357983
ab-0.025-w-a	24	4185983	2679771	≤60519952	≤22	187822350	285479412	473301762	4.094433
ab-0.025-wo-a	23	1962037	1724092	26132639	15	99269349	72519284	171788633	1.785933
ab-0.04-f-w-a	21	1046143	835226	≤15117462	≤18	60623229	288560487	349183716	2.062917
ab-0.04-f-wo-a	23	1739773	1533947	24145504	15	99533914	392102341	491636255	3.753533
ab-0.04-w-a	22	1961171	1470222	≤29849483	≤20	91909195	81103212	173012407	1.674017
ab-0.04-wo-a	23	2383084	2153415	33931337	15	125442771	69601505	195044276	1.946050
ab-0.06-f-w-a	22	1467991	1204405	≤21255292	≤17	77724130	361541651	439265781	3.024067
ab-0.06-f-wo-a	25	4607386	4012712	63317202	15	253047226	1008534101	1261581327	11.847383
ab-0.06-w-a	23	2556395	2089492	≤38585290	≤18	128828850	77355362	206184212	2.113167
ab-0.06-wo-a	24	2582815	2388006	35373842	14	145477815	54093507	199571322	1.922333
minisat	24	3368493	3172739	47811455	15	174744644	0	174744644	1.671700

Table 11: Statistics of crafted_SAT_mod2-rand3bip-sat-210-1.sat05-2158.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	20	758823	540094	≤9669131	≤17	37988372	235249313	273237685	1.702517
ab-0-f-wo-a	21	909164	729301	10955686	15	40686906	230949960	271636866	1.823650
ab-0-w-a	22	1777459	1060529	≤23242750	≤21	68417797	128222618	196640415	1.492140
ab-0-wo-a	19	524836	429131	6541204	15	26277287	41050056	67327343	0.518638
ab-0.025-f-w-a	15	93784	76507	≤1429663	≤18	5273618	29411603	34685221	0.157109
ab-0.025-f-wo-a	20	539811	457893	6875979	15	28964481	116559922	145524403	0.936675
ab-0.025-w-a	15	98691	62001	≤1462407	≤23	3640842	5319081	8959923	0.055758
ab-0.025-wo-a	20	650916	572963	9158149	15	34648543	30521315	65169858	0.580395
ab-0.04-f-w-a	22	1427545	1053956	≤17598713	≤16	69201921	359073848	428275769	2.725333
ab-0.04-f-wo-a	19	458247	387406	6064516	15	21520806	107701186	129221992	0.763333
ab-0.04-w-a	18	301275	206891	≤4482765	≤21	13203442	15195031	28398473	0.213833
ab-0.04-wo-a	21	1044673	924046	13926265	15	54968372	39135880	94104252	0.914012
ab-0.06-f-w-a	19	477776	376188	≤6319211	≤16	22407103	105685684	128092787	0.755685
ab-0.06-f-wo-a	19	418480	363559	5913042	16	23821213	105276839	129098052	0.803512
ab-0.06-w-a	22	1884378	1468805	≤26955957	≤18	90880366	65400638	156281004	1.368375
ab-0.06-wo-a	16	138285	122803	2021015	16	7623090	5147558	12770648	0.090070
minisat	19	443550	420042	6259982	14	23347081	0	23347081	0.193187

Table 12: Statistics of crafted_SAT_mod2-rand3bip-sat-210-2.sat05-2159.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	19	606683	429419	≤8441364	≤19	32290510	208059863	240350373	1.459528
ab-0-f-wo-a	24	3257234	2687487	43076014	16	186456103	933591029	1120047132	9.320617
ab-0-w-a	23	2838594	1721933	≤44507596	≤25	126359317	244738033	371097350	2.890667
ab-0-wo-a	25	4744532	3969099	62177962	15	251117808	376581730	627699538	5.948600
ab-0.025-f-w-a	24	3250898	2254312	≤41726320	≤18	174017486	1012149079	1186166565	10.022633
ab-0.025-f-wo-a	18	241370	207861	3834056	18	13532457	76800630	90333087	0.488508
ab-0.025-w-a	21	1378594	941251	≤21683546	≤23	71414297	89812775	161227072	1.177672
ab-0.025-wo-a	21	877699	762171	13365625	17	49808890	46215593	96024483	0.840838
ab-0.04-f-w-a	25	4965061	3739984	≤66317470	≤17	285769464	1435188431	1720957895	14.593200
ab-0.04-f-wo-a	22	1321760	1154125	19290174	16	66288094	325437250	391725344	2.917167
ab-0.04-w-a	19	443090	324736	≤7453474	≤22	22724186	24293096	47017282	0.340815
ab-0.04-wo-a	24	3737773	3355009	53896597	16	232723949	150434552	383158501	4.035017
ab-0.06-f-w-a	25	5702300	4493959	≤76877125	≤17	322936765	1470310364	1793247129	16.427800
ab-0.06-f-wo-a	21	760389	669845	11226438	16	42500297	182039576	224539873	1.604340
ab-0.06-w-a	21	1139686	878016	≤18522916	≤21	63716247	52277271	115993518	0.945057
ab-0.06-wo-a	24	2678554	2423450	40808659	16	163012290	80311997	243324287	2.275467
minisat	24	3397966	3209176	51825849	16	199318447	0	199318447	1.890333

Table 13: Statistics of crafted_SAT_mod2-rand3bip-sat-220-1.sat05-2173.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	26	8986601	6240674	≤115343883	≤18	504872677	2953300245	3458172922	29.216833
ab-0-f-wo-a	24	3011332	2501451	43281279	17	168322483	913885355	1082207838	8.629533
ab-0-w-a	26	11944907	7145711	≤190523590	≤26	478860984	845506076	1324367060	13.053333
ab-0-wo-a	27	11058859	9280299	157229611	16	641067751	725545906	1366613657	14.511767
ab-0.025-f-w-a	25	6250430	4552864	≤91694860	≤20	339196885	2255359672	2594556557	21.842000
ab-0.025-f-wo-a	25	4355700	3779367	64469297	17	262139681	1120310463	1382450144	12.107100
ab-0.025-w-a	27	13085414	8573890	≤204698026	≤23	547573868	692194603	1239768471	13.836917
ab-0.025-wo-a	26	8570573	7463562	125309485	16	505598138	433817284	939415422	10.601600
ab-0.04-f-w-a	27	10345445	7892388	≤151209567	≤19	532172024	3123760059	3655932083	36.118667
ab-0.04-f-wo-a	21	948659	813949	14408738	17	60164325	256801283	316965608	2.164483
ab-0.04-w-a	27	12872678	9943709	≤209486911	≤21	640730787	499122067	1139852854	13.945333
ab-0.04-wo-a	19	489837	434527	8656946	19	27162730	19588799	46751529	0.408872
ab-0.06-f-w-a	27	12617904	10122655	≤190102137	≤18	726779739	3557483860	4284263599	39.882667
ab-0.06-f-wo-a	26	6212583	5429534	89288924	16	386092736	1485884846	1871977582	18.045000
ab-0.06-w-a	27	10104229	8176528	≤179225799	≤21	566569466	386943195	953512661	9.856967
ab-0.06-wo-a	27	9051482	8325525	144390151	17	518520793	215526526	734047319	8.136133
minisat	27	8828696	8310864	141837492	17	538725780	0	538725780	5.198383

Table 14: Statistics of crafted_SAT_mod2-rand3bip-sat-220-2.sat05-2174.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	21	1514757	840296	≤34153069	≤40	14219129	840957483	855176612	12.230783
ab-0-f-wo-a	22	1706584	1067369	36456550	34	17107610	1043541604	1060649214	17.675333
ab-0-w-a	23	3614676	2005216	≤96658106	≤48	30017174	215803375	245820549	6.122167
ab-0-wo-a	23	2461142	1647967	60751513	36	22690170	134469993	157160163	4.216483
ab-0.025-f-w-a	21	1506390	846270	≤34410590	≤40	14090803	841823432	855914235	11.950033
ab-0.025-f-wo-a	21	1337562	842779	28895246	34	13496262	818627398	832123660	13.267133
ab-0.025-w-a	23	3032172	2146617	≤90447387	≤42	28776711	101661930	130438641	4.283117
ab-0.025-wo-a	23	2289748	2174705	80155381	36	26570910	8181625	34752535	1.797033
ab-0.04-f-w-a	22	2124694	1195274	≤47993926	≤40	20084131	1211141831	1231225962	19.322500
ab-0.04-f-wo-a	21	1489365	927929	31682818	34	14834379	893308792	908143171	15.157867
ab-0.04-w-a	24	3381631	3174670	≤118245822	≤37	40320432	13143667	53464099	2.801350
ab-0.04-wo-a	23	2234687	2122175	76618301	36	26218928	7643958	33862886	1.722167
ab-0.06-f-w-a	21	1523274	864837	≤34954358	≤40	14439286	860685514	875124800	12.455667
ab-0.06-f-wo-a	21	1205657	754182	25786193	34	11770946	698993658	710764604	11.005783
ab-0.06-w-a	24	3029231	2859125	≤106034362	≤37	34940640	11209624	46150264	2.467817
ab-0.06-wo-a	23	2173462	2067814	75193654	36	25390469	7115938	32506407	1.681000
minisat	23	2199931	2125530	78729027	37	25560184	0	25560184	1.291870

Table 15: Statistics of crafted_UNSAT_couting-easier-fphp-012-010.sat05-1214.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	22	2410469	1146135	≤47875335	≤41	20638342	953950042	974588384	7.027133
ab-0-f-wo-a	22	1892599	1052951	35663777	33	18409806	839078069	857487875	6.618300
ab-0-w-a	23	3672809	1923334	≤88233120	≤45	30954865	163404705	194359570	3.366983
ab-0-wo-a	24	3781296	2338208	83861814	35	35425751	158180814	193606565	3.671567
ab-0.025-f-w-a	22	2645483	1337842	≤54633355	≤40	23410067	1139015734	1162425801	8.884583
ab-0.025-f-wo-a	22	2370494	1339234	44937381	33	23306718	1056669200	1079975918	9.004033
ab-0.025-w-a	24	3710644	2590739	≤105652295	≤40	37449887	76781032	114230919	2.906117
ab-0.025-wo-a	25	5124299	4497864	163906918	36	63517069	10508697	74025766	2.794800
ab-0.04-f-w-a	22	2390822	1156094	≤49318449	≤42	20310343	987820293	1008130636	7.510817
ab-0.04-f-wo-a	22	2345241	1303042	44654138	34	22070940	1045039687	1067110627	8.549350
ab-0.04-w-a	24	3118991	2730082	≤99558621	≤36	38373050	8541740	46914790	1.648317
ab-0.04-wo-a	25	3952242	3477090	126193653	36	48726136	7135539	55861675	2.097533
ab-0.06-f-w-a	22	2697437	1401159	≤56954064	≤40	23625709	1100209646	1123835355	8.493467
ab-0.06-f-wo-a	22	2211056	1326498	45486350	34	21543467	924973006	946516473	7.277017
ab-0.06-w-a	24	3322721	2915576	≤108250414	≤37	40642073	8341107	48983180	1.793000
ab-0.06-wo-a	25	3858288	3397424	123900663	36	47569142	6785048	54354190	2.035367
minisat	24	3214593	2869668	105660490	36	39917470	0	39917470	1.394805

Table 16: Statistics of crafted_UNSAT_couting-easier-php-012-010.sat05-1172.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	18	788740	210116	≤4303659	≤20	10484793	150885164	161369957	2.838733
ab-0-f-wo-a	17	759408	180472	3733343	20	8720276	125724831	134445107	2.474533
ab-0-w-a	20	2332111	601168	≤16276185	≤27	25790259	82539110	108329369	5.012517
ab-0-wo-a	20	1610613	445910	10376494	23	18062283	41979131	60041414	2.134050
ab-0.025-f-w-a	18	743723	205953	≤4249307	≤20	10217627	149696871	159914498	3.850017
ab-0.025-f-wo-a	17	759408	180472	3733343	20	8720276	125724831	134445107	3.026217
ab-0.025-w-a	20	2268068	549431	≤14138640	≤25	23664809	74060312	97725121	4.745200
ab-0.025-wo-a	20	1741255	531688	12308261	23	21360274	46977422	68337696	3.358800
ab-0.04-f-w-a	18	745436	206528	≤4251244	≤20	10268029	149756452	160024481	3.674767
ab-0.04-f-wo-a	17	652654	171716	3568040	20	8299212	120102495	128401707	3.256417
ab-0.04-w-a	20	1834925	494847	≤12465263	≤25	20245745	54588436	74834181	3.829367
ab-0.04-wo-a	21	3067337	947512	23052027	24	38178227	69484616	107662843	7.469700
ab-0.06-f-w-a	18	768328	196896	≤4055187	≤20	9806065	143353426	153159491	3.491917
ab-0.06-f-wo-a	18	1154291	237606	5098525	21	11813831	174440384	186254215	4.426333
ab-0.06-w-a	22	3735196	1175076	≤29779885	≤25	44378006	48281652	92659658	6.492417
ab-0.06-wo-a	21	3001716	903745	21873612	24	32851741	30148218	62999959	3.539067
minisat	22	3329456	1170313	28774252	24	40875333	0	40875333	1.429167

Table 17: Statistics of crafted_UNSAT_QG-gensys-brn008.sat05-2685.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	18	898695	203032	≤4158699	≤20	10286774	152597308	162884082	3.463217
ab-0-f-wo-a	18	884307	198555	3938654	19	9875649	138240898	148116547	2.810067
ab-0-w-a	20	1873796	459207	≤11852287	≤25	19433610	60318291	79751901	3.660450
ab-0-wo-a	21	2952336	731697	17387218	23	31467889	74723059	106190948	4.398433
ab-0.025-f-w-a	18	899878	203469	≤4181570	≤20	10283890	153645485	163929375	4.098017
ab-0.025-f-wo-a	18	865052	197004	3986148	20	9699817	139881180	149580997	3.359467
ab-0.025-w-a	21	4043425	916632	≤24997380	≤27	41097986	130754478	171852464	9.082267
ab-0.025-wo-a	21	3284113	839915	20300048	24	35972945	83059204	119032149	6.261250
ab-0.04-f-w-a	18	899878	203469	≤4181570	≤20	10283890	153645485	163929375	3.520600
ab-0.04-f-wo-a	17	798690	180107	3550317	19	8801576	123027635	131829211	3.532417
ab-0.04-w-a	20	2170146	563583	≤14593390	≤25	23713323	68588640	92301963	4.716550
ab-0.04-wo-a	20	1836130	560324	12892575	23	21726346	39552815	61279161	3.905300
ab-0.06-f-w-a	18	914986	205354	≤4208947	≤20	10415563	154597572	165013135	2.874767
ab-0.06-f-wo-a	17	778564	179725	3521174	19	8787053	122463260	131250313	3.025083
ab-0.06-w-a	22	3815387	1104509	≤28342927	≤25	42117426	40417537	82534963	4.983683
ab-0.06-wo-a	20	1809998	602926	13739045	22	21609861	22681991	44291852	2.312017
minisat	23	6316199	1983149	50500933	25	71473237	0	71473237	3.033767

Table 18: Statistics of crafted_UNSAT_QG-gensys-icl003.sat05-2715.reshuffled-07 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	8	14380	3237	≤30503	≤9	589309	2957488	3546797	0.010532
ab-0-f-wo-a	7	14554	2872	27039	9	519393	2569530	3088923	0.008665
ab-0-w-a	8	16318	3743	≤43461	≤11	700281	1639763	2340044	0.008015
ab-0-wo-a	8	15620	3615	36742	10	653984	991885	1645869	0.006066
ab-0.025-f-w-a	8	14380	3237	≤30503	≤9	589309	2957488	3546797	0.009898
ab-0.025-f-wo-a	7	14554	2872	27039	9	519393	2569530	3088923	0.008899
ab-0.025-w-a	8	16318	3743	≤43461	≤11	700281	1639763	2340044	0.008865
ab-0.025-wo-a	8	15620	3615	36742	10	653984	991885	1645869	0.005749
ab-0.04-f-w-a	8	14380	3237	≤30503	≤9	589309	2957488	3546797	0.010782
ab-0.04-f-wo-a	7	14554	2872	27039	9	519393	2569530	3088923	0.009898
ab-0.04-w-a	8	16318	3743	≤43461	≤11	700281	1639763	2340044	0.008482
ab-0.04-wo-a	8	15620	3615	36742	10	653984	991885	1645869	0.006832
ab-0.06-f-w-a	8	14380	3237	≤30503	≤9	589309	2957488	3546797	0.011615
ab-0.06-f-wo-a	7	14554	2872	27039	9	519393	2569530	3088923	0.009932
ab-0.06-w-a	8	16318	3743	≤43461	≤11	700281	1639763	2340044	0.007949
ab-0.06-wo-a	8	15620	3615	36742	10	653984	991885	1645869	0.006699
minisat	8	15169	4026	41333	10	697284	0	697284	0.003050

Table 19: Statistics of crafted_UNSAT_lksat-n1800-m6151-k3-l4-s1077733694.used-as.sat04-912 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	7	15729	2950	≤35789	≤12	492810	3035058	3527868	0.010598
ab-0-f-wo-a	10	27659	10958	186626	17	2165957	18920067	21086024	0.087203
ab-0-w-a	10	28563	11156	≤203733	≤18	2178520	4979532	7158052	0.033961
ab-0-wo-a	9	22011	7117	122462	17	1322338	1920185	3242523	0.014814
ab-0.025-f-w-a	7	15729	2950	≤35789	≤12	492810	3035058	3527868	0.009632
ab-0.025-f-wo-a	10	27659	10958	186626	17	2165957	18920067	21086024	0.082388
ab-0.025-w-a	10	28563	11156	≤203733	≤18	2178520	4978405	7156925	0.036411
ab-0.025-wo-a	9	22011	7117	122462	17	1322338	1920185	3242523	0.013648
ab-0.04-f-w-a	7	15729	2950	≤35789	≤12	492810	3035058	3527868	0.012032
ab-0.04-f-wo-a	10	27659	10958	186626	17	2165957	18920067	21086024	0.088820
ab-0.04-w-a	11	31328	12551	≤223851	≤17	2461467	5622513	8083980	0.040427
ab-0.04-wo-a	9	22011	7117	122462	17	1322338	1920185	3242523	0.017764
ab-0.06-f-w-a	7	15729	2950	≤35789	≤12	492810	3035058	3527868	0.010648
ab-0.06-f-wo-a	10	27659	10958	186626	17	2165957	18917954	21083911	0.087970
ab-0.06-w-a	11	31328	12551	≤223851	≤17	2461467	5622513	8083980	0.040494
ab-0.06-wo-a	9	22011	7117	122462	17	1322338	1920185	3242523	0.016514
minisat	7	14450	2912	38753	13	459506	0	459506	0.001933

Table 20: Statistics of crafted_UNSAT_lksat-n1800-m6151-k3-l4-s255309316.used-as.sat04-913 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	15	139669	80602	≤1318543	≤16	17269589	148823345	166092934	0.930658
ab-0-f-wo-a	15	141174	82792	1298138	15	17733565	142616159	160349724	0.944023
ab-0-w-a	16	171772	96685	≤1864278	≤19	20351949	55816818	76168767	0.505057
ab-0-wo-a	15	143680	85751	1460448	17	17923872	33167967	51091839	0.349980
ab-0.025-f-w-a	15	140162	80893	≤1325979	≤16	17341114	149483917	166825031	1.001415
ab-0.025-f-wo-a	15	118700	69289	1049020	15	14891892	111961996	126853888	0.729888
ab-0.025-w-a	15	139056	77822	≤1493355	≤19	16130983	42462785	58593768	0.327950
ab-0.025-wo-a	15	136747	82788	1430209	17	17127042	28099304	45226346	0.277358
ab-0.04-f-w-a	15	148435	85934	≤1378429	≤16	18226983	155234339	173461322	1.007263
ab-0.04-f-wo-a	15	112665	65589	1028304	15	14042572	110197607	124240179	0.685445
ab-0.04-w-a	16	179071	105890	≤2010575	≤18	22222404	52040780	74263184	0.542850
ab-0.04-wo-a	16	164428	104339	1810228	17	21568971	32436054	54005025	0.427652
ab-0.06-f-w-a	15	141570	81769	≤1295723	≤15	17474882	144312037	161786919	0.861402
ab-0.06-f-wo-a	15	117571	69886	1048526	15	14976022	107790471	122766493	0.632537
ab-0.06-w-a	16	159528	99990	≤1820980	≤18	20729018	39515152	60244170	0.410822
ab-0.06-wo-a	16	161223	105512	1813685	17	21809428	26642669	48452097	0.392657
minisat	16	146436	111013	1892709	17	22200581	0	22200581	0.141462

Table 21: Statistics of crafted_UNSAT_lksat-n1800-m6151-k3-l4-s355586539.used-as.sat04-914 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	17	258913	154764	≤2587952	≤16	35408716	329120776	364529492	1.969583
ab-0-f-wo-a	16	196739	121153	1997714	16	27120432	245222316	272342748	1.687283
ab-0-w-a	17	248406	143635	≤3007189	≤20	32220837	90703368	122924205	0.882250
ab-0-wo-a	17	219633	135398	2452822	18	29850397	56974241	86824638	0.611290
ab-0.025-f-w-a	16	190776	111134	≤1841242	≤16	25424144	229798947	255223091	1.587975
ab-0.025-f-wo-a	17	219166	135995	2221755	16	30446299	270123493	300569792	1.887517
ab-0.025-w-a	17	268007	159961	≤3291389	≤20	35776342	89459159	125235501	0.711942
ab-0.025-wo-a	17	209885	133563	2434095	18	29419162	47784161	77203323	0.588793
ab-0.04-f-w-a	16	208992	124956	≤2160852	≤17	28259835	274783257	303043092	1.863617
ab-0.04-f-wo-a	17	241137	149566	2464462	16	33572107	298213760	331785867	2.079450
ab-0.04-w-a	17	257398	155418	≤3166271	≤20	34736331	83304476	118040807	0.965437
ab-0.04-wo-a	17	231681	148864	2909316	19	32492032	51272793	83764825	0.744303
ab-0.06-f-w-a	16	177214	105985	≤1719935	≤16	23926761	212254318	236181079	1.289220
ab-0.06-f-wo-a	16	182087	113696	1851061	16	25394514	217245866	242640380	1.411002
ab-0.06-w-a	17	270514	174675	≤3506086	≤20	38679147	72354462	111033609	0.939940
ab-0.06-wo-a	17	249263	170241	3170377	18	37185294	44621016	81806310	0.696343
minisat	17	253893	196613	3788859	19	41624752	0	41624752	0.298188

Table 22: Statistics of crafted_UNSAT_lksat-n2000-m6840-k3-l4-s1061036908.used-as.sat04-915 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	24	4802494	3110309	≤40777652	≤13	71734176	607549320	679283496	2.461950
ab-0-f-wo-a	24	4474780	3074605	37450590	12	70176141	522961031	593137172	2.247100
ab-0-w-a	25	5557649	3521611	≤51581240	≤14	84042918	201385666	285428584	1.444463
ab-0-wo-a	25	6024505	4277099	54247763	12	98403125	157362235	255765360	1.458528
ab-0.025-f-w-a	24	4113039	2686395	≤34658429	≤12	60548976	437259503	497808479	1.876467
ab-0.025-f-wo-a	24	4165582	2975990	36864754	12	67272614	385469515	452742129	1.840383
ab-0.025-w-a	25	5223516	3777127	≤50870751	≤13	85712333	81842268	167554601	1.064938
ab-0.025-wo-a	24	3993866	3231760	40401221	12	72706652	11222185	83928837	0.605792
ab-0.04-f-w-a	24	4767903	3185930	≤41535390	≤13	72922771	503308542	576231313	2.092500
ab-0.04-f-wo-a	24	3806088	2762318	34288402	12	61777901	323759630	385537531	1.583693
ab-0.04-w-a	25	5254412	4255925	≤55030614	≤12	96536961	16219946	112756907	0.806893
ab-0.04-wo-a	25	5290824	4352801	56359747	12	99375078	5936691	105311769	0.777648
ab-0.06-f-w-a	24	3814881	2620000	≤33239116	≤12	58438806	348723006	407161812	1.533167
ab-0.06-f-wo-a	24	3828127	2839113	35244249	12	64163022	274777432	338940454	1.430133
ab-0.06-w-a	25	4976550	4061209	≤51704500	≤12	92171656	4558342	96729998	0.718457
ab-0.06-wo-a	24	3769205	3080103	38301346	12	68459185	1968702	70427887	0.497708
minisat	24	4041245	3339137	42231217	12	75251672	0	75251672	0.542733

Table 23: Statistics of crafted_UNSAT_sgen_s77-100 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	26	10049492	6504975	≤90298820	≤13	152264692	1380612200	1532876892	5.834583
ab-0-f-wo-a	26	9576122	6544032	84559381	12	149169275	1209156557	1358325832	5.756933
ab-0-w-a	26	11089179	6990081	≤107821261	≤15	168755134	408692177	577447311	3.175233
ab-0-wo-a	27	11590587	8130571	107892405	13	190610739	341283595	531894334	3.199667
ab-0.025-f-w-a	26	9763207	6512879	≤90801752	≤13	152246623	1220495847	1372742470	5.524017
ab-0.025-f-wo-a	27	12746125	9141731	122176873	13	213701038	1424278316	1637979354	7.084067
ab-0.025-w-a	27	10528208	7725601	≤108507598	≤14	179465690	146681547	326147237	2.210083
ab-0.025-wo-a	27	9525741	7758753	105805117	13	181084626	29113443	210198069	1.657498
ab-0.04-f-w-a	26	9200320	6103489	≤83644947	≤13	142417425	1076478283	1218895708	4.827300
ab-0.04-f-wo-a	26	7252719	5317166	68829277	12	121282695	637853201	759135896	3.299300
ab-0.04-w-a	26	8498839	6908259	≤94938426	≤13	161859262	21559325	183418587	1.354810
ab-0.04-wo-a	27	11906152	9917809	135458047	13	235352579	11108352	246460931	2.050333
ab-0.06-f-w-a	26	9476691	6410355	≤87817004	≤13	150372623	1052295517	1202668140	4.826767
ab-0.06-f-wo-a	27	10384053	7813623	104289018	13	180537008	799958344	980495352	4.471667
ab-0.06-w-a	27	10698482	8844003	≤120601433	≤13	204461112	6439007	210900119	1.610988
ab-0.06-wo-a	26	9092099	7547994	102683495	13	175613199	3092419	178705618	1.380957
minisat	26	7882812	6451933	85654580	13	147673908	0	147673908	1.104882

Table 24: Statistics of crafted_UNSAT_sgen_s81-100 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	27	15603255	10052261	≤145274220	≤14	240982779	2284079137	2525061916	9.907267
ab-0-f-wo-a	28	21677779	14869647	205333099	13	355233856	3105910307	3461144163	15.242617
ab-0-w-a	27	17579842	10981642	≤175421893	≤15	270644630	660163137	930807767	5.335600
ab-0-wo-a	28	22488949	15926074	222025175	13	382216853	651723440	1033940293	6.544217
ab-0.025-f-w-a	28	18958667	12686661	≤184222451	≤14	304043275	2434361797	2738405072	11.599817
ab-0.025-f-wo-a	28	19684471	14211928	196827374	13	338598845	2200635060	2539233905	11.550233
ab-0.025-w-a	28	21043272	15345089	≤226467489	≤14	364319683	327891607	692211290	4.992900
ab-0.025-wo-a	28	19643066	16036159	227998332	14	383750421	54991720	438742141	3.770583
ab-0.04-f-w-a	27	16691631	11127843	≤161225740	≤14	265534118	2095735983	2361270101	9.771300
ab-0.04-f-wo-a	28	19269512	14094487	196886722	13	333006913	2023031138	2356038051	11.379933
ab-0.04-w-a	29	21929144	17877241	≤261042790	≤14	430020553	65162091	495182644	4.169250
ab-0.04-wo-a	29	25003198	20787961	300075722	14	502979384	17600583	520579967	4.595300
ab-0.06-f-w-a	28	21638927	14726581	≤210332992	≤14	350097962	2466152879	2816250841	12.219917
ab-0.06-f-wo-a	28	21482842	15849931	223175176	14	378454784	2132413482	2510868266	12.030933
ab-0.06-w-a	28	16744735	13670524	≤190416362	≤13	320417284	7535991	327953275	2.781683
ab-0.06-wo-a	29	23957837	20026613	289677632	14	482940160	4021477	486961637	4.151633
minisat	28	18346928	15114525	210179836	13	356647899	0	356647899	2.945300

Table 25: Statistics of crafted_UNSAT_sgen_s85-100 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	28	22023445	14166982	≤205408197	≤14	332713813	3207191203	3539905016	15.170967
ab-0-f-wo-a	28	22903168	15603080	215010275	13	361052606	3239454029	3600506635	15.829367
ab-0-w-a	29	28940643	18113045	≤292770794	≤16	434096893	1053316102	1487412995	9.308783
ab-0-wo-a	29	26086778	18334543	256119041	13	427882576	731739260	1159621836	7.646067
ab-0.025-f-w-a	28	22350686	14536444	≤212523857	≤14	345458661	3026701030	3372159691	14.792200
ab-0.025-f-wo-a	29	27299385	19462447	274126492	14	454047446	3212670022	3666717468	17.441667
ab-0.025-w-a	29	27750623	20121436	≤304418135	≤15	481923456	462222937	944146393	7.221667
ab-0.025-wo-a	30	32806804	26666429	386173611	14	628355783	82198351	710554134	6.585617
ab-0.04-f-w-a	28	24474431	16392310	≤240121813	≤14	390481480	3211006500	3601487980	15.858650
ab-0.04-f-wo-a	29	24868446	18282758	261814266	14	433355901	2529462465	2962818366	14.426833
ab-0.04-w-a	30	33146134	27056623	≤397675467	≤14	637151310	54789029	691940339	6.279333
ab-0.04-wo-a	29	30991002	25506827	367763069	14	597903091	13632241	611535332	5.540033
ab-0.06-f-w-a	28	24410352	16335356	≤237947497	≤14	387246722	3131666915	3518913637	15.550850
ab-0.06-f-wo-a	29	27762807	20819412	293573896	14	482836635	2197597454	2680434089	13.495533
ab-0.06-w-a	30	32617985	26931831	≤390947130	≤14	634438757	8634132	643072889	5.782950
ab-0.06-wo-a	30	32313118	26595910	382656830	14	622864864	3441751	626306615	5.723200
minisat	29	28738636	23889234	348873859	14	570356051	0	570356051	4.996733

Table 26: Statistics of crafted_UNSAT_sgen_s89-100 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	7	11076	2733	≤38100	≤13	7853086	84037686	91890772	0.386125
ab-0-f-wo-a	7	10224	2197	29146	13	5752628	44624302	50376930	0.134013
ab-0-w-a	7	12375	2377	≤48422	≤20	6285323	18188067	24473390	0.091219
ab-0-wo-a	8	17555	4315	71974	16	11258251	20015589	31273840	0.156826
ab-0.025-f-w-a	7	11076	2733	≤38100	≤13	7853086	84037686	91890772	0.467628
ab-0.025-f-wo-a	7	10224	2197	29146	13	5752628	44624302	50376930	0.255745
ab-0.025-w-a	7	12375	2377	≤48422	≤20	6285323	18188067	24473390	0.148644
ab-0.025-wo-a	8	17555	4315	71974	16	11258251	20015589	31273840	0.156876
ab-0.04-f-w-a	7	11076	2733	≤38100	≤13	7853086	84037686	91890772	0.464780
ab-0.04-f-wo-a	7	10224	2197	29146	13	5752628	44624302	50376930	0.234365
ab-0.04-w-a	7	12375	2377	≤48422	≤20	6285323	18188067	24473390	0.103134
ab-0.04-wo-a	8	17555	4315	71974	16	11258251	20015589	31273840	0.146761
ab-0.06-f-w-a	7	11076	2733	≤38100	≤13	7853086	84037686	91890772	0.217317
ab-0.06-f-wo-a	7	10224	2197	29146	13	5752628	44624302	50376930	0.159309
ab-0.06-w-a	7	12375	2377	≤48422	≤20	6285323	18188067	24473390	0.085387
ab-0.06-wo-a	8	17555	4315	71974	16	11258251	20015589	31273840	0.152527
minisat	8	12787	3909	86802	22	8462906	0	8462906	0.027996

Table 27: Statistics of industrial_SAT_clauses-2.renamed-as.sat05-1961 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	7	7742	2325	≤25431	≤10	6173184	39553954	45727138	0.310653
ab-0-f-wo-a	7	7847	2277	25803	11	5522122	35239471	40761593	0.144795
ab-0-w-a	8	12802	4423	≤65431	≤14	10065525	29042272	39107797	0.209602
ab-0-wo-a	9	15148	5097	77817	15	11197316	18378763	29576079	0.227065
ab-0.025-f-w-a	7	7742	2325	≤25431	≤10	6173184	39553954	45727138	0.378392
ab-0.025-f-wo-a	7	7847	2277	25803	11	5522122	35239471	40761593	0.278342
ab-0.025-w-a	8	12802	4423	≤65431	≤14	10065525	29042272	39107797	0.283707
ab-0.025-wo-a	9	15148	5097	77817	15	11197316	18378763	29576079	0.272792
ab-0.04-f-w-a	7	7742	2325	≤25431	≤10	6173184	39553954	45727138	0.360762
ab-0.04-f-wo-a	7	7847	2277	25803	11	5522122	35239471	40761593	0.374710
ab-0.04-w-a	8	12802	4423	≤65431	≤14	10065525	29042272	39107797	0.256112
ab-0.04-wo-a	9	15148	5097	77817	15	11197316	18378763	29576079	0.224467
ab-0.06-f-w-a	7	7742	2325	≤25431	≤10	6173184	39553954	45727138	0.186155
ab-0.06-f-wo-a	7	7847	2277	25803	11	5522122	35239471	40761593	0.220367
ab-0.06-w-a	8	12802	4423	≤65431	≤14	10065525	29042272	39107797	0.254578
ab-0.06-wo-a	9	15148	5097	77817	15	11197316	18378763	29576079	0.269358
minisat	10	16634	7903	137906	17	16049057	0	16049057	0.086704

Table 28: Statistics of industrial_SAT_clauses-2.shuffled-as.sat05-1966 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	12	86055	21833	≤618858	≤28	96794421	2909573177	3006367598	18.223000
ab-0-f-wo-a	11	70515	16570	437101	26	75824119	2201572912	2277397031	9.592083
ab-0-w-a	12	92804	20937	≤1305662	≤62	93270106	522416514	615686620	3.515667
ab-0-wo-a	13	137524	31373	1227197	39	128285249	374526596	502811845	3.305383
ab-0.025-f-w-a	12	86055	21833	≤618858	≤28	96794421	2909573177	3006367598	18.957167
ab-0.025-f-wo-a	11	70515	16570	437101	26	75824119	2201572912	2277397031	14.879133
ab-0.025-w-a	12	92804	20937	≤1305662	≤62	93270106	522416514	615686620	4.575317
ab-0.025-wo-a	13	137524	31373	1227197	39	128285249	374526596	502811845	3.811367
ab-0.04-f-w-a	12	86055	21833	≤618858	≤28	96794421	2909573177	3006367598	18.966333
ab-0.04-f-wo-a	11	70515	16570	437101	26	75824119	2201572912	2277397031	15.032467
ab-0.04-w-a	12	92804	20937	≤1305662	≤62	93270106	522416514	615686620	3.865383
ab-0.04-wo-a	13	137524	31373	1227197	39	128285249	374526596	502811845	3.550817
ab-0.06-f-w-a	12	86055	21833	≤618858	≤28	96794421	2909573177	3006367598	17.213000
ab-0.06-f-wo-a	11	70515	16570	437101	26	75824119	2201572912	2277397031	11.475567
ab-0.06-w-a	12	92804	20937	≤1305662	≤62	93270106	522416514	615686620	3.621983
ab-0.06-wo-a	13	137524	31373	1227197	39	128285249	374526596	502811845	3.159733
minisat	14	134471	50911	2729519	53	173754425	0	173754425	1.040608

Table 29: Statistics of industrial_SAT_clauses-4.renamed-as.sat05-1962 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	11	45771	14642	≤310728	≤21	72582009	1372908392	1445490401	13.322583
ab-0-f-wo-a	11	45463	16564	351218	21	71341645	1406817192	1478158837	9.080433
ab-0-w-a	13	88570	28875	≤896976	≤31	117795345	424867863	542663208	4.556133
ab-0-wo-a	12	67817	23671	693700	29	95420261	266420051	361840312	3.834133
ab-0.025-f-w-a	11	45771	14642	≤310728	≤21	72582009	1372908392	1445490401	14.470283
ab-0.025-f-wo-a	11	45463	16564	351218	21	71341645	1406817192	1478158837	12.244033
ab-0.025-w-a	13	88570	28875	≤896976	≤31	117795345	424867863	542663208	6.071550
ab-0.025-wo-a	12	67817	23671	693700	29	95420261	266420051	361840312	4.550650
ab-0.04-f-w-a	11	45771	14642	≤310728	≤21	72582009	1372908392	1445490401	15.079900
ab-0.04-f-wo-a	11	45463	16564	351218	21	71341645	1406817192	1478158837	13.431383
ab-0.04-w-a	13	88570	28875	≤896976	≤31	117795345	424867863	542663208	5.579950
ab-0.04-wo-a	12	67817	23671	693700	29	95420261	266420051	361840312	3.661783
ab-0.06-f-w-a	11	45771	14642	≤310728	≤21	72582009	1372908392	1445490401	11.773033
ab-0.06-f-wo-a	11	45463	16564	351218	21	71341645	1406817192	1478158837	10.090783
ab-0.06-w-a	13	88570	28875	≤896976	≤31	117795345	424867863	542663208	5.703383
ab-0.06-wo-a	12	67817	23671	693700	29	95420261	266420051	361840312	4.082267
minisat	14	87481	41257	1714939	41	148694919	0	148694919	1.555913

Table 30: Statistics of industrial_SAT_clauses-4.shuffled-as.sat05-1967 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	2	1329	249	≤9213	≤37	32447	1143953	1176400	0.006582
ab-0-f-wo-a	5	5061	1084	32980	30	118934	4018856	4137790	0.025913
ab-0-w-a	13	154154	35511	≤1863225	≤52	4087688	27397339	31485027	1.539717
ab-0-wo-a	5	4553	1293	60014	46	137205	514594	651799	0.005832
ab-0.025-f-w-a	2	1329	249	≤9213	≤37	32447	1143953	1176400	0.008232
ab-0.025-f-wo-a	5	5061	1084	32980	30	118934	4018856	4137790	0.035794
ab-0.025-w-a	13	154154	35511	≤1863225	≤52	4087688	27397339	31485027	1.952217
ab-0.025-wo-a	5	4553	1293	60014	46	137205	514594	651799	0.005849
ab-0.04-f-w-a	2	1329	249	≤9213	≤37	32447	1143953	1176400	0.008982
ab-0.04-f-wo-a	5	5061	1084	32980	30	118934	4018856	4137790	0.033595
ab-0.04-w-a	13	152504	35222	≤1851905	≤52	4054492	27139599	31194091	1.609705
ab-0.04-wo-a	5	4553	1293	60014	46	137205	514594	651799	0.005399
ab-0.06-f-w-a	2	1329	249	≤9213	≤37	32447	1143953	1176400	0.008415
ab-0.06-f-wo-a	5	5061	1084	32980	30	118934	4018856	4137790	0.029779
ab-0.06-w-a	13	152504	35222	≤1851905	≤52	4054492	27139599	31194091	1.714417
ab-0.06-wo-a	5	4553	1293	60014	46	137205	514594	651799	0.005499
minisat	12	42371	24853	1304035	52	2072901	0	2072901	0.092403

Table 31: Statistics of industrial_SAT_vmpc_21.renamed-as.sat05-1923 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	10	31564	11141	≤182572	≤16	1114403	20657615	21772018	0.233682
ab-0-f-wo-a	11	42281	16485	244450	14	1563629	25969384	27533013	0.276575
ab-0-w-a	14	119184	42346	≤1138299	≤26	4054506	30007416	34061922	0.927875
ab-0-wo-a	10	20481	8368	151686	18	782378	2974665	3757043	0.048593
ab-0.025-f-w-a	10	31564	11141	≤182572	≤16	1114403	20657615	21772018	0.263993
ab-0.025-f-wo-a	11	42281	16485	244450	14	1563629	25969384	27533013	0.395557
ab-0.025-w-a	10	22494	7558	≤148434	≤19	738618	4989769	5728387	0.067390
ab-0.025-wo-a	12	53855	22574	427826	18	2090723	7931725	10022448	0.168025
ab-0.04-f-w-a	10	31564	11141	≤182572	≤16	1114403	20657615	21772018	0.249578
ab-0.04-f-wo-a	11	29213	11346	168010	14	1081400	17881643	18963043	0.236730
ab-0.04-w-a	10	22494	7558	≤148434	≤19	738618	4989769	5728387	0.055192
ab-0.04-wo-a	12	53855	22574	427826	18	2090723	7931725	10022448	0.150027
ab-0.06-f-w-a	11	34106	12675	≤220317	≤17	1258334	25252667	26511001	0.294005
ab-0.06-f-wo-a	12	63002	24156	413529	17	2289818	45052005	47341823	0.685312
ab-0.06-w-a	10	22494	7558	≤148434	≤19	738618	4989769	5728387	0.063174
ab-0.06-wo-a	12	47553	19513	358165	18	1792159	6782845	8575004	0.130397
minisat	15	104210	73440	1994069	27	5399993	0	5399993	0.238813

Table 32: Statistics of industrial_SAT_vmpc_21.shuffled-as.sat05-1955 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	1	294	42	≤1474	≤35	7422	164750	172172	0.002300
ab-0-f-wo-a	1	276	51	1589	31	6651	188574	195225	0.001700
ab-0-w-a	9	25023	7005	≤454775	≤64	878500	5313271	6191771	0.078388
ab-0-wo-a	12	76337	23914	1158813	48	2772416	10922521	13694937	0.621088
ab-0.025-f-w-a	1	294	42	≤1474	≤35	7422	164750	172172	0.002300
ab-0.025-f-wo-a	1	276	51	1589	31	6651	188574	195225	0.002466
ab-0.025-w-a	9	25023	7005	≤454775	≤64	878500	5313271	6191771	0.103284
ab-0.025-wo-a	12	78388	24760	1192634	48	2873573	11298800	14172373	0.701693
ab-0.04-f-w-a	1	294	42	≤1474	≤35	7422	164750	172172	0.002500
ab-0.04-f-wo-a	1	276	51	1589	31	6651	188574	195225	0.002233
ab-0.04-w-a	9	25023	7005	≤454775	≤64	878500	5313271	6191771	0.079488
ab-0.04-wo-a	12	78388	24760	1192634	48	2873573	11298800	14172373	0.701377
ab-0.06-f-w-a	1	294	42	≤1474	≤35	7422	164750	172172	0.002083
ab-0.06-f-wo-a	1	276	51	1589	31	6651	188574	195225	0.002216
ab-0.06-w-a	9	25023	7005	≤454775	≤64	878500	5313271	6191771	0.080288
ab-0.06-wo-a	12	78388	24760	1192634	48	2873573	11298800	14172373	0.599242
minisat	1	133	40	1223	30	4249	0	4249	0.000383

Table 33: Statistics of industrial_SAT_vmpc_22.renamed-as.sat05-1924 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	11	35369	12582	≤223583	≤17	1393509	27063276	28456785	0.307487
ab-0-f-wo-a	11	40507	15859	252281	15	1629728	28677417	30307145	0.293755
ab-0-w-a	7	6196	2139	≤42130	≤19	≤216442	1470666	1687108	0.014781
ab-0-wo-a	12	49581	19440	360973	18	1967252	7682192	9649444	0.149294
ab-0.025-f-w-a	12	65846	24049	≤452001	≤18	2549318	55188497	57737815	0.857537
ab-0.025-f-wo-a	11	38982	14819	233173	15	1548337	26234745	27783082	0.374460
ab-0.025-w-a	7	6196	2139	≤42130	≤19	216442	1470666	1687108	0.018714
ab-0.025-wo-a	12	45888	17940	325250	18	1852531	6979834	8832365	0.143112
ab-0.04-f-w-a	13	108368	38325	≤713818	≤18	3977720	86217921	90195641	1.707367
ab-0.04-f-wo-a	11	38982	14819	233173	15	1548337	26228658	27776995	0.378210
ab-0.04-w-a	7	6196	2139	≤42130	≤19	216442	1470666	1687108	0.014681
ab-0.04-wo-a	13	93950	37213	753339	20	3716658	14362170	18078828	0.419470
ab-0.06-f-w-a	13	108368	38325	≤713818	≤18	3977720	86217921	90195641	1.705650
ab-0.06-f-wo-a	11	38982	14819	233173	15	1548337	26228658	27776995	0.333083
ab-0.06-w-a	7	6196	2139	≤42130	≤19	216442	1470666	1687108	0.014581
ab-0.06-wo-a	11	43106	16965	314060	18	1739343	6535017	8274360	0.135613
minisat	15	89442	60475	1457027	24	5019470	0	5019470	0.143461

Table 34: Statistics of industrial_SAT_vmpc_22.shuffled-as.sat05-1956 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	11	56564	13232	≤555592	≤41	1800240	79149789	80950029	0.944240
ab-0-f-wo-a	11	47230	12943	525733	40	1576093	80618666	82194759	0.871152
ab-0-w-a	14	181842	42572	≤2702426	≤63	5964981	38230687	44195668	2.539550
ab-0-wo-a	14	135172	41382	1768968	42	5461951	20937839	26399790	1.487323
ab-0.025-f-w-a	11	56564	13232	≤555592	≤41	1800240	79149789	80950029	1.208683
ab-0.025-f-wo-a	11	47230	12943	525733	40	1576093	80618666	82194759	1.246177
ab-0.025-w-a	14	181842	42572	≤2702426	≤63	5964981	38230687	44195668	3.761333
ab-0.025-wo-a	14	144712	46274	2023153	43	6011990	22015121	28027111	2.234033
ab-0.04-f-w-a	11	56564	13232	≤555592	≤41	1800240	79149789	80950029	1.255110
ab-0.04-f-wo-a	11	47230	12943	525733	40	1576093	80618666	82194759	1.260408
ab-0.04-w-a	14	181842	42572	≤2702426	≤63	5964981	38230687	44195668	2.766500
ab-0.04-wo-a	14	136210	41989	1815049	43	5525548	20150610	25676158	1.441680
ab-0.06-f-w-a	11	56564	13232	≤555592	≤41	1800240	79149789	80950029	1.210850
ab-0.06-f-wo-a	11	47230	12943	525733	40	1576093	80618666	82194759	1.078337
ab-0.06-w-a	14	181842	42572	≤2702426	≤63	5964981	38230687	44195668	2.904783
ab-0.06-wo-a	14	136210	41989	1815049	43	5525548	20150610	25676158	1.702017
minisat	14	84180	51061	2398539	46	5489501	0	5489501	0.291622

Table 35: Statistics of industrial_SAT_vmpc_23.renamed-as.sat05-1927 instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	13	81192	30491	≤560258	≤18	3477589	73367596	76845185	1.240128
ab-0-f-wo-a	12	46080	18129	300677	16	2038453	36106040	38144493	0.436217
ab-0-w-a	9	19435	7055	≤143728	≤20	809607	5261513	6071120	0.061341
ab-0-wo-a	10	23876	10061	185595	18	1089189	4139999	5229188	0.061274
ab-0.025-f-w-a	11	32547	12167	≤202579	≤16	1437934	26027041	27464975	0.333000
ab-0.025-f-wo-a	10	20215	8335	133050	15	969663	16111920	17081583	0.187288
ab-0.025-w-a	9	19435	7055	≤143728	≤20	809607	5261513	6071120	0.079871
ab-0.025-wo-a	10	23876	10061	185595	18	1089189	4139999	5229188	0.080921
ab-0.04-f-w-a	11	32547	12167	≤202579	≤16	1437934	26027041	27464975	0.326000
ab-0.04-f-wo-a	10	20215	8335	133050	15	969663	16111920	17081583	0.198837
ab-0.04-w-a	9	19435	7055	≤143728	≤20	809607	5261513	6071120	0.062707
ab-0.04-wo-a	10	23876	10061	185595	18	1089189	4139999	5229188	0.068190
ab-0.06-f-w-a	11	32547	12167	≤202579	≤16	1437934	26026308	27464242	0.318218
ab-0.06-f-wo-a	10	20215	8335	133050	15	969663	16111920	17081583	0.131347
ab-0.06-w-a	9	19435	7055	≤143728	≤20	809607	5260787	6070394	0.055491
ab-0.06-wo-a	10	21130	8773	157171	17	988597	3632413	4621010	0.048776
minisat	14	65897	44631	1065111	23	4179039	0	4179039	0.105467

Table 36: Statistics of industrial_SAT_vmpc_23.shuffled-as.sat05-1959 instance

Solver	**Restarts**	**Decisions**	**Conflicts**	**Conflict Literals**	**Avg. conflict clause size**	**Propagations**	**Afterburn propagations**	**Total Propagations**	**Time spent (minutes)**
ab-0-f-w-a	15	244153	64148	≤3208626	≤50	9091256	510494181	519585437	32.406167
ab-0-f-wo-a	14	170775	47111	1890135	40	6316551	298684296	305000847	9.415150
ab-0-w-a	15	327425	80270	≤5357721	≤66	11860869	77387921	89248790	7.928333
ab-0-wo-a	13	118405	36080	1919595	53	4851744	19428164	24279908	1.184220
ab-0.025-f-w-a	15	244153	64148	≤3208626	≤50	9091256	510494181	519585437	36.201667
ab-0.025-f-wo-a	14	170775	47111	1890135	40	6316551	298684296	305000847	11.685017
ab-0.025-w-a	15	307903	75903	≤5061877	≤66	11187997	72879618	84067615	10.009417
ab-0.025-wo-a	13	119368	37034	1965844	53	4975128	19709441	24684569	1.574010
ab-0.04-f-w-a	15	244153	64148	≤3208626	≤50	9091256	510494181	519585437	36.527333
ab-0.04-f-wo-a	14	170775	47111	1890135	40	6316551	298684296	305000847	10.869433
ab-0.04-w-a	16	334916	87609	≤5934312	≤67	12613149	80302615	92915764	14.675900
ab-0.04-wo-a	13	119368	37034	1965844	53	4975128	19709441	24684569	1.335580
ab-0.06-f-w-a	15	244153	64148	≤3208626	≤50	9091256	510494181	519585437	36.908000
ab-0.06-f-wo-a	14	170775	47111	1890135	40	6316551	298684296	305000847	11.104883
ab-0.06-w-a	15	266997	67326	≤4618470	≤68	9801692	62485019	72286711	6.962083
ab-0.06-wo-a	13	119368	37034	1965844	53	4975128	19709441	24684569	1.495807
minisat	16	157267	97078	5004104	51	10811844	0	10811844	0.909662

Table 37: Statistics of industrial_SAT_vmpc_24.renamed-as.sat05-1912 instance

Solver	**Restarts**	**Decisions**	**Conflicts**	**Conflict Literals**	**Avg. conflict clause size**	**Propagations**	**Afterburn propagations**	**Total Propagations**	**Time spent (minutes)**
ab-0-f-w-a	13	101456	36737	≤723058	≤19	4374585	99983273	104357858	1.851450
ab-0-f-wo-a	16	241869	93166	1986599	21	10819943	265847822	276667765	8.590317
ab-0-w-a	11	37648	13728	≤312241	≤22	1664466	11048148	12712614	0.166792
ab-0-wo-a	16	273034	110029	2819419	25	12544628	51636727	64181355	3.606133
ab-0.025-f-w-a	15	239001	84230	≤1885008	≤22	10303186	261212676	271515862	9.517100
ab-0.025-f-wo-a	14	135324	50973	938139	18	5921255	121733159	127654414	3.005067
ab-0.025-w-a	14	122573	43817	≤1084324	≤24	5195616	36605445	41801061	1.252477
ab-0.025-wo-a	17	430914	169211	4566080	26	18469055	77880974	96350029	7.861367
ab-0.04-f-w-a	11	47555	16578	≤323499	≤19	2082174	44822532	46904706	0.633053
ab-0.04-f-wo-a	14	135324	50973	938139	18	5921255	121733159	127654414	2.924033
ab-0.04-w-a	17	365623	133575	≤4013076	≤30	15196727	119858306	135055033	8.603167
ab-0.04-wo-a	16	319151	126810	3376587	26	14778165	58973913	73752078	4.099783
ab-0.06-f-w-a	13	80440	27923	≤531591	≤19	3498213	73169898	76668111	1.185503
ab-0.06-f-wo-a	15	174129	67157	1332294	19	7691757	175775298	183467055	4.903533
ab-0.06-w-a	16	305861	112308	≤3256312	≤28	12645018	98840461	111485479	5.320200
ab-0.06-wo-a	17	359322	143441	3762204	26	16842748	66295775	83138523	6.444383
minisat	16	142888	96972	2581770	26	9372431	0	9372431	0.439300

Table 38: Statistics of industrial_SAT_vmpc_24.shuffled-as.sat05-1944 instance

Solver	**Restarts**	**Decisions**	**Conflicts**	**Conflict Literals**	**Avg. conflict clause size**	**Propagations**	**Afterburn propagations**	**Total Propagations**	**Time spent (minutes)**
ab-0-f-w-a	9	22350	6881	≤142031	≤20	52847873	1793432616	1846280489	16.056633
ab-0-f-wo-a	10	26909	9824	181560	18	60120387	1970282517	2030402904	14.601017
ab-0-w-a	11	38417	11504	≤385033	≤33	56862467	501595515	558457982	3.720167
ab-0-wo-a	11	47660	15356	672658	43	73499156	558401894	631901050	5.633550
ab-0.025-f-w-a	9	22350	6881	≤142031	≤20	52847873	1793432616	1846280489	17.922333
ab-0.025-f-wo-a	10	26909	9824	181560	18	60120387	1970282517	2030402904	18.538333
ab-0.025-w-a	11	38417	11504	≤385033	≤33	56862467	501595515	558457982	5.689500
ab-0.025-wo-a	11	47660	15356	672658	43	73499156	558401894	631901050	7.289617
ab-0.04-f-w-a	9	22350	6881	≤142031	≤20	52847873	1793432616	1846280489	17.680500
ab-0.04-f-wo-a	10	26909	9824	181560	18	60120387	1970282517	2030402904	17.754833
ab-0.04-w-a	11	38417	11504	≤385033	≤33	56862467	501595515	558457982	5.710067
ab-0.04-wo-a	11	47660	15356	672658	43	73499156	558401894	631901050	6.073500
ab-0.06-f-w-a	9	22350	6881	≤142031	≤20	52847873	1793432616	1846280489	17.602667
ab-0.06-f-wo-a	10	26909	9824	181560	18	60120387	1970282517	2030402904	16.953333
ab-0.06-w-a	11	38417	11504	≤385033	≤33	56862467	501595515	558457982	5.048650
ab-0.06-wo-a	11	47660	15356	672658	43	73499156	558401894	631901050	6.657133
minisat	11	40245	15168	1151819	75	54077372	0	54077372	0.666298

Table 39: Statistics of industrial_UNSAT_dated-10-15-u instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	15	222810	75046	≤2161886	≤28	281168662	10552755067	10833923729	93.708833
ab-0-f-wo-a	15	167892	63079	1990358	31	202311897	9833888624	10036200521	81.816167
ab-0-w-a	16	342251	98148	≤5946874	≤60	265488112	1972367986	2237856098	19.468667
ab-0-wo-a	16	310193	99439	3926180	39	262519721	1117583452	1380103173	19.671833
ab-0.025-f-w-a	15	222810	75046	≤2161886	≤28	281168662	10552755067	10833923729	99.903833
ab-0.025-f-wo-a	15	167892	63079	1990358	31	202311897	9833888624	10036200521	103.330500
ab-0.025-w-a	16	342251	98148	≤5946874	≤60	265488112	1972367986	2237856098	29.438667
ab-0.025-wo-a	16	303231	100520	4074829	40	279655910	1129177072	1408832982	24.102000
ab-0.04-f-w-a	15	222810	75046	≤2161886	≤28	281168662	10552755067	10833923729	107.571500
ab-0.04-f-wo-a	15	167186	61551	1932319	31	198399443	9549287508	9747686951	89.052167
ab-0.04-w-a	16	354098	98724	≤6014328	≤60	264822439	2030193097	2295015536	29.817667
ab-0.04-wo-a	16	332027	111825	4537011	40	298897193	1161708148	1460605341	25.346833
ab-0.06-f-w-a	15	222810	75046	≤2161886	≤28	281168662	10552755067	10833923729	94.075667
ab-0.06-f-wo-a	15	166455	63215	1969779	31	202200492	9920316088	10122516580	89.712833
ab-0.06-w-a	16	339522	98602	≤6066039	≤61	264724095	1948994957	2213719052	30.984333
ab-0.06-wo-a	16	332430	106507	4338433	40	285256525	1134125400	1419381925	23.865500
minisat	16	194140	130375	6849573	52	304699819	0	304699819	5.215833

Table 40: Statistics of industrial_UNSAT_dated-5-11-u instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	23	2480249	1765531	≤39919601	≤22	395736449	7174751816	7570488265	53.116000
ab-0-f-wo-a	24	3542882	2565331	54132091	21	584823984	9046182199	9631006183	71.260167
ab-0-w-a	24	4844402	3052887	≤126818903	≤41	673288604	2562827785	3236116389	30.034167
ab-0-wo-a	24	4616480	3270630	111520563	34	659454543	2068984223	2728438766	32.711000
ab-0.025-f-w-a	23	2723211	1881785	≤36913424	≤19	428071321	6142278710	6570350031	51.328500
ab-0.025-f-wo-a	24	3439206	2493170	56902456	22	557516658	9748279550	10305796208	86.174667
ab-0.025-w-a	24	5339569	3347986	≤138054195	≤41	726488387	2758317481	3484805868	48.703667
ab-0.025-wo-a	24	4622196	3343317	119348780	35	683455516	1951565410	2635020926	42.223000
ab-0.04-f-w-a	23	3132079	2206376	≤44701189	≤20	503908529	7569030445	8072938974	65.906000
ab-0.04-f-wo-a	23	2728693	1993891	39578490	19	451276612	6073887836	6525164448	52.655667
ab-0.04-w-a	24	4824225	3078081	≤135124755	≤43	652384701	2363785920	3016170621	43.293833
ab-0.04-wo-a	25	4793694	3601905	124304422	34	720269216	1612794987	2333064203	33.964000
ab-0.06-f-w-a	24	3738426	2678119	≤59211553	≤22	630868399	10622179385	11253047784	92.822667
ab-0.06-f-wo-a	24	3236074	2377077	50161567	21	537382014	7970355103	8507737117	67.433500
ab-0.06-w-a	25	5817877	4330223	≤187154711	≤43	847673851	1406617791	2254291642	37.868500
ab-0.06-wo-a	25	4885160	3915643	126635687	32	762363412	1230645424	1993008836	33.552000
minisat	25	4767990	3957971	155717918	39	723795010	0	723795010	8.993017

Table 41: Statistics of industrial_UNSAT_eq.atree.braun.10.unsat instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	27	12463973	8795418	≤192113881	≤21	2497956837	41921885122	44419841959	267.385000
ab-0-f-wo-a	26	8707572	6333759	136518159	21	1713220139	27579749365	29292969504	247.241667
ab-0-w-a	28	21820075	12906249	≤786038917	≤60	3122558402	13621464975	16744023377	252.910000
ab-0-wo-a	29	24114395	17298382	746554902	43	4114912223	14191923554	18306835777	196.101667
ab-0.025-f-w-a	26	10001004	6988109	≤162282838	≤23	1863645161	34961560450	36825205611	383.495000
ab-0.025-f-wo-a	27	10863428	7880526	168437097	21	2111124265	31949452427	34060576692	373.586667
ab-0.025-w-a	28	27201448	16350369	≤963541286	≤58	3934771966	17160989154	21095761120	429.241667
ab-0.025-wo-a	28	21531636	15168507	731489937	48	3533187492	10973492834	14506680326	308.298333
ab-0.04-f-w-a	27	14424792	10236165	≤248003625	≤24	2930040812	55949585306	58879626118	662.035000
ab-0.04-f-wo-a	28	16820379	12186222	293020072	24	3304210624	59994414357	63298624981	684.578333
ab-0.04-w-a	29	30527788	19463416	≤1154933954	≤59	4569591749	17056565339	21626157088	476.580000
ab-0.04-wo-a	28	19590382	15950009	732596618	45	3431639972	2634616021	6066255993	141.335500
ab-0.06-f-w-a	26	10726922	7572162	≤167944936	≤22	2002110525	34549795262	36551905787	370.165000
ab-0.06-f-wo-a	27	11020977	8036798	187220234	23	2117359547	36213822860	38331182407	309.825000
ab-0.06-w-a	29	22863061	18654807	≤986006293	≤52	4052570812	1075270500	5127841312	124.682667
ab-0.06-wo-a	29	28583482	23542806	1149979612	48	5142578966	1664420515	6806999481	166.941667
minisat	29	25973213	22417889	989351713	44	4998108302	0	4998108302	58.240500

Table 42: Statistics of industrial_UNSAT_eq.atree.braun.11.unsat instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	17	254977	176766	≤2838476	≤16	30532586	321387741	351920327	1.595323
ab-0-f-wo-a	18	278600	205600	3182990	15	34700827	346482232	381183059	1.613505
ab-0-w-a	18	405672	249368	≤6240665	≤25	39915572	138297299	178212871	0.909995
ab-0-wo-a	18	320473	226573	4673376	20	34570229	93312380	127882609	0.744170
ab-0.025-f-w-a	17	228533	158806	≤2572614	≤16	27233706	291296552	318530258	1.330332
ab-0.025-f-wo-a	17	258008	190120	3223636	16	31695310	361973033	393668343	1.754683
ab-0.025-w-a	18	338981	215055	≤5357801	≤24	35433135	115368968	150802103	0.888032
ab-0.025-wo-a	18	330699	237444	5172330	21	35557767	83575274	119133041	0.841538
ab-0.04-f-w-a	17	250288	173831	≤2817271	≤16	29771970	319733744	349505714	1.441813
ab-0.04-f-wo-a	17	231838	172493	2735763	15	29270662	287469332	316739994	1.218598
ab-0.04-w-a	17	302180	191574	≤4741837	≤24	30215605	91808471	122024076	0.712375
ab-0.04-wo-a	18	317863	235582	4841300	20	36515011	76960539	113475550	0.777282
ab-0.06-f-w-a	17	230931	160175	≤2638584	≤16	26847969	291352877	318200846	1.297437
ab-0.06-f-wo-a	17	232648	173006	2792543	16	29658013	294708075	324366088	1.384223
ab-0.06-w-a	18	313218	205404	≤5653169	≤27	31318224	91836255	123154479	0.821542
ab-0.06-wo-a	19	410970	312922	6814280	21	45805350	77356354	123161704	0.891998
minisat	18	318925	278066	6963163	25	39826511	0	39826511	0.309153

Table 43: Statistics of industrial_UNSAT_eq.atree.braun.8.unsat instance

Solver	Restarts	Decisions	Conflicts	Conflict Literals	Avg. conflict clause size	Propagations	Afterburn propagations	Total Propagations	Time spent (minutes)
ab-0-f-w-a	20	644260	452929	≤8287625	≤18	90789831	1168158447	1258948278	6.748017
ab-0-f-wo-a	20	644280	470421	8716647	18	92010344	1202056619	1294066963	6.498933
ab-0-w-a	21	1312165	808926	≤31042443	≤38	148797974	555987048	704785022	4.742667
ab-0-wo-a	21	1036299	739162	21427007	28	132849748	387499367	520349115	4.083167
ab-0.025-f-w-a	20	677254	472689	≤8381844	≤17	98118588	1140697949	1238816537	6.924900
ab-0.025-f-wo-a	20	638586	461563	8244310	17	94112823	1037619641	1131732464	6.325833
ab-0.025-w-a	20	1074541	660170	≤23939919	≤36	124799603	452712381	577511984	4.965883
ab-0.025-wo-a	21	1031551	742053	19923230	26	132986654	341671308	474657962	4.804533
ab-0.04-f-w-a	20	747993	525947	≤9716452	≤18	111063717	1334443565	1445507282	7.688867
ab-0.04-f-wo-a	20	779109	571471	10721838	18	111419274	1327310330	1438729604	8.813567
ab-0.04-w-a	20	776809	496001	≤13173860	≤26	89855568	287723954	377579522	2.931050
ab-0.04-wo-a	21	1212853	904341	26026690	28	161684079	376059287	537743366	5.036167
ab-0.06-f-w-a	20	898457	639114	≤12030225	≤18	132528182	1656305343	1788833525	10.172950
ab-0.06-f-wo-a	20	642854	474458	9291249	19	95533569	1150751585	1246285154	6.932683
ab-0.06-w-a	20	970910	646114	≤22111147	≤34	115221581	314767766	429989347	3.670417
ab-0.06-wo-a	21	889176	691637	19190944	27	122627603	215547673	338175276	3.366283
minisat	21	913190	784256	21583844	27	135238176	0	135238176	1.226313

Table 44: Statistics of industrial_UNSAT_eq.atree.braun.9.unsat instance