An experimental evaluation of Max-SAT and PB solvers on over-subscription planning problems

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Context

- Planning as Satisfiability (SAT) is the best approach for solving classical planning problems optimally wrt makespan
- The role of “optimization/preferences” in recent International Planning Competitions (IPCs) has increased and become central to design more and more realistic problems
- An idea is to reduce IPC planning problems to optimization problems that (*i*) extend SAT and (*ii*) can deal with optimizations/preferences

Here....

We

1. present a reduction of IPC-5 benchmarks, at fixed makespan, to (linear) Pseudo-Boolean (PB) and Partial Weighted Max-SAT problems, that can natively handle (*i*) integer weights and (*ii*) linear optimization functions
2. run SOTA Max-SAT and PB solvers on benchmarks coming from planning problems of the IPC-5 "SimplePreferences" category, which includes problems having actions with soft preconditions, and soft goals

in order to

- evaluate Max-SAT and PB solvers on this new application domain
- possibly identify challenging benchmarks

Example: TPP domain – soft preconditions (I)

```
(:action drive
:parameters (?t - truck ?from ?to - place)
:precondition (and (at ?t ?from) (connected ?from ?to)
                   (preference p-drive (and
                            (ready-to-load goods1 ?from level0)
                            (ready-to-load goods2 ?from level0)
                            (ready-to-load goods3 ?from level0))))
:effect (and (not (at ?t ?from)) (at ?t ?to)))
```
(1)

Action drive, which contains one preference formula, is split into two (mutually exclusive) actions:

- drive itself, where soft preconditions are considered as hard; and
- a second action, where soft preconditions are considered as hard and negated, with a literal added as effect (goal-p-drive)

Example: TPP domain – soft preconditions (I)

```
(:action drive
:parameters (?t - truck ?from ?to - place)
:precondition (and (at ?t ?from) (connected ?from ?to)
                   (ready-to-load goods1 ?from level0)      (2)
                   (ready-to-load goods2 ?from level0)
                   (ready-to-load goods3 ?from level0))
:effect (and (not (at ?t ?from)) (at ?t ?to)))

(:action drive'
:parameters (?t - truck ?from ?to - place)
:precondition (and (at ?t ?from) (connected ?from ?to)
                   (not (and (ready-to-load goods1 ?from level0)
                             (ready-to-load goods2 ?from level0)
                             (ready-to-load goods3 ?from level0))))
:effect (and (not (at ?t ?from)) (at ?t ?to) (goal-p-drive)))
                                                            (3)
```

Example: TPP domain – soft goals and metric

```
(:goal (and
    (preference p4A
        (and (ready-to-load goods3 market1 level0)
             (loaded goods3 truck1 level0)))
    ...
    (preference p0A (stored goods3 level1))
    ...))                                                   (4)

(:metric minimize (+ (* 1 (is-violated p0A))
                     ...
                     (* 16 (is-violated p4A))
                     (* 1 (is-violated p-drive))))
```

For each goal preference, a dummy action is introduced, e.g.,

```
(:action dummy-p4A
:parameters ()
:precondition (and (ready-to-load goods3 market1 level0)     (5)
                   (loaded goods3 truck1 level0))
:effect (and (goal-p4A))).
```

SATPLAN's (simplified) algorithm

function SATPLAN(Π)

```
1  n := 1;
2  V := SAT(cnf(plangraph(Π, n)))
3  if V = FALSE
4      n := n + 1;
5      go back to step 2
6  return V
```

- Π is a classical STRIPS problem
- SATPLAN(Π) returns an optimal plan (having minimal makespan)

If Π' is a non-STRIPS planning problem:

1. Π' is first "adapted" as we have seen before (to eliminate the "preference" construct), and then
2. non-STRIPS actions are compiled into a STRIPS actions (with ADL2STRIPS)

Generating the PB problem

Given the "adapted" IPC-5 problem Π':

1. it is compiled into a STRIPS problem Π'', which possibly contains multiple STRIPS actions for a single non-STRIPS action
2. Π'' is reduced to a PB problem by
   - converting each SAT clause in $\mathit{cnf}(\mathit{plangraph}(\Pi, n))$, generated by SATPLAN, into a corresponding PB constraint; and
   - specifying the optimization function

The optimization function of our working example is

$$\mathit{max:} +1 \ \ (\mathit{goal\text{-}p0A}) + \ldots \ +16 \ (\mathit{goal\text{-}p4A}) - \sum_{i=1}^{n} +1 \ (\mathit{goal\text{-}p\text{-}drive}_i)$$

or, if an action can be executed at most once

$$\mathit{max:} +1 \ \ (\mathit{goal\text{-}p0A}) + \ldots \ +16 \ (\mathit{goal\text{-}p4A}) \ -1 \ (\mathit{goal\text{-}p\text{-}drive})$$

(Weighted Partial) Max-SAT and (linear) PB solvers

1. MINIMAXSAT ver. 1.0 (Heras, Larrosa, and Oliveras 2008)
2. WMAXSATZ ver. 2.5 (Li et al. 2009)
3. INCWMAXSATZ (Lin and Su 2007)
4. MSUNCORE ver. 1.2 and ver. 4.0 (Marques-Silva and Manquinho 2008)
5. MINISAT+ ver. 1.14 (Een and Sorensson 2006)
6. GLPPB ver. 0.2 (Sheini and Sakallah 2005)
7. BSOLO ver. 3.0.17 (Manquinho and Marques-Silva 2006)
8. SAT4J ver. 2.1 (Le Berre, 2004-)
9. SCIPSPX ver. 1.2.0 (Achterberg et al 2009)

Domains analyzed

1. TPP (actions soft preconditions and soft goals)
2. Pathways and Storage (soft goals)
3. Trucks and Openstacks (mixed hard/soft goals)

For each planning problem, we have considered the first satisfiable Max-SAT/PB instance generated by the (modified) SAT-based approach

In planning, this would correspond to find a plan with optimal plan metric at (minimal) makespan

Experimental analysis: TPP domain

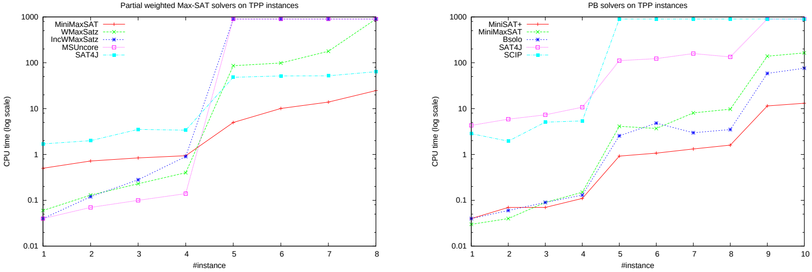

Figure: Results of Max-SAT (Left) and PB (Right) solvers on the TPP domain.

Experimental analysis: Pathways domain

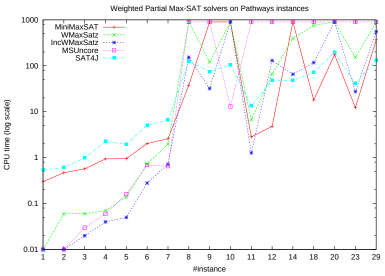

Figure: Results of Max-SAT (Left) and PB (Right) solvers on the Pathways domain.

Experimental analysis: Storage and Trucks domains (I)

instance	MINIMAXSAT	WMAXSATZ	INCWMAXSATZ	MSUNCORE	SAT4J
storage1	0.21	0.03	0.01	0.01	0.32
storage2	0.44	0.04	0.01	0.02	0.65
storage3	0.59	0.05	0.02	0.07	1.45
storage4	0.71	0.1	0.04	0.22	2.8
storage5	58.79	0.81	0.45	TIME	16.35
storage6	TIME	14.4	9.33	TIME	70.6
storage7	TIME	21.19	25.09	TIME	365.53
trucks1	7.7	TIME	TIME	0.74	359.17
trucks2	308.92	TIME	TIME	17.93	TIME

Table: Results of Max-SAT solvers on Storage and Trucks domains.

Experimental analysis: Storage and Trucks domains (II)

instance	MINISAT+	MINIMAXSAT	GLPPB	BSOLO	SAT4J	SCIPSPX
storage1	0.01	0.01	0.03	0.03	0.65	0.06
storage2	0.02	0.02	1.14	0.32	1.91	0.2
storage3	0.08	0.03	TIME	0.46	4.15	0.38
storage4	0.21	0.09	TIME	0.97	9.7	0.9
storage5	2.47	2.87	TIME	62.76	48.18	4.38
storage6	4.99	7.83	TIME	TIME	151.35	140.52
storage7	36.08	TIME	TIME	TIME	678.74	51.66
trucks1	5.19	3.11	TIME	119.59	TIME	TIME
trucks2	385.07	54.84	TIME	TIME	TIME	TIME

Table: Results of PB solvers on Storage and Trucks domains.

Preliminary observations on the results

- Overall, MINISAT+ is the best performing system on the benchmarks analyzed
- MINIMAXSAT and SAT4J, the solvers evaluated on both formulations, show different behaviors: the first is better on PB instances, the second is better on Max-SAT.
- Pathways and Trucks domains share an observation: all unsolved instances have more than 10K variables and 200K clauses.
- the excellent results of WMAXSATZ and INCWMAXSATZ on the (large) Storage instances are quite surprising given they are “look-ahead” solvers. By inspection of their behaviors, the reason seems to be the very good bounds they provide initially.

Conclusions

1. MINISAT+ is (still) the overall best systems (see results of PB Evaluations on problems with a vast majority of SAT clauses)
2. challenging Max-SAT and PB benchmarks have been identified
3. we plan to submit such benchmarks to next evaluations

Current and future work

- model and analyze IPC-6 domains of the “net benefit” optimization track, which includes actions’s costs
- evaluate a “Planning with IPC preferences as Pseudo-Boolean/Max-SAT Optimization” approach (preliminary results in COPLAS’10, j.w.w. Enrico Giunchiglia)

Some related works

IPPLAN reduces classical planning problems into 0/1 Integer Programming problems, and then calls CPLEX

An encoding of IPC-5 benchmarks into 0/1 IP is available (van den Briel, Kambhampati and Vossen, ICAPS Workshop 2006) but no implementation and experimental evaluation

Our modeling of soft goals is similar to the YOCHANPS planner (Benton, Kambhampati, Do, IPC-6)

Our modeling of actions is similar to (Keyder, Geffner, 2009)

Plan-A (Lv, Chen, Huang, IPC-6): DPLL-opt (DPLL with linear cost function optimization) + branch-and-bound pruning

CO-Plan (Robinson, Gretton, Nghia Pham, IPC-6): SAT planner to find min-cost step-optimal plan + forward search to find cost-optimal plan