Sixth Pseudo-Boolean Competition
PB11

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Outline

- Pseudo-Boolean constraints
- PBS, PBO, WBO
- Benchmarks and Solvers
- Evaluation Environment
- Results

Linear Pseudo-Boolean Constraints

- A **linear** pseudo-Boolean (PB) constraint may be defined over Boolean variables by

$$\sum_i a_i.l_i \geq d \text{ with } a_i, d \in \mathbb{Z}, l_i \in \{x_i, \bar{x}_i\}, x_i \in \mathbb{B}$$

  Example: $3x_1 - 3x_2 + 2\bar{x}_3 + \bar{x}_4 + x_5 \geq 5$
- Extends both clauses and cardinality constraints
  - cardinalities: all $a_i = 1$ and $d > 1$
  - clauses: all $a_i = 1$ and $d = 1$
- PB constraints are more expressive than clauses (one PB constraint may replace an exponential number of clauses)
- A pseudo-Boolean instance is a conjunction of PB constraints

Non-Linear Pseudo-Boolean Constraints

- A **non-linear** pseudo-Boolean constraint may be defined over Boolean variables by

$$\sum_i a_i(\prod_j l_{i,j}) \geq d \text{ with } a_i, d \in \mathbb{Z}, l_{i,j} \in \{x_{i,j}, \bar{x}_{i,j}\}, x_{i,j} \in \mathbb{B}$$

  Example: $3x_1\bar{x}_2 - 3x_2x_4 + 2\bar{x}_3 + \bar{x}_4 + x_5x_6x_7 \geq 5$
- A product is a AND
- Compact encoding for several problems (e.g. factoring problem encoded by one constraint)
- Can be easily translated into linear pseudo-Boolean by introducing new variables and constraints such that

$$p \leftrightarrow x_0 \wedge x_1 \wedge \ldots \wedge x_n$$

  (requires 2 PB constraints or n+1 clauses)

Different problems: PBS, PBO,...

- **PBS (Pseudo Boolean Satisfaction)**
  decide of the satisfiability of a conjunction of PB constraints
- **PBO (Pseudo Boolean Optimization)**
  find a model of a conjunction of PB constraints which optimizes one objective function

$$\begin{cases} \text{minimize} & f = \sum_i c_i.x_i \text{ with } c_i \in \mathbb{Z}, x_i \in \mathbb{B} \\ \text{subject to} & \text{the conjunction of constraints} \end{cases}$$

Different problems: ... and WBO

WBO (Weighted Boolean Optimization)

- generalization of maximum satisfiability for PB constraints
- hard constraints **must** be satisfied
- soft constraints may be violated, but this has a cost
- the cost of an interpretation is the sum of the costs of violated soft constraints
- as in WCSP, there is a top cost. Interpretations with a cost greater or equal to the top cost are non admissible.
- the goal is to find an admissible interpretation with the smallest cost
- to avoid any intersection with the Max-SAT competition, at least one constraint must not be a clause.

Benchmark categories (1)

For PBS/PBO, classification based on the objective function

- DEC: No objective function to optimize (decision problem). The solver must simply find a solution.
- OPT: An objective function is present. The solver must find a solution with the best possible value of the objective function.

For WBO, classification based on the existence of hard clauses

- SOFT: No hard clause at all.
- PARTIAL: At least one hard clause.

Benchmark categories (2)

Classification based on the size of coefficients

SMALLINT small integers: no constraint with a sum of coefficients greater than 2^{20} (20 bits): expected to be safe for solvers using 32 bits integers and simple techniques (be careful with learning), but strong limit to the encoding of concrete problems.

BIGINT big integers: at least one constraint with a sum of coefficients greater than 2^{20} (20 bits): requires arbitrary precision.

Classification based on the linearity of constraints

LIN All constraints are linear

NLC At least one constraint is non linear (contains products of literals)

Instances submitted this year

PBS-PBO

- instances of MIPLIB 2010 (S. Heinz and M. Winkler)
  4 DEC-SMALLINT-LIN instances, all selected
  57 OPT-SMALLINT-LIN instances, 25 selected randomly
  27 OPT-BIGINT-LIN instances, 25 selected randomly
- AES minimum components benchmarks (O. Kullmann and M. Gwynne)
  7 OPT-SMALLINT-LIN instances, all selected
- Multiple Constant Multiplication problem (N. Lopes)
  193 DEC-SMALLINT-LIN, 25 selected randomly
- haplotyping with pedigrees (HwP) (A. Graça, I. Lynce, J. Marques-Silva)
  100 instances unfortunately forgotten in the selection!

WBO

- no submission at all !! (second year w/o submission)

Solvers and benchmark selection

Submitted solvers:

- PBS/PBO: 8 different solvers, 12 versions by 6 different teams
- WBO: 4 solvers by 4 teams
- only two solvers with support for BIGINT

Selected instances:

- PBS/PBO: same as PB10 + selection of new benchmarks
- WBO: same as PB10

Categories

- **DEC-SMALLINT-LIN (481 instances)**
- **DEC-SMALLINT-NLC (100 instances)**
- DEC-BIGINT-LIN
- DEC-BIGINT-NLC
- **OPT-SMALLINT-LIN (731 instances)**
- **OPT-SMALLINT-NLC (409 instances)**
- **OPT-BIGINT-LIN (557 instances)**
- OPT-BIGINT-NLC
- **PARTIAL-SMALLINT-LIN (536 instances)**
- PARTIAL-BIGINT-LIN (263 instances)
- **SOFT-SMALLINT-LIN (201 instances)**
- SOFT-BIGINT-LIN (46 instances)

Evaluation environment

kindly provided by CRIL, University of Artois, France

Same environment as the SAT competition

- Cluster of bi-Xeon quad-core 2.66 GHz, 8 MB cache, 32 GB RAM
- Each solver was given a time limit of 30 minutes (1800s) and a memory limit of 15500 MB (to avoid swapping).
- 2 solvers per node (limited interactions because of the 2 CPU and the memory limit)

Verification of results

- The environment performs the following, efficient checks:
  - for SATISFIABLE answers, solvers must output a complete instantiation and the system checks that it satisfies all constraints
  - for UNSATISFIABLE answers, the system only checks that no other solver proved satisfiability
  - for OPTIMUM FOUND answers, solvers must output a complete instantiation; the system checks if all constraints are satisfied and that no other solver found a better solution
- UNSATISFIABLE and OPTIMUM FOUND answers cannot be completely checked efficiently and therefore should be taken with caution.
- Solvers giving a wrong answer in a category are disqualified in that category.

Ranking of solvers and Virtual Best Solver (VBS)

Ranking based on two criteria:

1. the number of solved instances
2. ties are broken by considering the cumulated time on solved instances

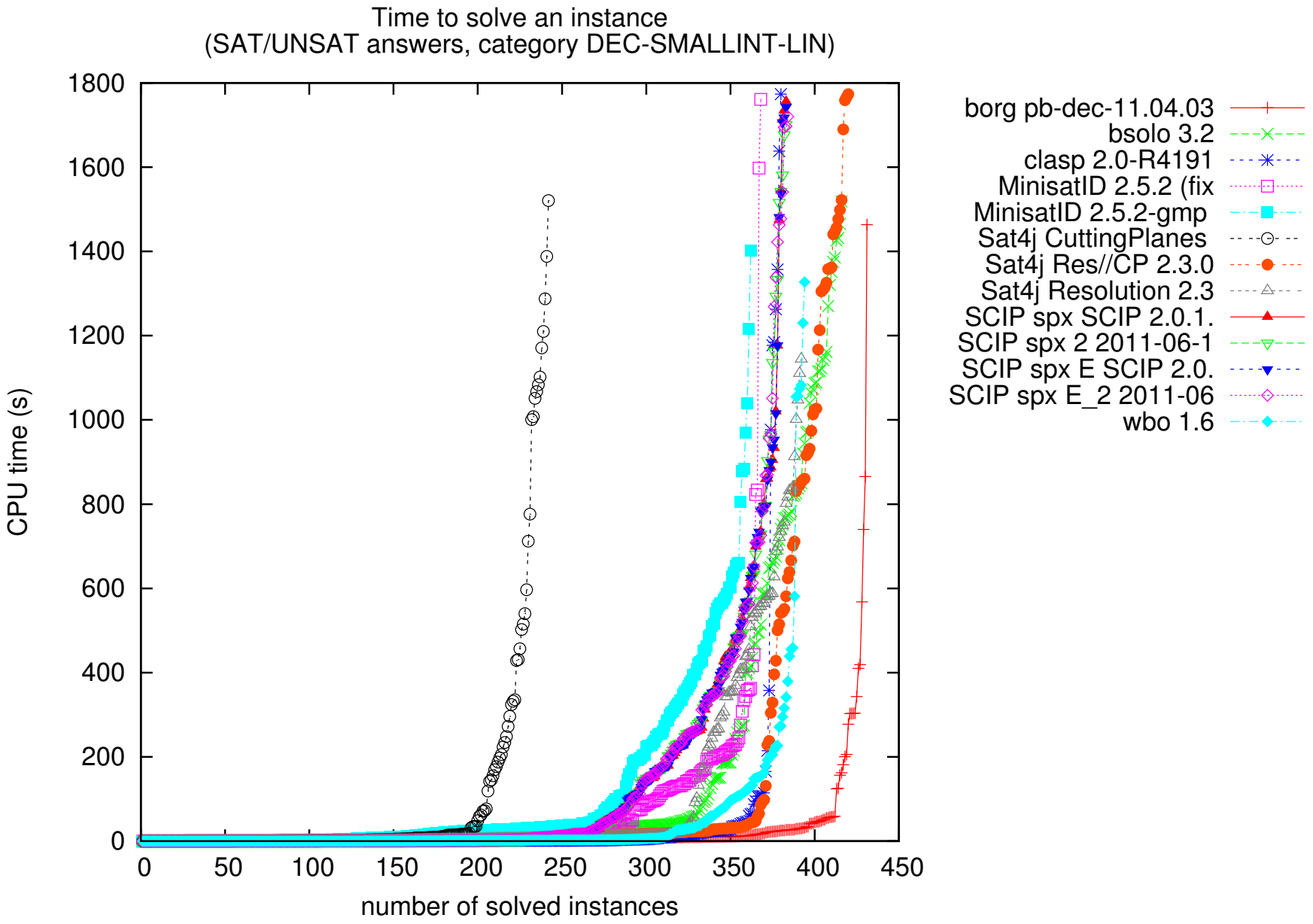
The Virtual Best Solver (VBS)

- is the virtual solver obtained by combining the best results of all submitted solvers.
- could be obtained by running in parallel all submitted solvers
- represents the current state of the art (SOTA)
- is a reference for the evaluation of the other solvers

Results for DEC-SMALLINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 481					
Virtual Best Solver (VBS)		448	191 S, 257 U	93%	100%
1	borg	431	183 S, 248 U	90%	96%
2	Sat4j Res//CP	420	183 S, 237 U	87%	94%
3	bsolo	416	179 S, 237 U	86%	93%
4	wbo	394	180 S, 214 U	82%	88%
5	Sat4j Res.	392	184 S, 208 U	81%	88%
6	SCIP spx E_2	384	149 S, 235 U	80%	86%
7	SCIP spx 2	383	148 S, 235 U	80%	85%
8	clasp	380	168 S, 212 U	79%	85%
9	MinisatID	368	169 S, 199 U	77%	82%
10	MinisatID *gmp*	362	165 S, 197 U	75%	81%
11	Sat4j CP	242	114 S, 128 U	50%	54%

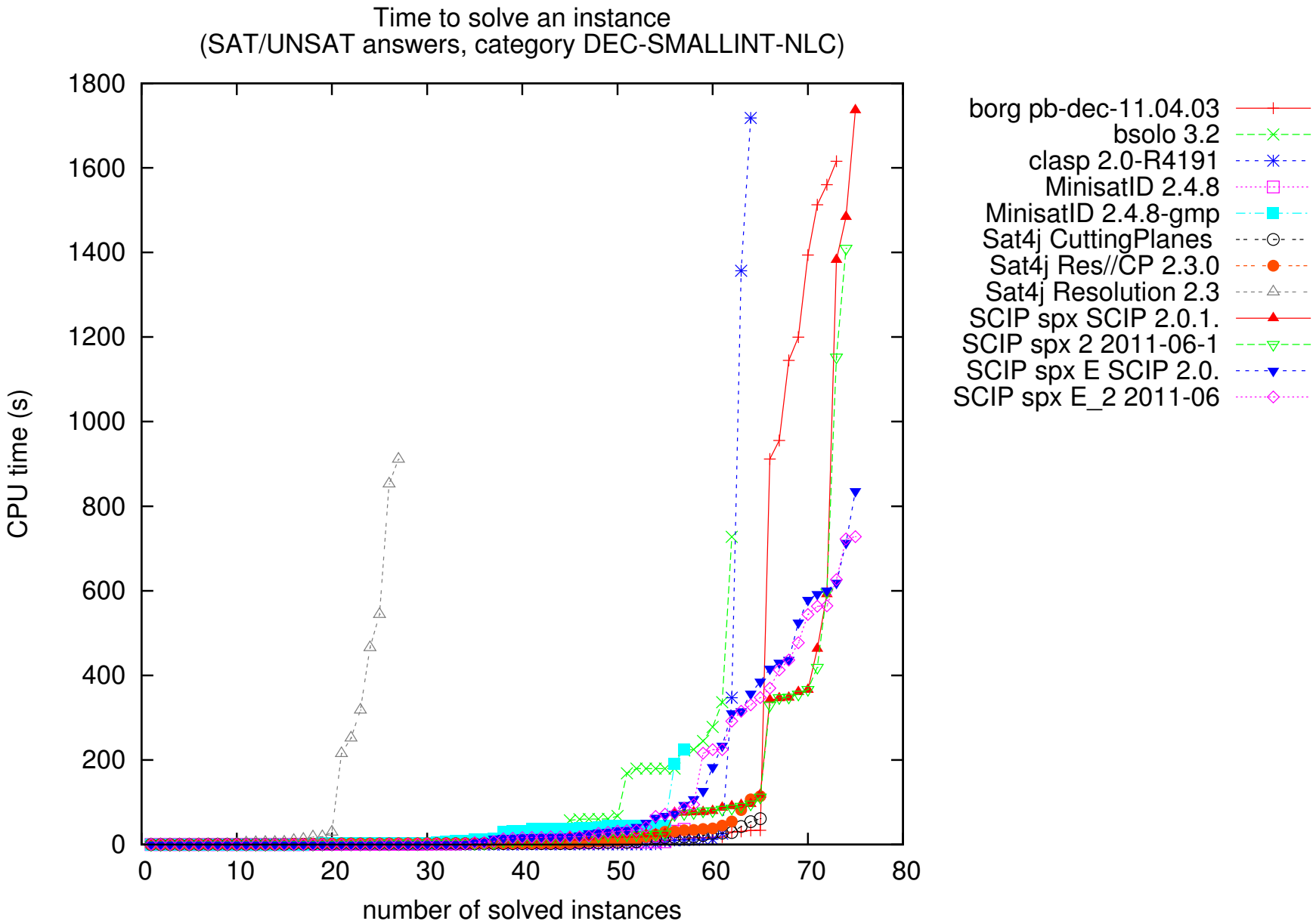
DEC-SMALLINT-LIN



Results for DEC-SMALLINT-NLC

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 100					
Virtual Best Solver (VBS)		76	55 S, 21 U	76%	100%
1	SCIP spx E_2	75	55 S, 20 U	75%	99%
2	SCIP spx 2	74	54 S, 20 U	74%	97%
3	borg	73	53 S, 20 U	73%	96%
4	Sat4j CP	65	50 S, 15 U	65%	86%
5	Sat4j Res//CP	65	50 S, 15 U	65%	86%
6	clasp	64	49 S, 15 U	64%	84%
7	bsolo	62	47 S, 15 U	62%	82%
8	Sat4j Res.	27	12 S, 15 U	27%	36%
9	MinisatID	0		0%	0%
10	MinisatID *gmp*	0		0%	0%

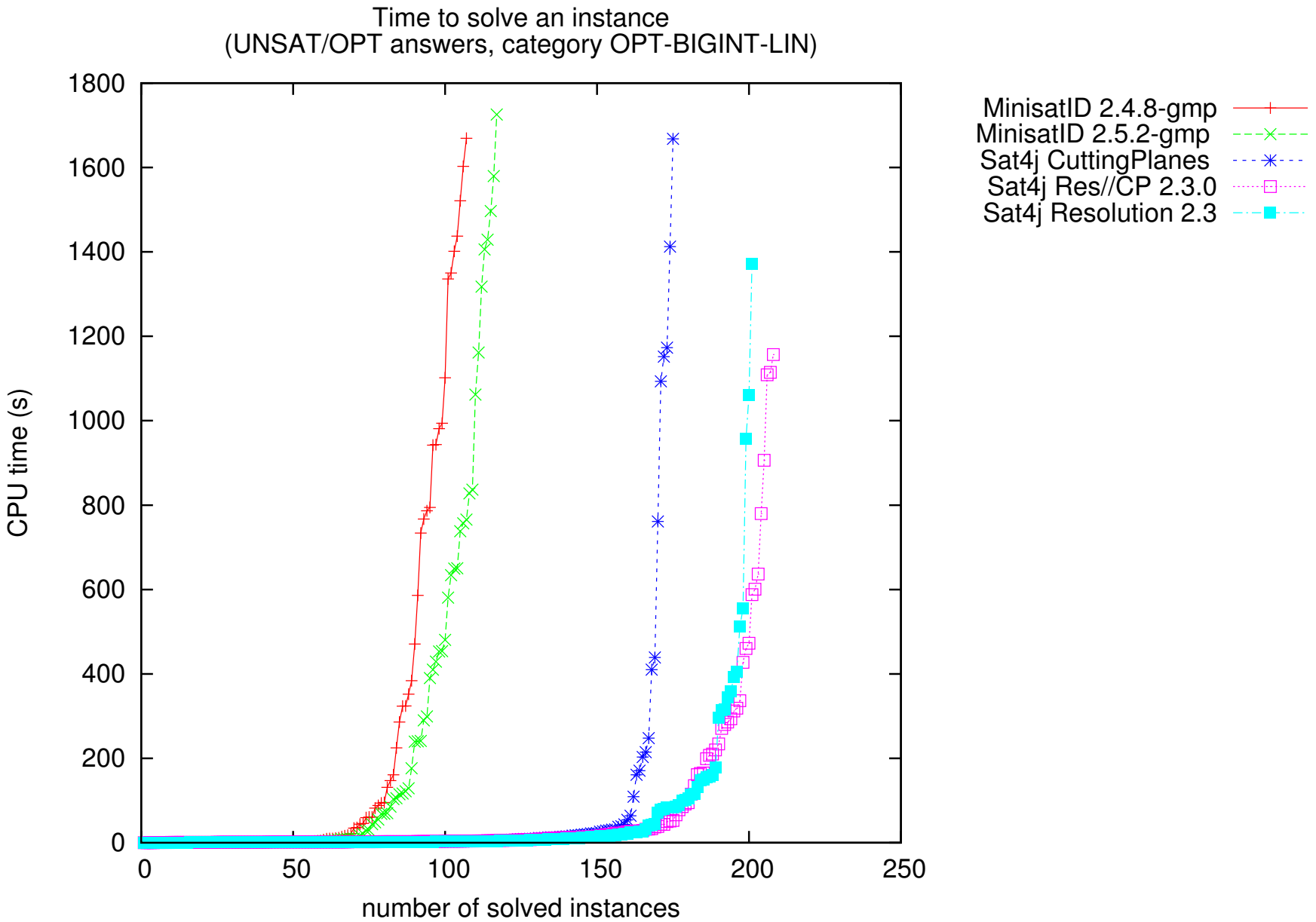
DEC-SMALLINT-NLC



Results for OPT-BIGINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 557					
Virtual Best Solver (VBS)		213	154 OPT, 59 U	38%	100%
1	Sat4j Res//CP	208	149 OPT, 59 U	37%	98%
2	Sat4j Res.	201	144 OPT, 57 U	36%	94%
3	Sat4j CP	175	116 OPT, 59 U	31%	82%
4	MinisatID *gmp*	117	60 OPT, 57 U	21%	55%

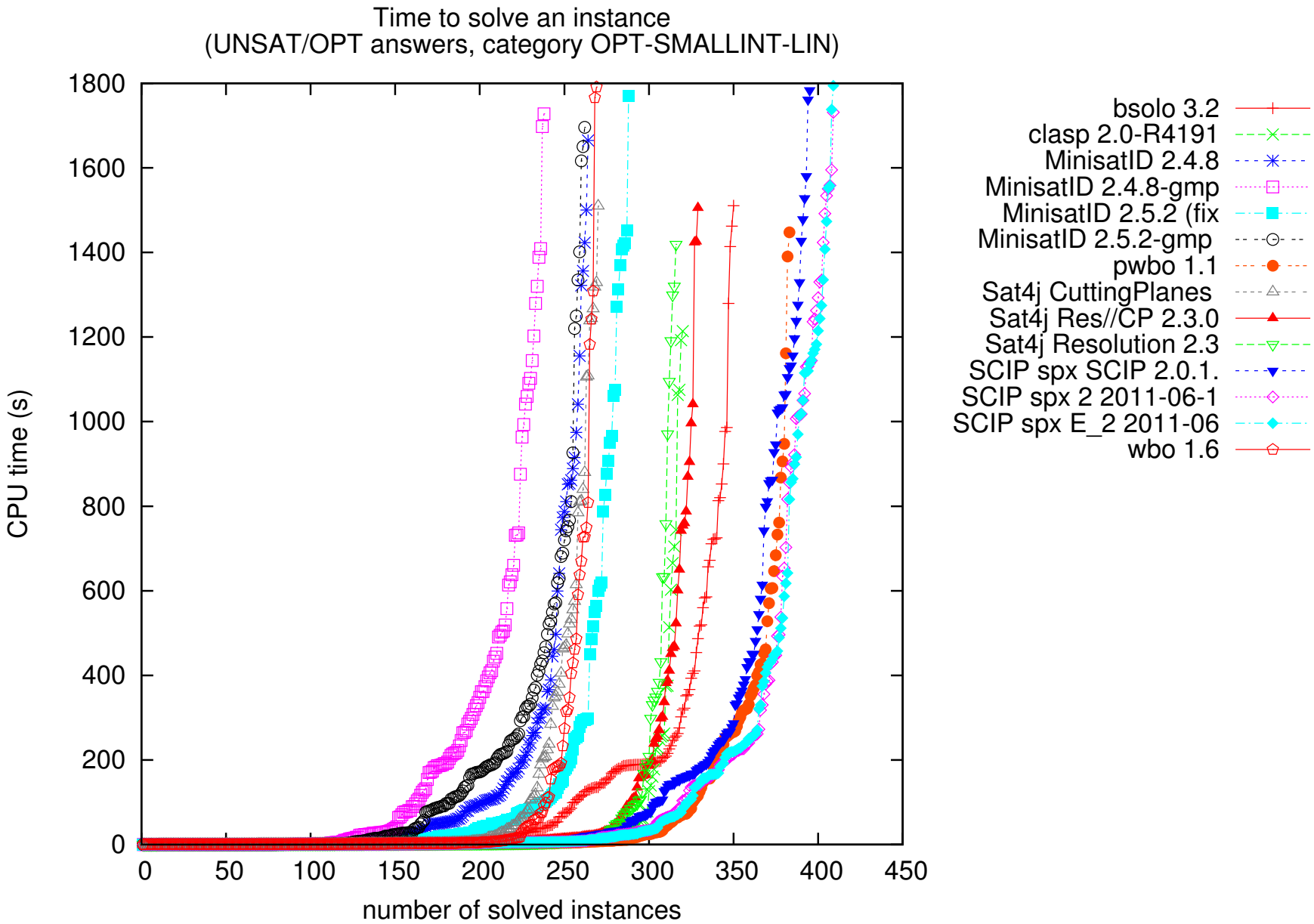
OPT-BIGINT-LIN



Results for OPT-SMALLINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 731					
Virtual Best Solver (VBS)		494	459 OPT, 35 U	68%	100%
1	SCIP spx E_2	409	374 OPT, 35 U	56%	83%
2	SCIP spx 2	409	374 OPT, 35 U	56%	83%
3	pwbo	383	350 OPT, 33 U	52%	78%
4	bsolo	350	316 OPT, 34 U	48%	71%
5	Sat4j Res//CP	329	295 OPT, 34 U	45%	67%
6	clasp	320	286 OPT, 34 U	44%	65%
7	Sat4j Res.	316	282 OPT, 34 U	43%	64%
8	MinisatID	288	256 OPT, 32 U	39%	58%
9	Sat4j CP	270	240 OPT, 30 U	37%	55%
10	wbo	269	236 OPT, 33 U	37%	54%
11	MinisatID *gmp*	262	232 OPT, 30 U	36%	53%

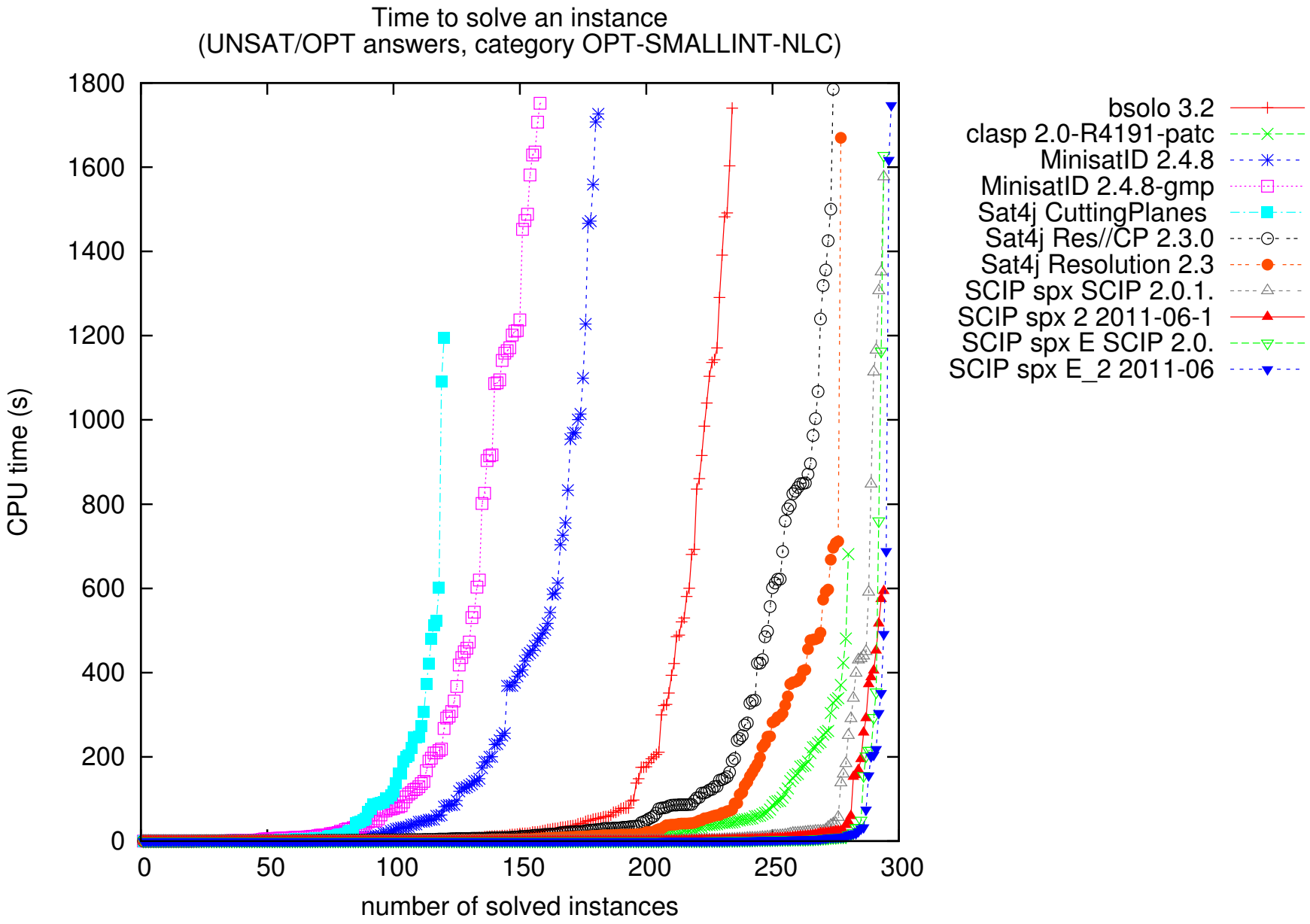
OPT-SMALLINT-LIN



Results for OPT-SMALLINT-NLC

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 409					
Virtual Best Solver (VBS)		298	298 OPT	73%	100%
1	SCIP spx E_2	297	297 OPT	73%	100%
2	SCIP spx 2	294	294 OPT	72%	99%
3	clasp	280	280 OPT	68%	94%
4	Sat4j Res.	277	277 OPT	68%	93%
5	Sat4j Res//CP	274	274 OPT	67%	92%
6	bsolo	234	234 OPT	57%	79%
7	Sat4j CP	120	120 OPT	29%	40%
8	MinisatID	0		0%	0%
9	MinisatID *gmp*	0		0%	0%

OPT-SMALLINT-NLC



Results for PARTIAL-SMALLINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 536					
Virtual Best Solver (VBS)		530	529 MOPT, 1 U	99%	100%
1	clasp	455	454 MOPT, 1 U	85%	86%
2	Sat4j Res.	448	447 MOPT, 1 U	84%	85%
3	SCIP spx	383	382 MOPT, 1 U	71%	72%
4	wbo	373	372 MOPT, 1 U	70%	70%

Results for SOFT-SMALLINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 201					
Virtual Best Solver (VBS)		201	201 MOPT	100%	100%
1	clasp	163	163 MOPT	81%	81%
2	Sat4j Res.	162	162 MOPT	81%	81%
3	wbo	160	160 MOPT	80%	80%
4	SCIP spx	120	120 MOPT	60%	60%

Some lessons

- Linear programming techniques seem particularly relevant for optimization, less for the decision problem.
- A portfolio approach is valuable
- CDCL solvers working with PB constraints from end to end doesn't seem competitive.
- WBO not considered by the community

<*Add you own conclusion here*>

What's a competition worth?

The goal of a competition is to:

- evaluate solvers in the same conditions
- help collecting publicly available benchmarks
- help identifying new solvers on the market
- help the community identify good ideas and strange results: the goal is to raise questions and get new ideas!

Competitions should not be misunderstood:

- The results are not an absolute truth: they depend on the benchmark selection, experimental condition,...
- A competition is not limited to a ranking: rankings are just an over-simplified view, but still relevant to motivate authors
- There are a lot of data collected and published to benefit the whole community
- Competitions must be driven by the community: benchmark submission/selection advices, suggestions for improvements...

More information/Second round

- All details are on the web site **http://www.cril.univ-artois.fr/PB11**
- Thanks to all participants!

Since a few points were not perfect in this edition, a **second round will be organized in September**:

- **warm encouragements to submit new solvers and new benchmarks**
- a new selection will be made
- the best solvers of the previous competitions will be run for comparison purpose
- possible redefinition of the BIGINT category (switch to 64 bits)