Seventh Pseudo-Boolean Competition
PB12

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Outline

- A few words on the competition
- Pseudo-Boolean constraints
- PBS, PBO, WBO
- Benchmarks and Solvers
- Evaluation System
- Results

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...

Last PB competition?

- PB12 is the last competition organized by the current team (V. Manquinho, O. Roussel)
  after 7 editions, it's time for change.
- Anyone willing to organize the next competitions is welcome!

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) but there exists good encodings to SAT.
- 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 (decision problem)
- **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

- Optimization of a visit in a museum (S. Roussel)
  2522 instances
- Optimization of cluster formation in mobile ad-hoc networks (S. Zahidi, F. Aloul, A. Sagahyroon, W. El-Hajj)
  160 instances
- haplotyping with pedigrees (HwP) (A. Graça, I. Lynce, J. Marques-Silva)
  100 instances actually submitted last year, but forgotten!

WBO

- third year w/o new submission!

Instance selection

- For this last competition, every instance collected since 2005 was candidate
- Random selection with 2012 used as seed
- Huge differences in the number of instances in each series (up to thousands)
  $\Rightarrow$at most 30 instances selected in each series.

Solvers

Submitted solvers:

- PBS/PBO: 10 different solvers, 33 versions by 8 different teams
- WBO: 8 solvers, 18 versions by 6 different teams

Unsubmitted solvers:

- Solvers from previous competitions (starting with PB07) which ranked first in a category and gave at least 100 answers
- minisatp (latest version of minisat+)
- These solvers are identified by a 'PB*yy*:' prefix

Categories and selected instances

- **DEC-SMALLINT-LIN (355 instances)**
- DEC-SMALLINT-NLC (30 instances)
- DEC-BIGINT-LIN (14 instances)
- DEC-BIGINT-NLC (0 instance)
- **OPT-SMALLINT-LIN (657 instances)**
- **OPT-SMALLINT-NLC (124 instances)**
- **OPT-BIGINT-LIN (416 instances)**
- OPT-BIGINT-NLC (0 instance)
- **PARTIAL-SMALLINT-LIN (276 instances)**
- **PARTIAL-BIGINT-LIN (238 instances)**
- **SOFT-SMALLINT-LIN (133 instances)**
- SOFT-BIGINT-LIN (46 instances)

Evaluation environment

kindly provided by CRIL, University of Artois, France

- 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 (each solver is given 4 cores)
  - limited interactions because of the 2 CPU and the memory limit
  - *only two instances of the same solver allowed to run concurrently*
- 697 days of CPU time used

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.
- Submitting a bug fix was allowed

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.
- **can 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 (1/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 355					
Virtual Best Solver (VBS)		284	156 SAT, 128 UNS	80%	100%
1	SAT 4j PB Res//CP	249	130 SAT, 119 UNS	70%	88%
2	PB11: Sat4j Res//CP	247	129 SAT, 118 UNS	70%	87%
3	clasp *(dec)*	246	149 SAT, 97 UNS	69%	87%
4	PB11: borg	243	124 SAT, 119 UNS	68%	86%
5	PB10: SAT4J Res//CP	243	129 SAT, 114 UNS	68%	86%
6	PB10: borg-pb	241	129 SAT, 112 UNS	68%	85%
7	PB07: Pueblo	240	128 SAT, 112 UNS	68%	85%
8	bsolo *3.2*	238	123 SAT, 115 UNS	67%	84%
9	Sat 4j PB Res	231	140 SAT, 91 UNS	65%	81%
10	pwbo *2.0*	228	134 SAT, 94 UNS	64%	80%
11	PB07: PB-clasp	226	133 SAT, 93 UNS	64%	80%
12	wbo *1.72*	226	131 SAT, 95 UNS	64%	80%
13	pwbo *2.02*	226	131 SAT, 95 UNS	64%	80%
14	wbo *1.7*	225	131 SAT, 94 UNS	63%	79%

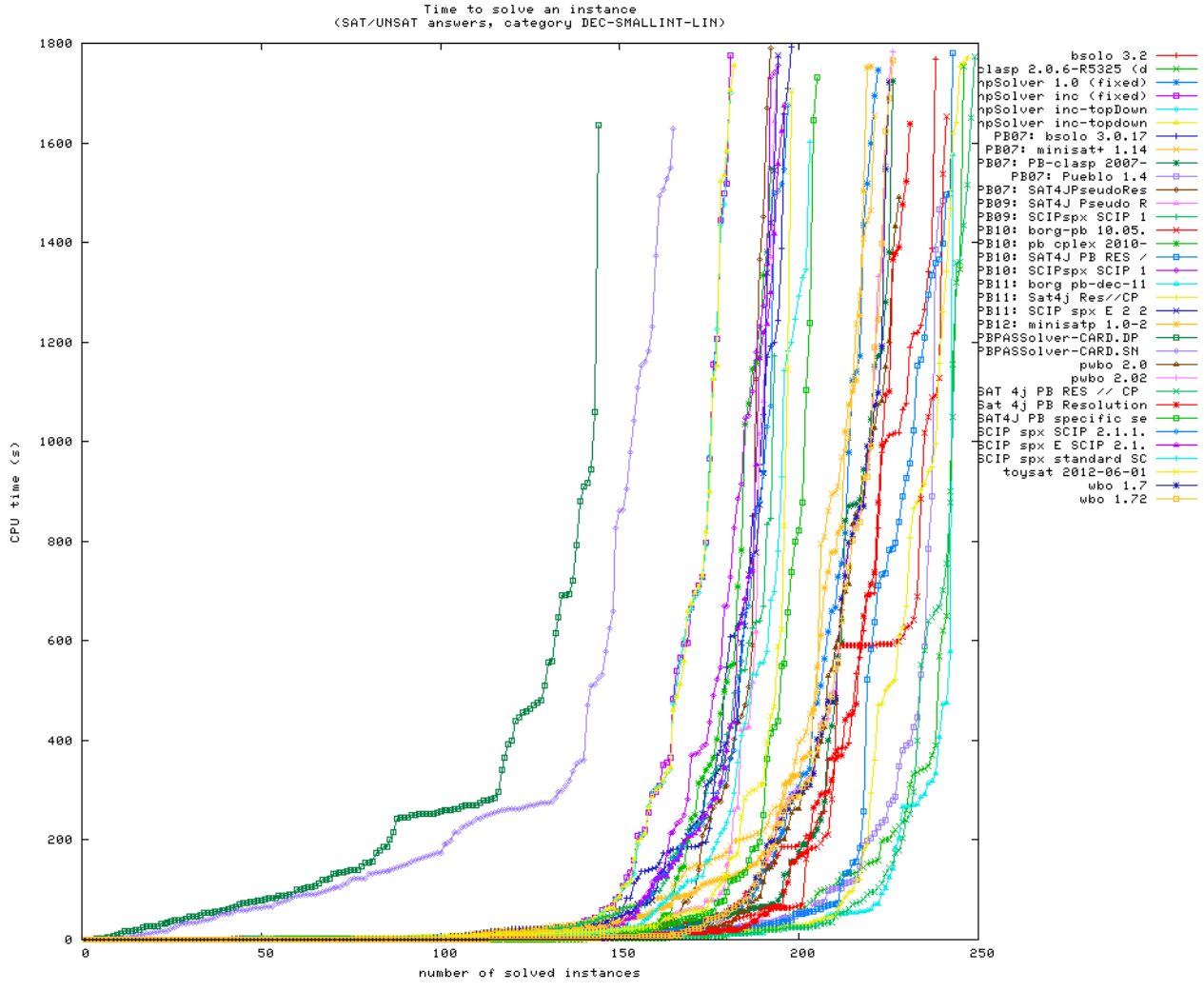
Results for DEC-SMALLINT-LIN (2/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
15	npSolver	222	125 SAT, 97 UNS	63%	78%
16	PB07: minisat+	221	130 SAT, 91 UNS	62%	78%
17	PB12: minisatp	220	129 SAT, 91 UNS	62%	77%
18	SAT4J PB specific settings	205	114 SAT, 91 UNS	58%	72%
19	SCIP spx standard	203	90 SAT, 113 UNS	57%	71%
20	toysat	198	114 SAT, 84 UNS	56%	70%
21	PB07: bsolo *3.0.17*	198	113 SAT, 85 UNS	56%	70%
22	SCIP spx	197	84 SAT, 113 UNS	55%	69%
23	SCIP spx E	196	83 SAT, 113 UNS	55%	69%
24	PB09: SAT4J PB Res	194	106 SAT, 88 UNS	55%	68%
25	PB11: SCIP spx E_2	194	81 SAT, 113 UNS	55%	68%
26	PB10: SCIPspx	194	81 SAT, 113 UNS	55%	68%
27	PB09: SCIPspx	193	81 SAT, 112 UNS	54%	68%
28	PB07: SAT4J PB res	192	103 SAT, 89 UNS	54%	68%
29	PB10: pb_cplex	192	88 SAT, 104 UNS	54%	68%
30	npSolver *inc-td-qb*	182	85 SAT, 97 UNS	51%	64%

Results for DEC-SMALLINT-LIN (3/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
31	npSolver *inc-td*	181	84 SAT, 97 UNS	51%	64%
32	npSolver *inc*	181	85 SAT, 96 UNS	51%	64%
33	PBPASSolver-CARD.SN	165	98 SAT, 67 UNS	46%	58%
34	PBPASSolver-CARD.DP	144	79 SAT, 65 UNS	41%	51%
35	pb2satCp2	0		0%	0%
36	pb2sat	0		0%	0%
37	npSolver *inc-td*	0		0%	0%
38	npSolver *inc*	0		0%	0%
39	npSolver *1.0*	0		0%	0%
40	npSolver *inc-td-qb*	0		0%	0%

DEC-SMALLINT-LIN



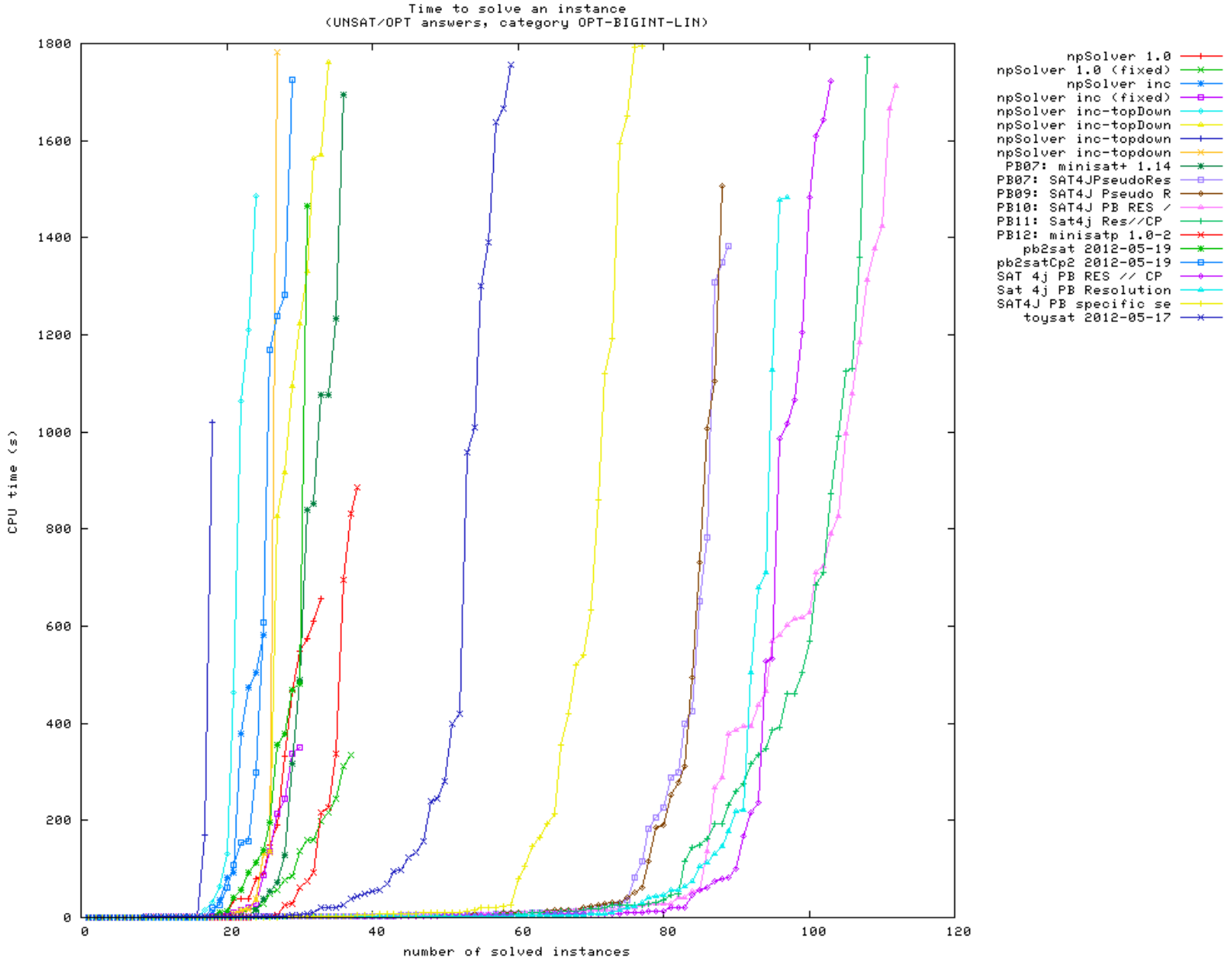
Results for OPT-BIGINT-LIN (1/2)

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 416					
Virtual Best Solver (VBS)		125	102 OPT, 23 UNS	30%	100%
1	PB10: SAT4J Res//CP	112	89 OPT, 23 UNS	27%	90%
2	PB11: Sat4j Res//CP	108	85 OPT, 23 UNS	26%	86%
3	SAT 4j PB Res//CP	103	80 OPT, 23 UNS	25%	82%
4	Sat 4j PB Res	97	74 OPT, 23 UNS	23%	78%
5	PB07: SAT4J PB res	89	66 OPT, 23 UNS	21%	71%
6	PB09: SAT4J PB Res	88	65 OPT, 23 UNS	21%	70%
7	SAT4J PB specific settings	77	54 OPT, 23 UNS	19%	62%
8	toysat	59	40 OPT, 19 UNS	14%	47%
9	PB12: minisatp	38	15 OPT, 23 UNS	9%	30%
10	npSolver	37	18 OPT, 19 UNS	9%	30%
11	PB07: minisat+	36	13 OPT, 23 UNS	9%	29%
12	npSolver *inc-td*	34	15 OPT, 19 UNS	8%	27%
13	npSolver *1.0*	33	17 OPT, 16 UNS	8%	26%
14	pb2sat	31	15 OPT, 16 UNS	7%	25%

Results for OPT-BIGINT-LIN (2/2)

Rank	Solver	#solved	Detail	%inst.	%VBS
15	npSolver *inc*	30	11 OPT, 19 UNS	7%	24%
16	pb2satCp2	29	13 OPT, 16 UNS	7%	23%
17	npSolver *inc-td-qb*	27	8 OPT, 19 UNS	6%	22%
18	npSolver *inc*	25	9 OPT, 16 UNS	6%	20%
19	npSolver *inc-td*	24	8 OPT, 16 UNS	6%	19%
20	npSolver *inc-td-qb*	18	2 OPT, 16 UNS	4%	14%

OPT-BIGINT-LIN



Results for OPT-SMALLINT-LIN (1/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 657					
Virtual Best Solver (VBS)		463	441 OPT, 22 UNS	70%	100%
1	PB10: pb_cplex	376	355 OPT, 21 UNS	57%	81%
2	SCIP spx E	351	329 OPT, 22 UNS	53%	76%
3	SCIP spx	350	328 OPT, 22 UNS	53%	76%
4	SCIP spx standard	349	327 OPT, 22 UNS	53%	75%
5	pwbo *2.02*	342	323 OPT, 19 UNS	52%	74%
6	npSolver	337	315 OPT, 22 UNS	51%	73%
7	pb2sat	331	309 OPT, 22 UNS	50%	71%
8	PB11: SCIP spx E_2	331	309 OPT, 22 UNS	50%	71%
9	npSolver *1.0*	325	307 OPT, 18 UNS	49%	70%
10	pb2satCp2	314	292 OPT, 22 UNS	48%	68%
11	PB10: SCIPspx	308	287 OPT, 21 UNS	47%	67%
12	bsolo *3.2*	300	279 OPT, 21 UNS	46%	65%
13	clasp *(opt)*	281	260 OPT, 21 UNS	43%	61%
14	PB11: Sat4j Res//CP	279	258 OPT, 21 UNS	42%	60%

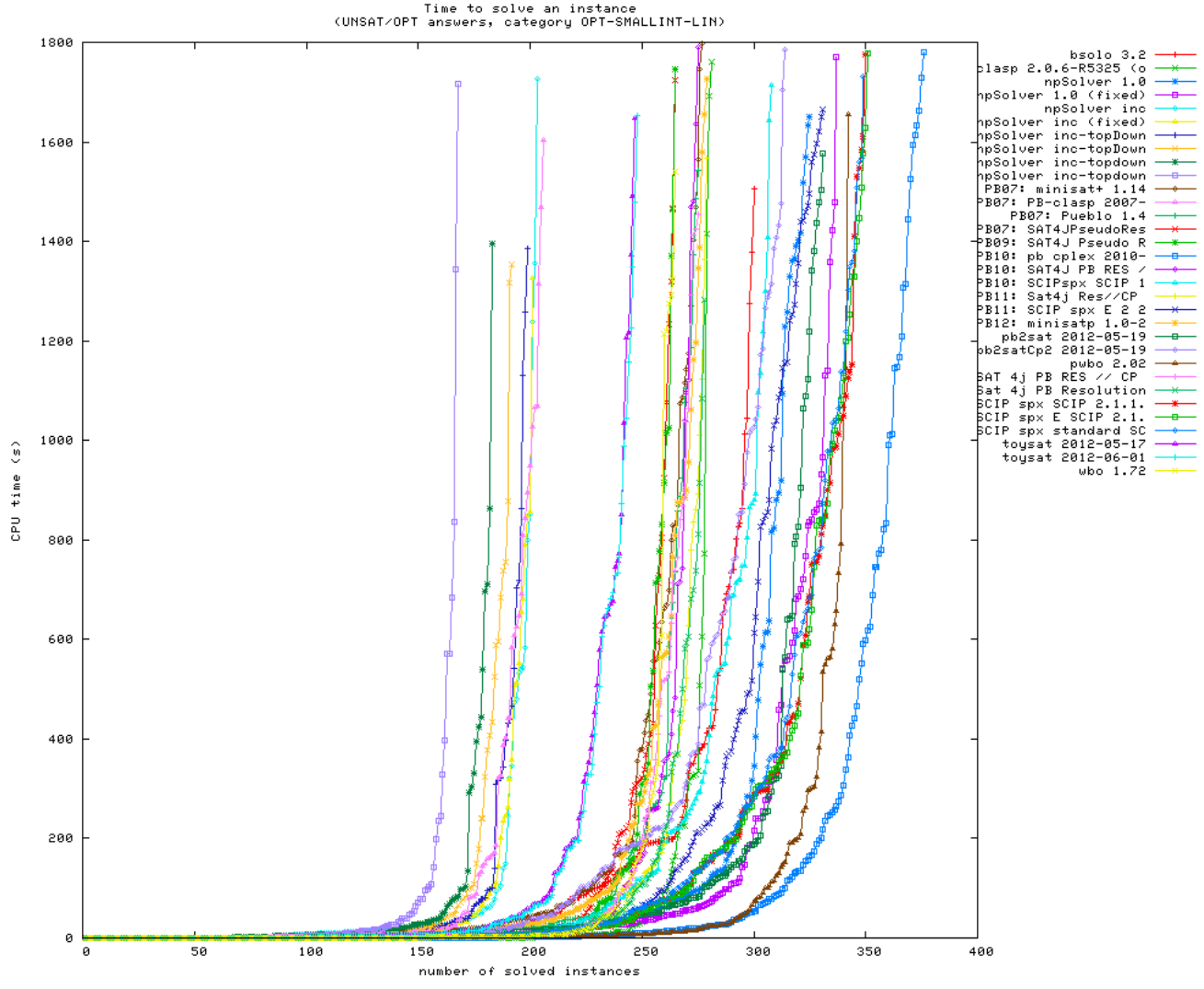
Results for OPT-SMALLINT-LIN (2/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
15	PB12: minisatp	279	257 OPT, 22 UNS	42%	60%
16	Sat 4j PB Res	278	257 OPT, 21 UNS	42%	60%
17	PB07: minisat+	277	255 OPT, 22 UNS	42%	60%
18	PB10: SAT4J Res//CP	275	254 OPT, 21 UNS	42%	59%
19	SAT 4j PB Res//CP	275	253 OPT, 22 UNS	42%	59%
20	PB07: Pueblo	275	254 OPT, 21 UNS	42%	59%
21	wbo *1.72*	265	245 OPT, 20 UNS	40%	57%
22	PB09: SAT4J PB Res	265	244 OPT, 21 UNS	40%	57%
23	PB07: SAT4J PB res	265	243 OPT, 22 UNS	40%	57%
24	toysat	248	227 OPT, 21 UNS	38%	54%
25	toysat	247	226 OPT, 21 UNS	38%	53%
26	PB07: PB-clasp	206	186 OPT, 20 UNS	31%	44%
27	npSolver *inc*	203	185 OPT, 18 UNS	31%	44%
28	npSolver *inc*	201	179 OPT, 22 UNS	31%	43%
29	npSolver *inc-td*	199	181 OPT, 18 UNS	30%	43%
30	npSolver *inc-td*	192	170 OPT, 22 UNS	29%	41%

Results for OPT-SMALLINT-LIN (3/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
31	npSolver *inc-td-qb*	183	165 OPT, 18 UNS	28%	40%
32	npSolver *inc-td-qb*	168	146 OPT, 22 UNS	26%	36%

OPT-SMALLINT-LIN



Results for OPT-SMALLINT-NLC (1/2)

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 124					
Virtual Best Solver (VBS)		67	67 OPT	54%	100%
1	SCIP spx E	67	67 OPT	54%	100%
2	PB11: SCIP spx E_2	67	67 OPT	54%	100%
3	SCIP spx	66	66 OPT	53%	99%
4	SCIP spx standard	65	65 OPT	52%	97%
5	PB09: SCIPspx	65	65 OPT	52%	97%
6	PB10: SCIPspx	62	62 OPT	50%	93%
7	npSolver	60	60 OPT	48%	90%
8	clasp *(opt)*	60	60 OPT	48%	90%
9	npSolver *inc-td*	59	59 OPT	48%	88%
10	npSolver *inc*	59	59 OPT	48%	88%
11	PB07: minisat+	59	59 OPT	48%	88%
12	PB07: Pueblo	57	57 OPT	46%	85%
13	PB11: Sat4j Res//CP	56	56 OPT	45%	84%
14	Sat 4j PB Res	55	55 OPT	44%	82%

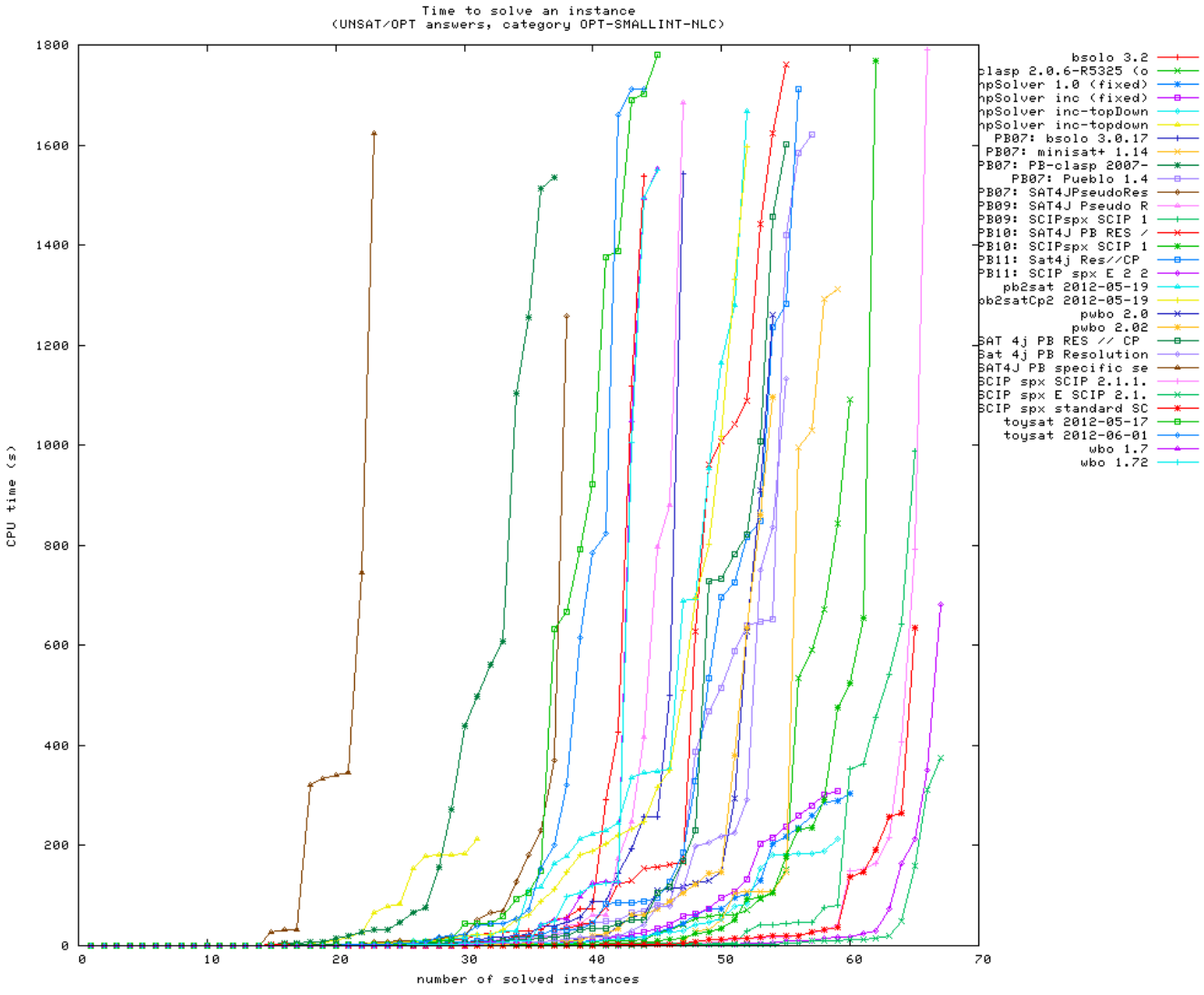
Results for OPT-SMALLINT-NLC (2/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
15	SAT 4j PB Res//CP	55	55 OPT	44%	82%
16	PB10: SAT4J Res//CP	55	55 OPT	44%	82%
17	pwbo *2.02*	54	54 OPT	44%	81%
18	pwbo *2.0*	54	54 OPT	44%	81%
19	pb2satCp2	52	52 OPT	42%	78%
20	pb2sat	52	52 OPT	42%	78%
21	PB07: bsolo *3.0.17*	47	47 OPT	38%	70%
22	PB09: SAT4J PB Res	47	47 OPT	38%	70%
23	wbo *1.72*	45	45 OPT	36%	67%
24	wbo *1.7*	45	45 OPT	36%	67%
25	toysat	45	45 OPT	36%	67%
26	bsolo *3.2*	44	44 OPT	35%	66%
27	toysat	44	44 OPT	35%	66%
28	PB07: SAT4J PB res	38	38 OPT	31%	57%
29	PB07: PB-clasp	37	37 OPT	30%	55%

Results for OPT-SMALLINT-NLC (3/3)

Rank	Solver	#solved	Detail	%inst.	%VBS
30	npSolver *inc-td-qb*	31	31 OPT	25%	46%
31	SAT4J PB specific settings	23	23 OPT	19%	34%
32	PB12: minisatp	0		0%	0%

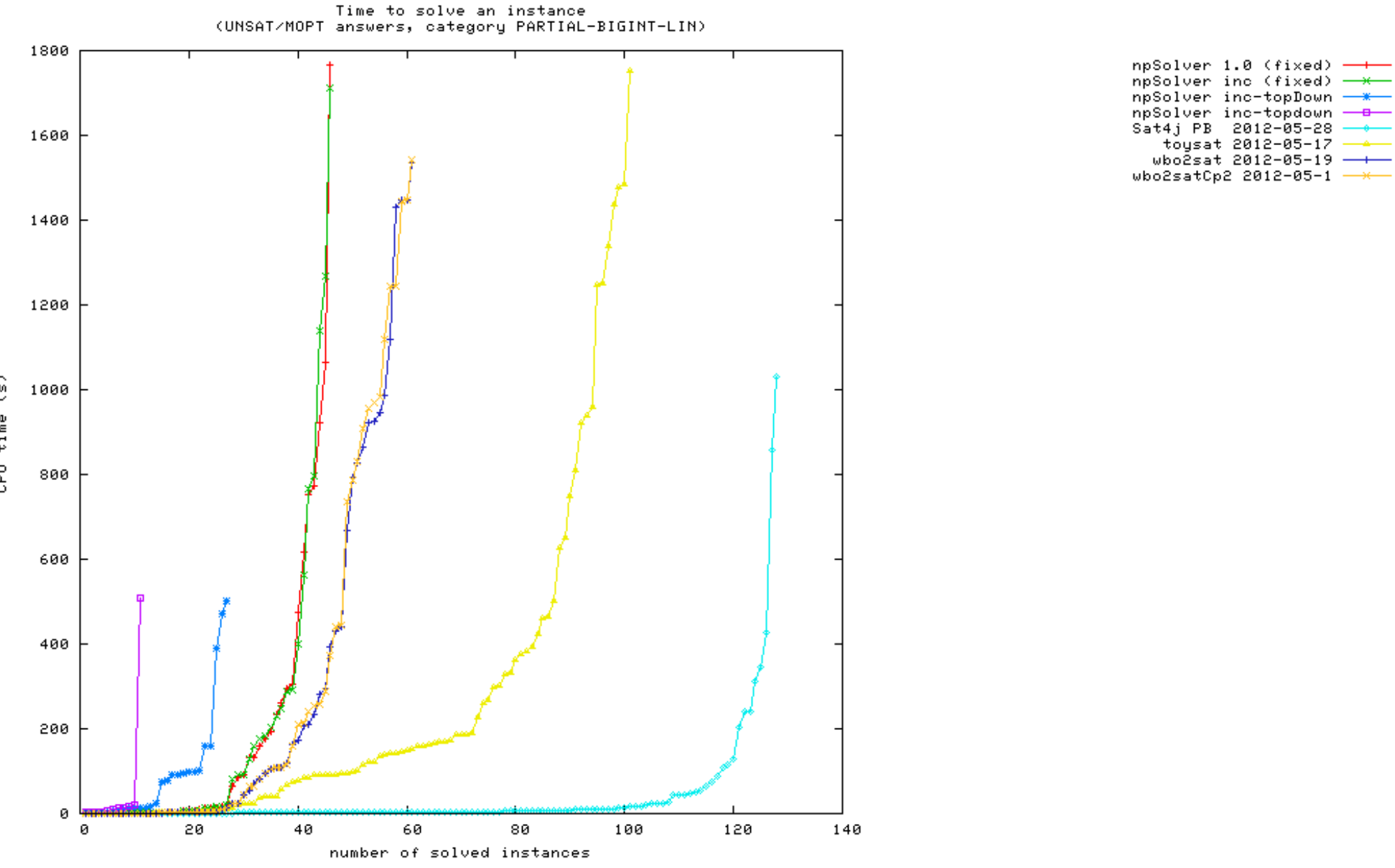
OPT-SMALLINT-NLC



Results for PARTIAL-BIGINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 238					
Virtual Best Solver (VBS)		133	133 MOPT	56%	100%
1	Sat4j PB	128	128 MOPT	54%	96%
2	toysat	101	101 MOPT	42%	76%
3	wbo2sat	61	61 MOPT	26%	46%
4	wbo2satCp2	61	61 MOPT	26%	46%
5	npSolver *1.0 (fix)*	46	46 MOPT	19%	35%
6	npSolver *inc (fix*	46	46 MOPT	19%	35%
7	npSolver *inc-td (fix)*	27	27 MOPT	11%	20%
8	npSolver *inc-td-qb (fix)*	11	11 MOPT	5%	8%

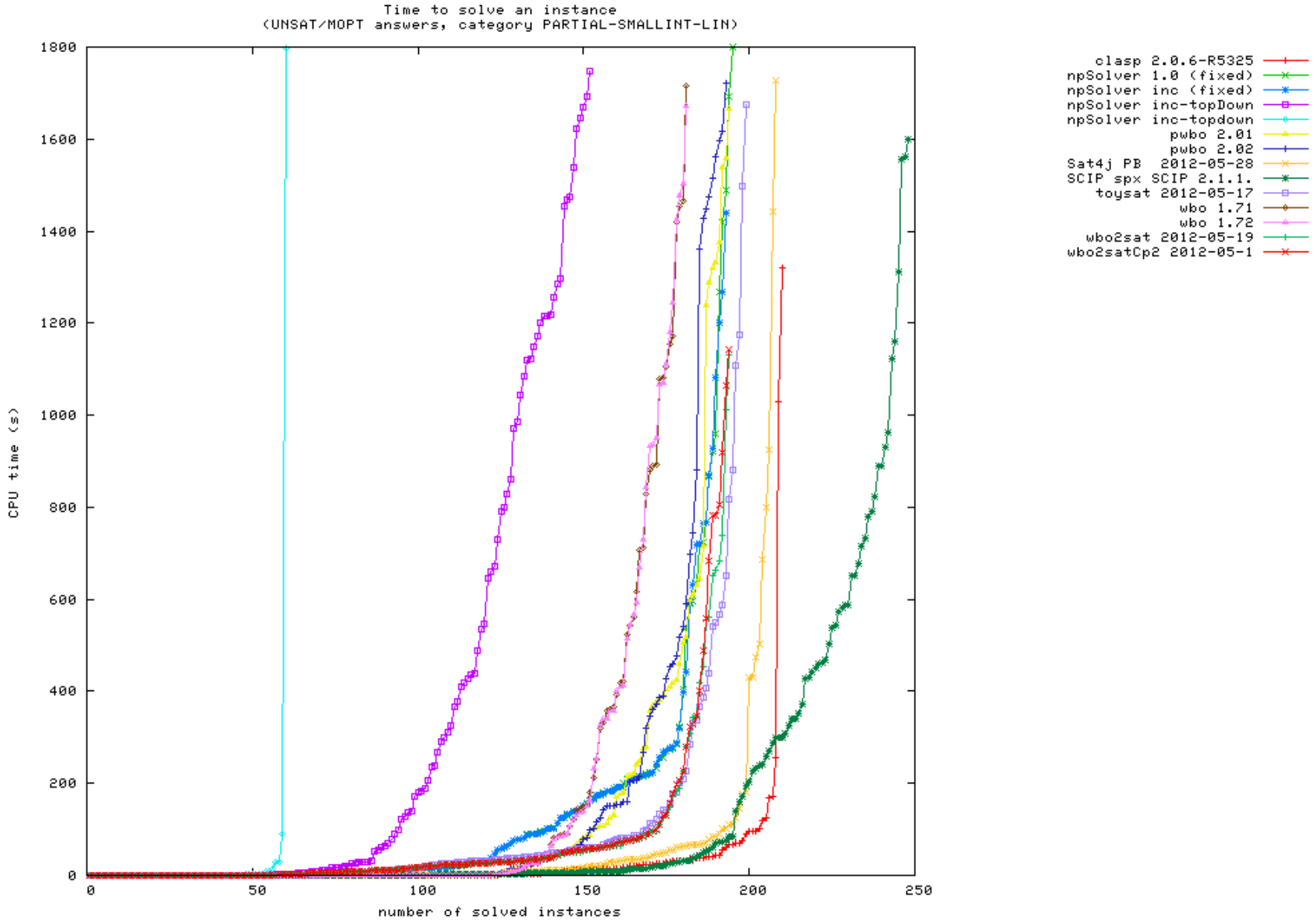
PARTIAL-BIGINT-LIN



Results for PARTIAL-SMALLINT-LIN

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 276					
Virtual Best Solver (VBS)		270	269 MOPT, 1 UNS	98%	100%
1	SCIP spx	248	247 MOPT, 1 UNS	90%	92%
2	clasp	210	209 MOPT, 1 UNS	76%	78%
3	Sat4j PB	208	207 MOPT, 1 UNS	75%	77%
4	toysat	199	198 MOPT, 1 UNS	72%	74%
5	npSolver *1.0 (fix)*	195	195 MOPT	71%	72%
6	wbo2sat	194	194 MOPT	70%	72%
7	wbo2satCp2	194	194 MOPT	70%	72%
8	pwbo *2.01*	194	193 MOPT, 1 UNS	70%	72%
9	npSolver *inc (fix*	193	193 MOPT	70%	71%
10	pwbo *2.02*	193	192 MOPT, 1 UNS	70%	71%
11	wbo *1.71*	181	180 MOPT, 1 UNS	66%	67%
12	wbo *1.72*	181	180 MOPT, 1 UNS	66%	67%
13	npSolver *inc-td (fix)*	152	152 MOPT	55%	56%
14	npSolver *inc-td-qb (fix)*	60	60 MOPT	22%	22%

PARTIAL-SMALLINT-LIN



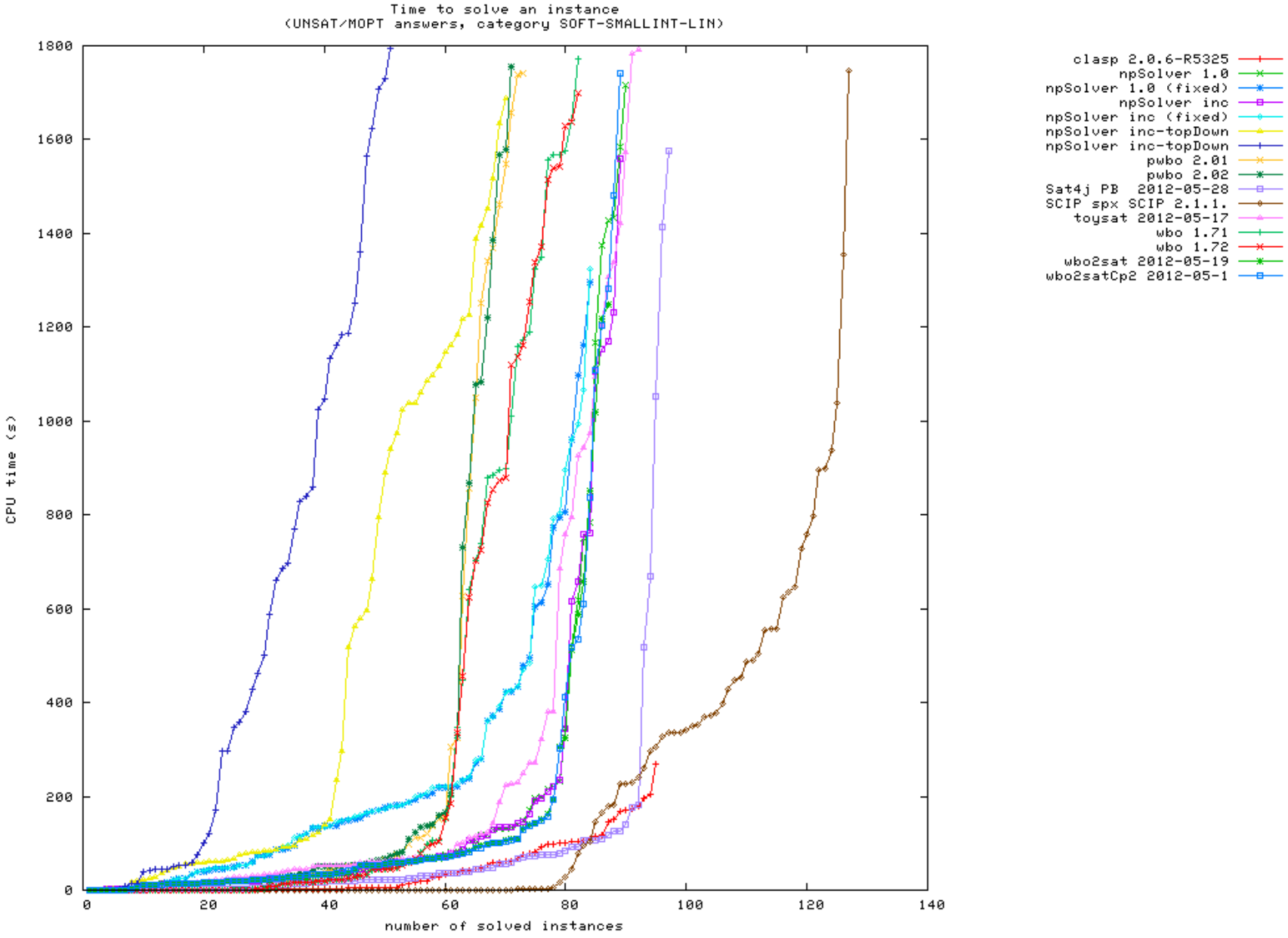
Results for SOFT-SMALLINT-LIN (1/2)

Rank	Solver	#solved	Detail	%inst.	%VBS
Total number of instances: 133					
Virtual Best Solver (VBS)		133	133 MOPT	100%	100%
1	SCIP spx	127	127 MOPT	95%	95%
2	Sat4j PB	97	97 MOPT	73%	73%
3	clasp	95	95 MOPT	71%	71%
4	toysat	92	92 MOPT	69%	69%
5	npSolver	90	90 MOPT	68%	68%
6	npSolver *inc*	89	89 MOPT	67%	67%
7	wbo2satCp2	89	89 MOPT	67%	67%
8	wbo2sat	87	87 MOPT	65%	65%
9	npSolver *1.0 (fix)*	84	84 MOPT	63%	63%
10	npSolver *inc (fix*	84	84 MOPT	63%	63%
11	wbo *1.72*	82	82 MOPT	62%	62%
12	wbo *1.71*	82	82 MOPT	62%	62%
13	pwbo *2.01*	73	73 MOPT	55%	55%
14	pwbo *2.02*	71	71 MOPT	53%	53%

Results for SOFT-SMALLINT-LIN (2/2)

Rank	Solver	#solved	Detail	%inst.	%VBS
15	npSolver *inc-td*	70	70 MOPT	53%	53%
16	npSolver *inc-td (fix)*	51	51 MOPT	38%	38%
17	npSolver *inc-td-qb*	0		0%	0%
18	npSolver *inc-td-qb (fix)*	0		0%	0%

SOFT-SMALLINT-LIN



Some lessons

- Linear programming techniques
  - dominate in optimization problems
  - but are dominated in decision problems.
- In CDCL solvers,
  - learning only PB constraints doesn't seem competitive,
  - learning only clauses is not sufficient,
  - a mixed scheme seems to be the right approach.
- Portfolios are also effective for PB problems
- Solvers don't necessarilly improve with time

<*Add you own conclusion here*>

More information

- All details are on the web site **http://www.cril.univ-artois.fr/PB12/**
- after 7 years of competitions:
  - 13512 instances (9.6 GB) collected and published
  - 172 solvers were run since 2006
- Thanks to all participants!
- **Reminder: new organizers are expected!**