

30 Years of Faster and Faster SAT Solving

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25th Conference on
Logic for Programming, Artificial Intelligence and Reasoning
LPAR 2024

May 27, 2024, BalACLava, Mauritius

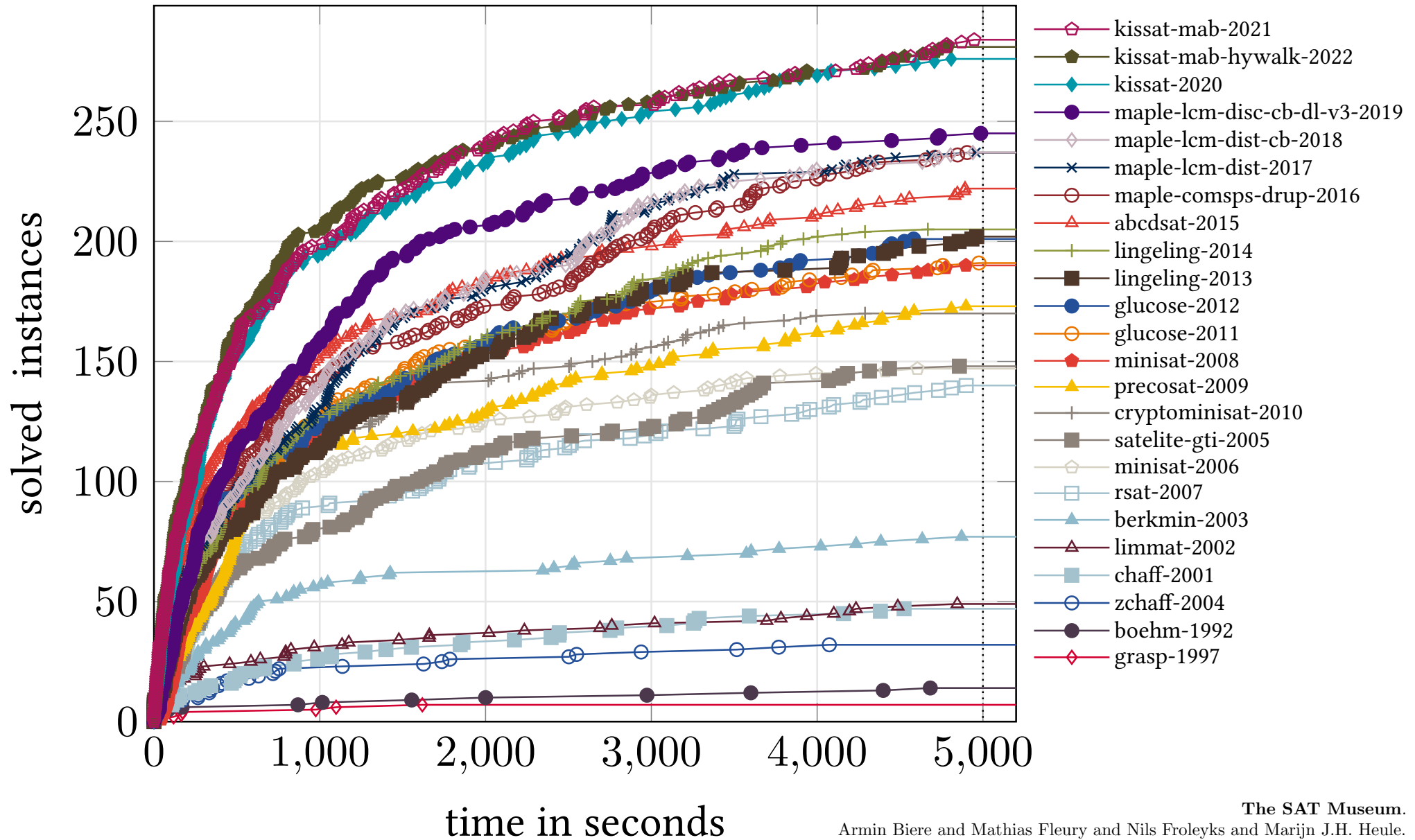
extended version of

Shonan Seminar **The ART of SAT** in Oct. '23 and the POS @ SAT talk in July'23 on

The SAT Museum

<https://cca.informatik.uni-freiburg.de/satmuseum>

SAT Competition All Time Winners on SAT Competition 2022 Benchmarks



The SAT Museum.

Armin Biere and Mathias Fleury and Nils Froleyks and Marijn J.H. Heule.
In *Proceedings 14th International Workshop on Pragmatics of SAT (POS'23)*,
vol. 3545, CEUR Workshop Proceedings, pages 72-87, CEUR-WS.org 2023.
[paper - bibtex - data - zenodo - ceur - workshop - proceedings]

<https://cca.informatik.uni-freiburg.de/satmuseum>

Goal

It has been stated that

“No major performance breakthrough [in SAT solving] in close to two decades”

where notable proponents of this claim are

- Karem Sakallah at the recent Simons Institute’s seminar in 2023
- João Marques-Silva during his invited talk at POS’19

The SAT Museum exists to document the history of SAT solving and to show in contrast to these claims that indeed

SAT solvers are getting Faster and Faster

and thus document how to ***ignite the art of SAT solving***



Shonan Seminar The ART of SAT

with mount Fuji somewhere behind the clouds

Motivation

- assess progress of SAT solving in the last decades
- **25** all-time-winners of SAT Competitions (1992, **1995**, 2002 - 2022, **2023**)
 - application / main track
- plus versions of historically interesting solvers
 - Grasp, Chaff, zChaff, Siege, MiniSAT, PicoSAT, CaDiCaL
- apple-to-apple comparison on same hardware / software
- competition instances from 7 years: 2002, 2011, 2019, 2020, 2021, 2022, **2023**
 - again only application / main track
 - not merged so compared separately per year
no need to remove duplicates
- collect and patch solvers

after POS

after Shonan Seminar

Solvers Features - First and Second Decade

■ Before Preprocessing

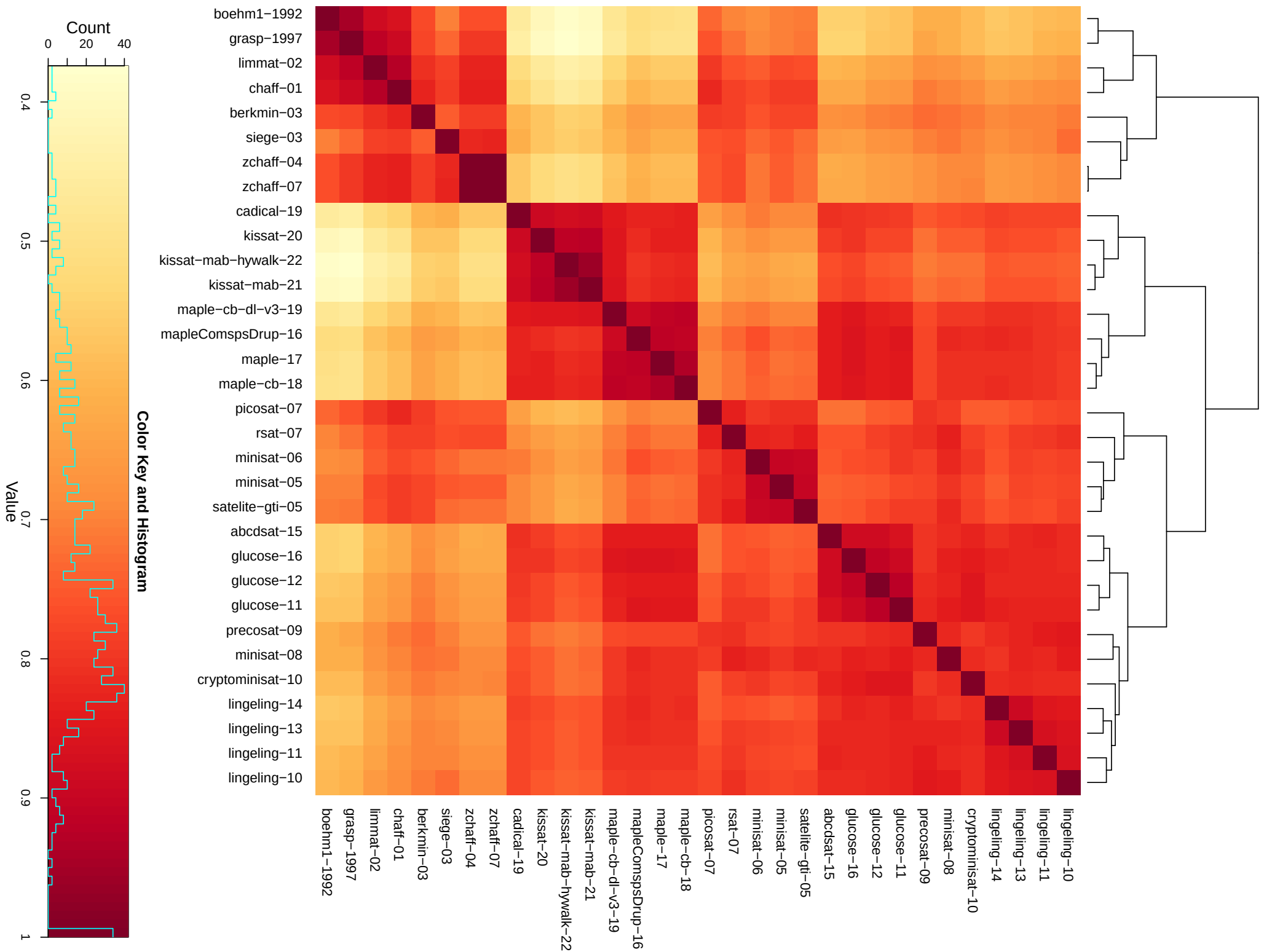
- DPLL solvers boehm1-1992, **posit-1995**
- seminal CDCL solvers grasp-1997, chaff-2001, zchaff-200[147]
- look-ahead Solver **march-2011**
- (almost) winners limmat-2002, siege-2003 (VMTF), berkmin-2003
- SAT'22 test-of-time awardee minisat-200[5678] incl. minimization
note however that the MiniSat paper is from 2003 – Test of Time Award SAT'23

■ With Preprocessing

- seminal preprocessing solver satellite-gti-2005 (SatElite + MiniSAT)
- phase saving and rapid restarts rsat-2007
- LBD and better restarts in glucose-20{11,12,16}

Solvers Features - Third Decade

- With Inprocessing
 - first inprocessing solvers precosat-2009, cryptominisat-2010
 - advanced inprocessing in lingeling-201[0134], abcdsat-2015
- With Mode Switching (stable mode for SAT, focused mode for UNSAT)
 - maple-comsps-drup-2016 (plus LRB and reason-side bumping),
maple-lcm-dist-2017 (vivification),
maple-lcm-dist-cb-2018 (chronological backtracking) and
maple-lcm-disc-cb-dl-v3-2019 (hashing) each by different sets of authors
- Local Search / Target Phases
 - cadical-2019 (target phases) was improved and optimized in kissat-2020
 - kissat-mab-2021 (stable decisions), kissat-mab-hywalk-2022 (random walks)
- Latest winning solver **sbva-cadical-2023** (with bounded variable edition)



Patches

- binary only solvers siege-2003, berkmin-2003, abcdsat-2015

- collected original source code and provided patches:

```
satmuseum/solvers$ wc -l */*patch*|tail -1
9758 total
```

- including proper build environment (makefiles)
- oldest solvers required largest effort
 - for grasp-1997 we started with patched version from João dated 2008
- typical MiniSat patches (formatting, default argument, friend)
- several solvers had hard coded line buffers or maximum clause size
 - silently truncate longer clauses
- also needed patches to make solvers 64-bit clean
 - some where trivial and some hard to find and fix

Two Decades of SAT Competition Main / Application Benchmarks

- **100** benchmarks of first “modern” SAT competition 2002
- **324** benchmarks of the “hard” SAT competition **2004**
- **300** benchmarks in 2011 competition
 - different organizers
 - CDCL improvements vs. inprocessing solvers
- **400** benchmarks in the SAT Race 2019 (when this work started)
- **400** benchmarks for each of the last three years in 2020 - 2022 as well as **2023**
 - satisfies the SAT Practitioner’s Manifesto <https://zenodo.org/doi/10.5281/zenodo.4500927>
 - much more trusted results as proofs became mandatory (since 2013)
 - focus on submitted benchmarks: bring-your-own benchmarks
 - smaller batches (max. 14) of benchmarks from the same group
 - another decade later
- **5355** benchmarks from the 2022 **anniversary** track

Execution Environment

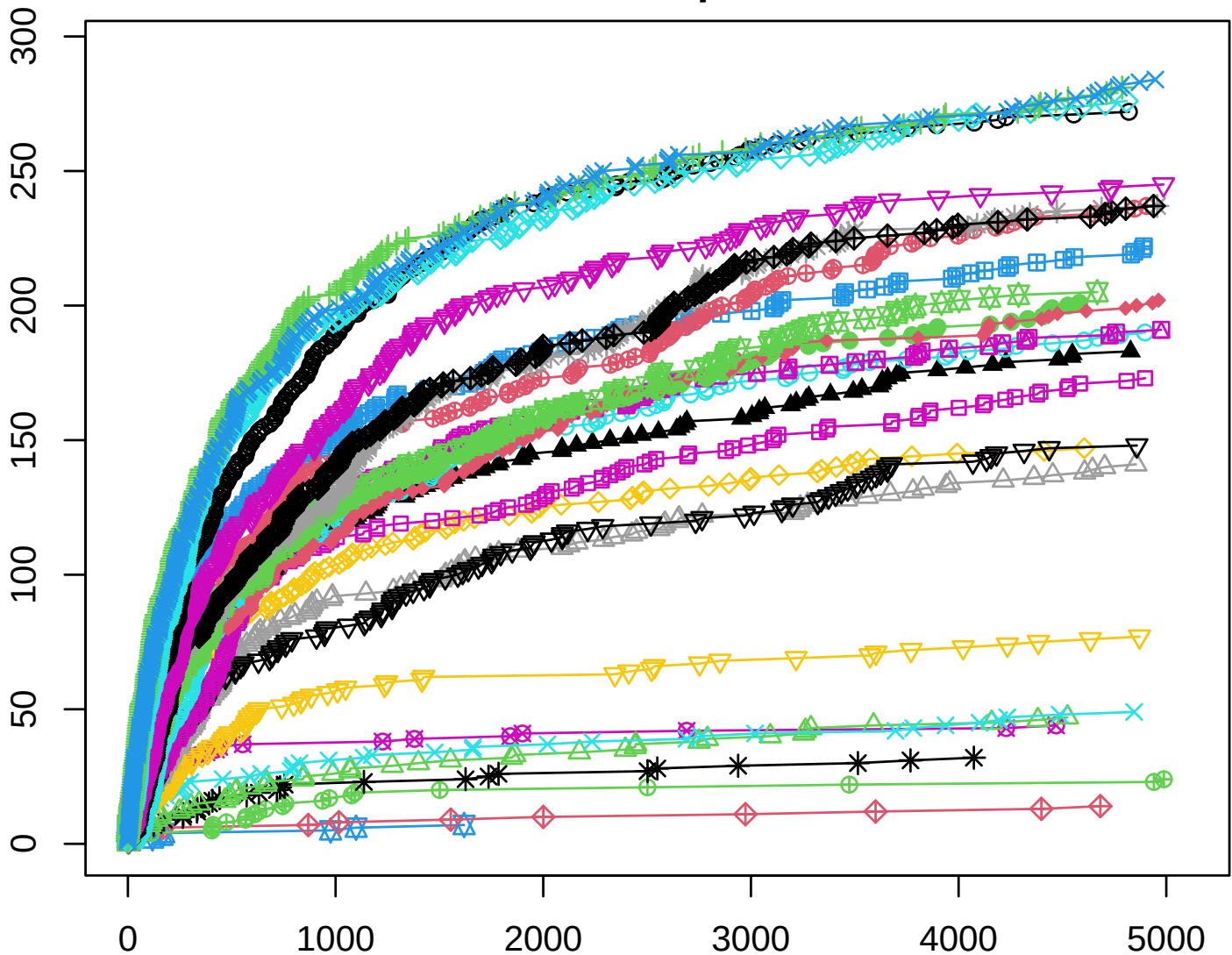
■ Hardware

- 32 node cluster with two processors per node
- 8-core Intel Xeon E5-2620 v4 CPUs at 2.10 GHz (no turbo-mode)
- memory limit 127 GB (increased iteratively)
- time limit 500 seconds (as in recent SAT competitions)

■ Software

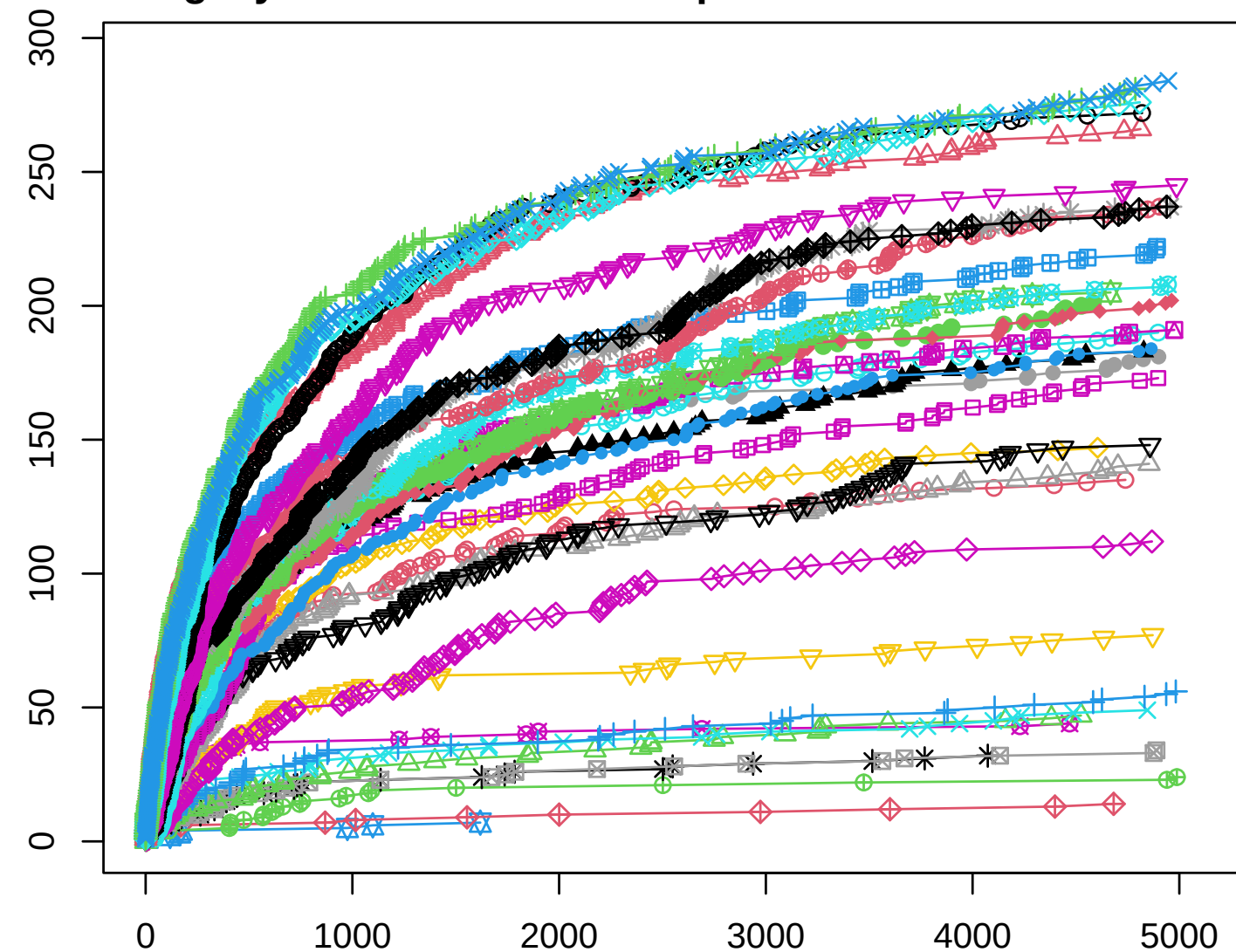
- Slurm: whenever possible maximum usage of (512) cores
- Ubuntu 20.04
- gcc 9.4.0 (64-bit)
- runlim

All Time Winners on SAT Competition 2022 Benchmarks



- 284 kissat-mab-2021
- 281 kissat-mab-hywalk-2022
- 276 kissat-2020
- 272 sbva-cadical-2023
- 245 maple-lcm-disc-cb-dl-v3-2019
- 237 maple-lcm-dist-cb-2018
- 237 maple-lcm-dist-2017
- 237 maple-comsps-drup-2016
- 222 abcdsat-2015
- 205 lingeling-2014
- 202 lingeling-2013
- 201 glucose-2012
- 191 glucose-2011
- 190 minisat-2008
- 183 cryptominisat-2010
- 173 precosat-2009
- 148 satellite-gti-2005
- 147 minisat-2006
- 141 rsat-2007
- 77 berkmin-2003
- 49 limmat-2002
- 47 chaff-2001
- 44 march-2011
- 32 zchaff-2004
- 24 posit-1995
- 14 boehm1-1992
- 7 grasp-1997

Legacy Solvers on SAT Competition 2022 Benchmarks



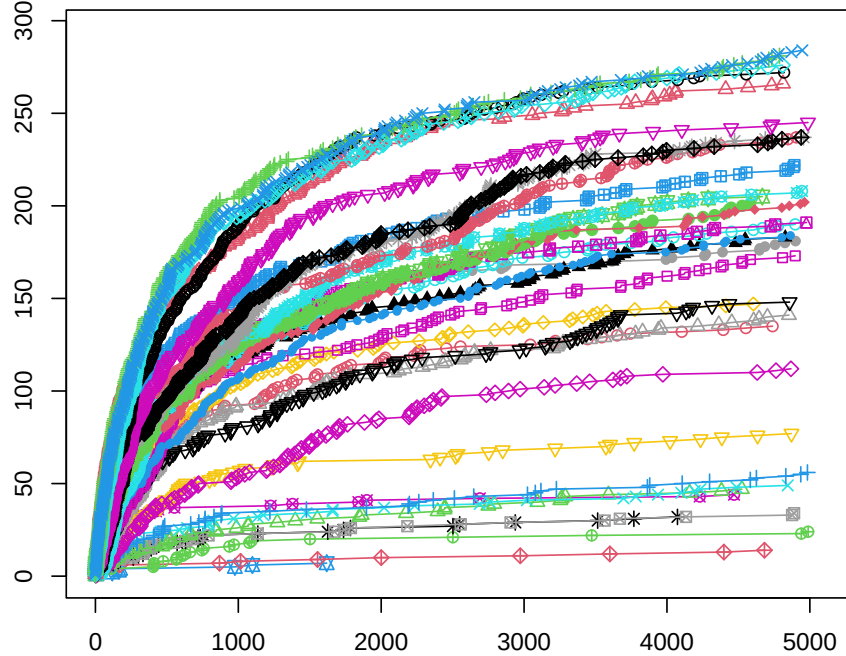
- × 284 kissat-mab-2021
- + 281 kissat-mab-hywalk-2022
- ◇ 276 kissat-2020
- 272 sbva-cadical-2023
- △ 266 cadical-2019
- ▽ 245 maple-lcm-disc-cb-dl-v3-2019
- ◆ 237 maple-lcm-dist-cb-2018
- * 237 maple-lcm-dist-2017
- 237 maple-comsps-drup-2016
- ▣ 222 abcdsat-2015
- ⊠ 208 glucose-2016
- ⋈ 205 lingeling-2014
- ◆ 202 lingeling-2013
- 201 glucose-2012
- ⊠ 191 glucose-2011
- 190 minisat-2008
- 184 lingeling-2011
- ▲ 183 cryptominisat-2010
- 181 lingeling-2010
- ⊠ 173 precosat-2009
- ▽ 148 satellite-gti-2005
- ◇ 147 minisat-2006
- △ 141 rsat-2007
- 135 minisat-2005
- ◇ 112 picosat-2007
- ▽ 77 berkmin-2003
- + 56 siege-2003
- × 49 limmat-2002
- △ 47 chaff-2001
- ⊠ 44 march-2011
- ⊠ 34 zchaff-2007
- * 32 zchaff-2004
- 24 posit-1995
- ◆ 14 boehm1-1992
- ⊠ 7 grasp-1997

Winners & Legacy Solvers — SAT Competition 2022

	solver	ok	sat	uns	fld	to	s11	s6	unk	time	space	max	best	uniq
	kissat-mab-2021	284	138	146	116	116	0	0	0	265782	150888	8560	23	0
	kissat-mab-hywalk-2022	281	141	140	119	119	0	0	0	243481	144848	5074	23	2
	kissat-2020	276	133	143	124	124	0	0	0	250172	140684	5800	29	3
	sbva-cadical-2023	272	139	133	128	128	0	0	0	237023	863369	40021	26	1
	cadical-2019	266	130	136	134	134	0	0	0	226275	338834	15287	36	1
	maple-lcm-disc-cb-dl-v3-2019	245	114	131	155	155	0	0	0	240050	252515	15342	3	0
	maple-lcm-dist-cb-2018	237	107	130	163	163	0	0	0	278238	241274	15342	14	1
	maple-lcm-dist-2017	237	109	128	163	157	6	0	0	282569	232392	15342	10	0
	maple-comsps-drup-2016	237	109	128	163	163	0	0	0	296217	254699	13707	27	0
	abcsat-2015	222	102	120	178	175	1	2	0	218955	160324	11921	17	0
	glucose-2016	208	93	115	192	192	0	0	0	220600	150531	11923	1	0
	lingeling-2014	205	98	107	195	195	0	0	0	229105	153486	6317	2	0
	lingeling-2013	202	86	116	198	198	0	0	0	249622	124551	6233	4	0
	glucose-2012	201	88	113	199	198	0	0	1	225987	112212	5424	8	0
	glucose-2011	191	85	106	209	209	0	0	0	189747	109528	7737	17	0
	minisat-2008	190	91	99	210	210	0	0	0	210046	194259	11139	12	0
	lingeling-2011	184	89	95	216	211	1	0	4	227743	92008	4111	5	0
	cryptominisat-2010	183	78	105	217	215	0	0	2	197523	209314	13620	8	0
	lingeling-2010	181	82	99	219	211	0	0	8	173349	98203	6965	2	0
	precosat-2009	173	85	88	227	226	0	0	1	211820	258453	21011	10	0
	satellite-gti-2005	148	72	76	252	252	0	0	0	191724	180730	18383	1	0
	minisat-2006	147	64	83	253	253	0	0	0	131637	100257	11749	4	0
	rsat-2007	141	68	73	259	259	0	0	0	164560	155831	18925	2	1
	minisat-2005	135	60	75	265	254	0	0	11	118366	110412	11838	6	0
	picosat-2007	112	57	55	288	273	0	0	15	146944	37585	3879	0	0
	berkmin-2003	77	36	41	323	304	0	0	19	77844	17913	4066	0	0
	siege-2003	56	42	14	344	242	0	0	102	82966	15819	3385	2	0
	limmat-2002	49	24	25	351	324	0	27	0	61160	119707	15146	7	0
	chaff-2001	47	26	21	353	353	0	0	0	63674	91987	20260	0	0
	march-2011	44	15	29	356	355	1	0	0	22220	14652	12284	17	0
	zchaff-2007	34	24	10	366	281	0	0	85	41662	9359	995	3	0
	zchaff-2004	32	23	9	368	283	0	0	85	32304	7984	875	0	0
	posit-1995	24	5	19	376	234	0	0	142	27943	830	270	1	0
	boehm1-1992	14	11	3	386	381	5	0	0	21429	38911	35939	0	0
	grasp-1997	7	6	1	393	393	0	0	0	4156	90404	83832	1	0

Cumulative Distribution Function (CDF)

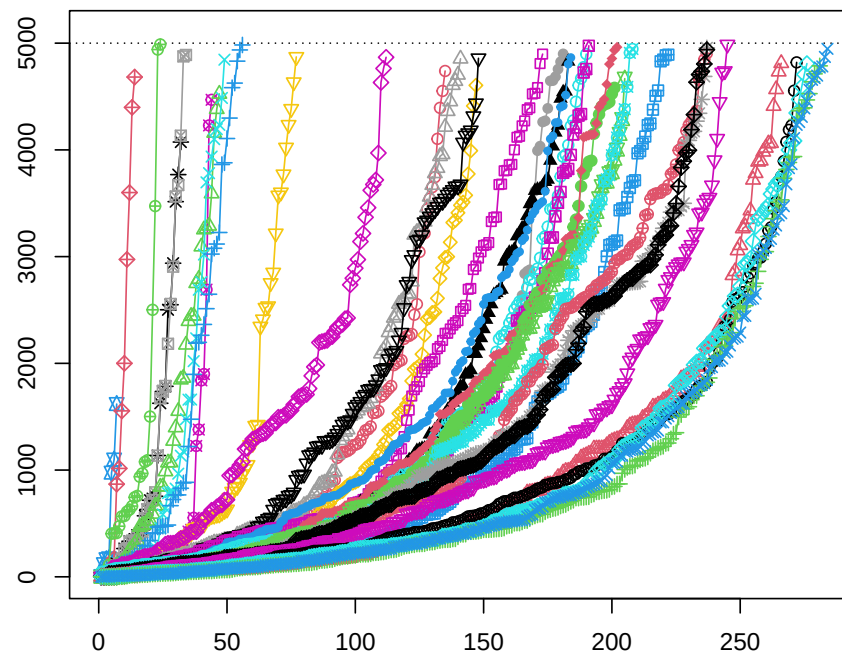
Legacy Solvers on SAT Competition 2022 Benchmarks

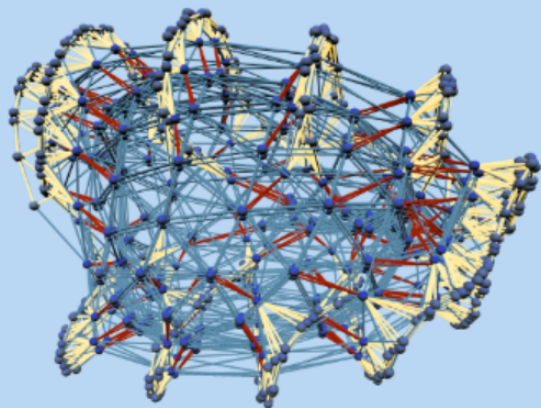


VS.

Cactus Plot

Legacy Solvers on SAT Competition 2022 Benchmarks





SAT Competition 2022

Affiliated with the 25th International Conference on Theory and Applications of Satisfiability Testing taking place on the 2nd - 5th of August 2022 in Haifa, Israel.

[Overview](#)

[Competition Tracks](#)

[Solver Submission](#)

- [UNSAT Certificates](#)
- [StarExec Cluster](#)
- [AWS Cloud](#)

[Benchmark Submission](#)

[Downloads](#)

[Results](#)

[Organizers](#)

Results

Main Track, Sequential Solvers

Solver	Score $\blacktriangle\blacktriangledown$	Solved $\blacktriangle\blacktriangledown$	Score SAT $\blacktriangle\blacktriangledown$	Solved SAT $\blacktriangle\blacktriangledown$	Score UNSAT $\blacktriangle\blacktriangledown$	Solved UNSAT $\blacktriangle\blacktriangledown$
vbs	2331.877677	320	161.346875	164	681.347329	156
Kissat_MAB-HyWalk	3334.222964	290	1779.608623	144	1550.213919	146
kissat_inc	3351.932903	290	1769.021467	145	1606.754107	145
kissat_pre	3380.168998	288	1852.654662	143	1591.232273	145
ekissat-mab-db-v1	3402.947269	287	1888.587822	142	1611.862210	145
Kissat_MAB_MOSS	3404.378146	288	1967.836812	141	1532.218086	147
Kissat_MAB_UCB	3410.286408	287	1989.183907	140	1524.925658	147
kissat-mab-gb	3431.166946	285	2003.943832	139	1562.948653	146
Kissat_MAB_ESA	3446.109112	284	2058.191244	137	1544.232569	147
ekissat-mab-gb-db	3488.459816	283	2032.167165	139	1680.182765	144
ekissat-mab-db-v2	3525.053222	282	2216.387135	136	1580.344863	146
SeqFROST-ERE-All	3534.520771	282	1715.505564	144	2131.188435	138
kissat-sc2022-bulky	3575.940505	282	2443.728270	133	1471.825422	149
SeqFROST-NoExtend	3578.233229	280	1709.416537	144	2249.672946	136
CaDiCaL-watchesat-lto	3593.382356	279	2074.628066	138	1904.576535	141

The Results of SAT Competition 2023

A New Hope
... Strikes Back
The Return of ...

Tomáš Balyo, **Marijn J. H. Heule**, Markus Iser,
Matti Järvisalo, and Martin Suda

SAT 2023 Conference, Alghero (Italy)

July 7, 2023

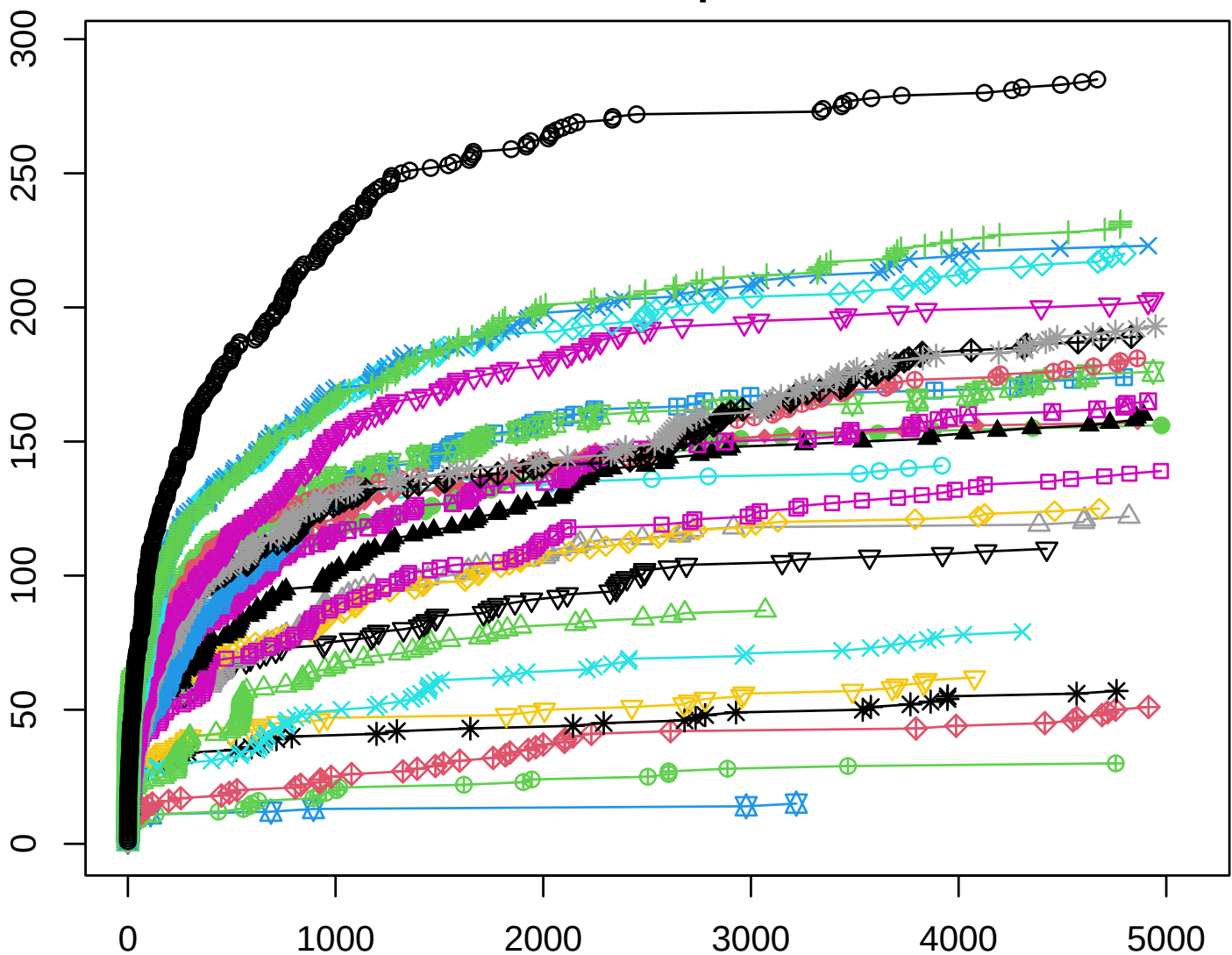
What happened in 2023 after POS'23?

- SAT competition 2023 with surprising results

CaDiCaL strikes back

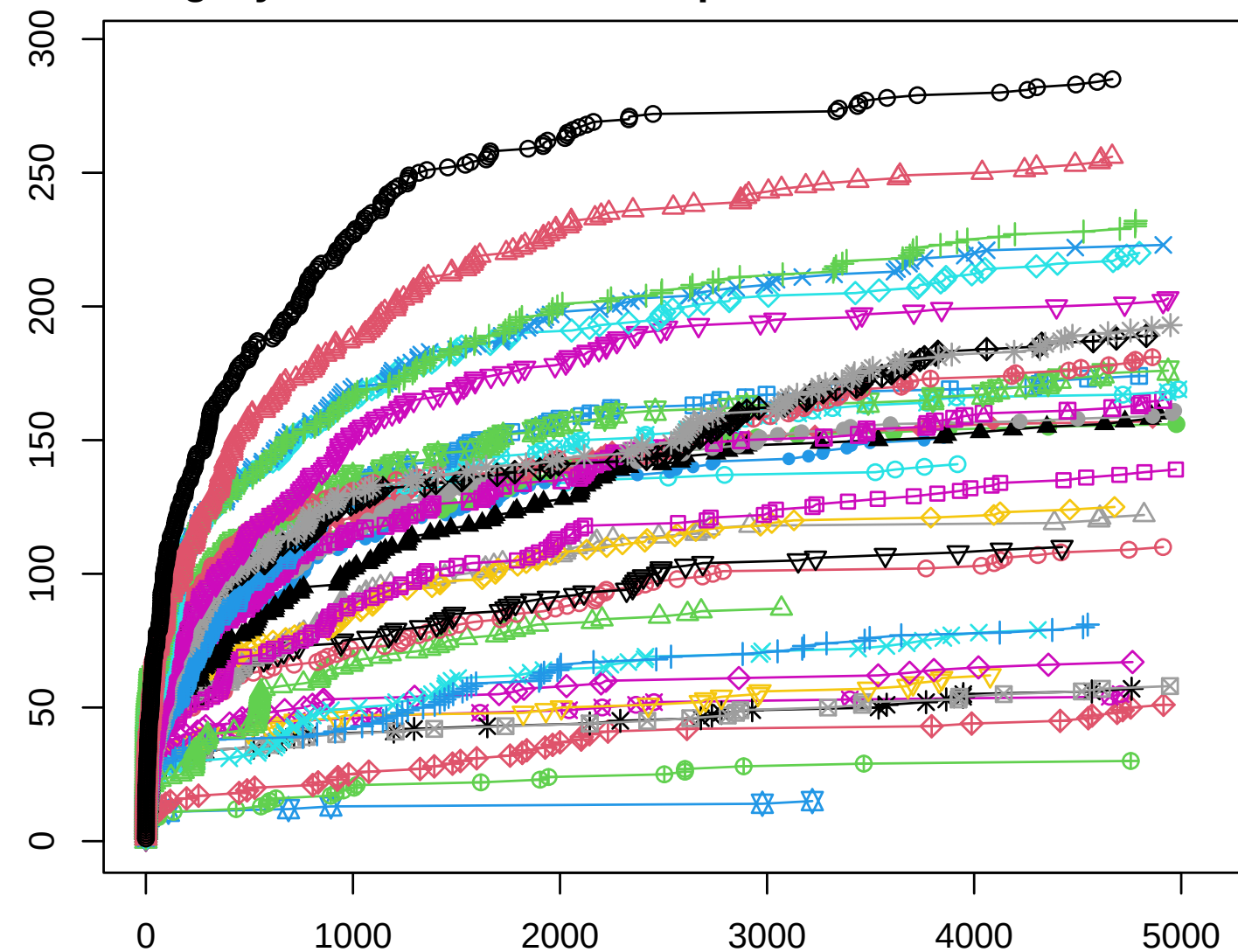
- tight race for the top with several solvers with “symmetry reasoning”
 - first of all efficiently and effectively, but also with proofs
- (but) new implementation of bounded variable elimination (BVA) won
[HaberlandtGreenHeule-SAT'23] better tie breaking than [MantheyHeuleBiere-HVC'11]
- teams arguably handed in benchmarks which benefit from these techniques
 - hard combinatorial benchmarks such as hash collision, pigeon holes, etc.
- do we see a large bias due to “bring your own benchmarks”?
and many teams betting on the same kind of benchmarks

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- × 223 kissat-mab-2021
- ◇ 220 kissat-2020
- ▽ 203 maple-lcm-disc-cb-dl-v3-2019
- * 193 maple-lcm-dist-2017
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- 181 maple-comsps-drup-2016
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- ⊞ 174 abcdsat-2015
- ⊡ 165 glucose-2011
- ▲ 160 cryptominisat-2010
- ◆ 158 lingeling-2013
- 156 glucose-2012
- 141 minisat-2008
- ⊡ 139 precosat-2009
- ◇ 125 minisat-2006
- △ 122 rsat-2007
- ▽ 110 satellite-gti-2005
- △ 87 chaff-2001
- × 79 limmat-2002
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- * 57 zchaff-2004
- ◇ 51 boehm1-1992
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Legacy Solvers on SAT Competition 2023 Benchmarks



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	solver	solved	sat	uns	fld	to	s11	s6	unk	time	space	max	best	uniq
	sbva-cadical-2023	285	123	162	115	115	0	0	0	176968	656226	25424	39	10
	cadical-2019	256	117	139	144	144	0	0	0	189859	265132	17856	36	0
	kissat-mab-hywalk-2022	232	106	126	168	168	0	0	0	197690	103423	7886	16	1
	kissat-mab-2021	223	101	122	177	177	0	0	0	164198	101178	7886	15	0
	kissat-2020	220	97	123	180	180	0	0	0	171279	100824	7738	18	1
	maple-lcm-disc-cb-dl-v3-2019	203	75	128	197	197	0	0	0	156011	175959	12430	10	0
	maple-lcm-dist-2017	193	69	124	207	207	0	0	0	219246	169869	12431	6	0
	maple-lcm-dist-cb-2018	189	65	124	211	211	0	0	0	207834	172320	12430	4	0
	maple-comsps-drup-2016	181	70	111	219	219	0	0	0	170938	151271	11211	18	0
	lingeling-2014	176	60	116	224	224	0	0	0	130314	125554	10584	21	0
	abcsat-2015	174	74	100	226	224	1	1	0	133485	139216	9693	7	0
	glucose-2016	169	68	101	231	231	0	0	0	126291	136950	10394	10	0
	glucose-2011	165	68	97	235	235	0	0	0	153415	114781	8026	13	0
	lingeling-2010	161	65	96	239	238	0	0	1	132551	96454	7630	14	0
	cryptominisat-2010	160	53	107	240	230	0	0	10	162231	126873	11493	14	0
	lingeling-2013	158	59	99	242	242	0	0	0	105440	123244	10427	16	0
	glucose-2012	156	63	93	244	244	0	0	0	115053	113506	8390	9	0
	lingeling-2011	151	68	83	249	247	0	0	2	114131	102526	8042	4	1
	minisat-2008	141	61	80	259	257	0	0	2	62599	130291	9176	22	0
	precosat-2009	139	51	88	261	261	0	0	0	149497	209108	17548	6	0
	minisat-2006	125	54	71	275	275	0	0	0	102875	93834	7192	11	0
	rsat-2007	122	55	67	278	277	0	0	0	94083	127765	10890	4	0
	satelite-gti-2005	110	48	62	290	290	0	0	0	89574	174206	14973	5	0
	minisat-2005	110	49	61	290	290	0	0	0	107882	24629	3534	10	0
	chaff-2001	87	41	46	313	313	0	0	0	57957	47125	5492	4	0
	siege-2003	81	32	49	319	257	0	0	62	93295	6289	282	9	0
	limmat-2002	79	41	38	321	295	1	25	0	83615	22088	2279	7	0
	picosat-2007	67	35	32	333	315	0	0	18	48671	6551	983	0	0
	berkmin-2003	62	26	36	338	301	0	0	37	52358	3553	801	3	0
	zchaff-2007	58	31	27	342	303	0	0	39	62240	5659	493	1	0
	zchaff-2004	57	30	27	343	304	0	0	39	57320	5446	493	0	0
	march-2011	55	20	35	345	343	0	0	2	30377	9818	3476	19	1
	boehm1-1992	51	17	34	349	346	3	0	0	78139	2381	202	3	0
	posit-1995	30	14	16	370	266	0	0	104	32163	305	40	0	0
	grasp-1997	15	13	2	385	385	0	0	0	7935	2059	537	1	0

Bounded Variable Elimination

[EénBiere-SAT'05]

$$\text{Replace } \begin{array}{l} (\bar{x} \vee a)_1 \\ (\bar{x} \vee b)_2 \\ (\bar{x} \vee c)_3 \end{array} \quad \begin{array}{l} (x \vee \bar{a} \vee \bar{b})_4 \\ (x \vee d)_5 \end{array} \quad \text{by} \quad \begin{array}{l} \cancel{(a \vee \bar{a} \vee \bar{b})}_{14} \\ \cancel{(b \vee \bar{a} \vee \bar{b})}_{24} \\ (c \vee \bar{a} \vee \bar{b})_{34} \end{array} \quad \begin{array}{l} (a \vee d)_{15} \\ (b \vee d)_{25} \\ (c \vee d)_{45} \end{array}$$

- number of clauses not increasing
- strengthen and remove subsumed clauses too
- most important and most effective preprocessing we have

Bounded Variable Addition

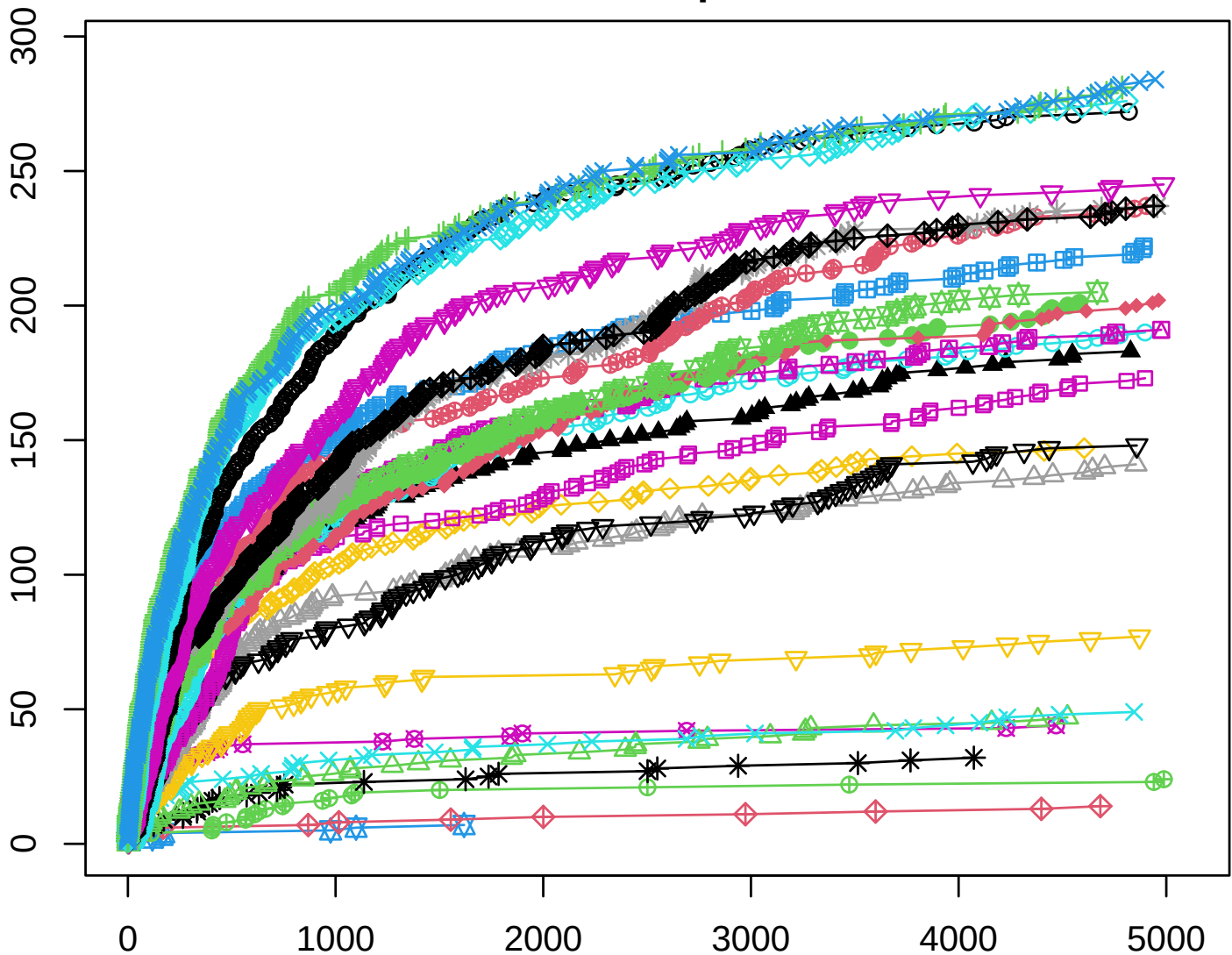
[MantheyHeuleBiere-HVC'12]

[HaberlandtGreenHeule-SAT'23]

$$\text{Replace } \begin{array}{l} (a \vee d) \\ (b \vee d) \\ (c \vee d) \end{array} \quad \begin{array}{l} (a \vee e) \\ (b \vee e) \\ (c \vee e) \end{array} \quad \text{by} \quad \begin{array}{l} (\bar{x} \vee a) \\ (x \vee d) \end{array} \quad \begin{array}{l} (\bar{x} \vee b) \\ (x \vee e) \end{array} \quad (\bar{x} \vee c)$$

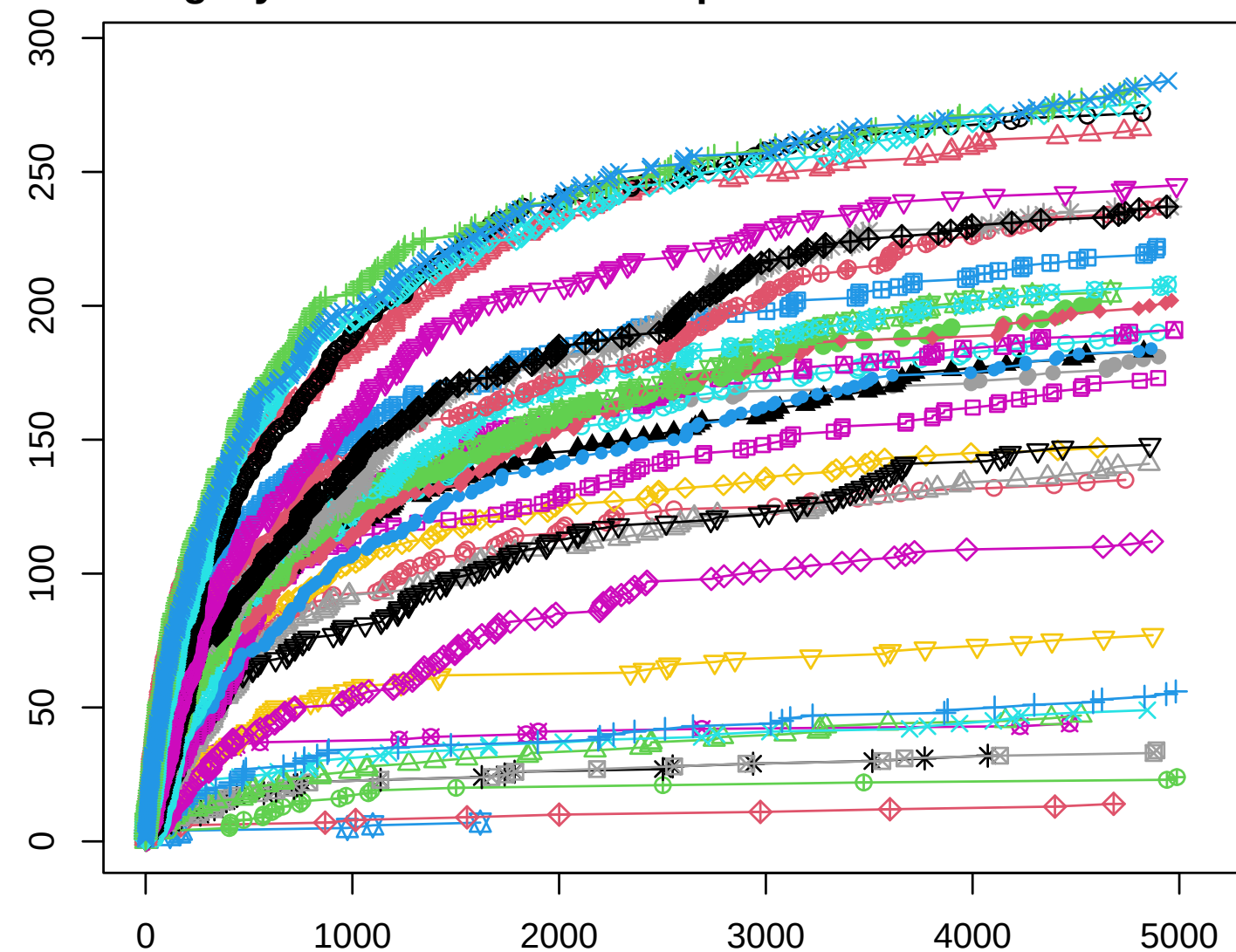
- number of clauses has to decrease strictly
- reencodes for instance naive at-most-one constraint encodings
- actually an interesting form of extended resolution

All Time Winners on SAT Competition 2022 Benchmarks



- × 284 kissat-mab-2021
- + 281 kissat-mab-hywalk-2022
- ◇ 276 kissat-2020
- 272 sbva-cadical-2023
- ▽ 245 maple-lcm-disc-cb-dl-v3-2019
- ◆ 237 maple-lcm-dist-cb-2018
- * 237 maple-lcm-dist-2017
- 237 maple-comsps-drup-2016
- 222 abcdsat-2015
- ☆ 205 lingeling-2014
- ◆ 202 lingeling-2013
- 201 glucose-2012
- 191 glucose-2011
- 190 minisat-2008
- ▲ 183 cryptominisat-2010
- 173 precosat-2009
- ▽ 148 satellite-gti-2005
- ◇ 147 minisat-2006
- △ 141 rsat-2007
- ▽ 77 berkmin-2003
- × 49 limmat-2002
- △ 47 chaff-2001
- 44 march-2011
- * 32 zchaff-2004
- 24 posit-1995
- ◆ 14 boehm1-1992
- × 7 grasp-1997

Legacy Solvers on SAT Competition 2022 Benchmarks

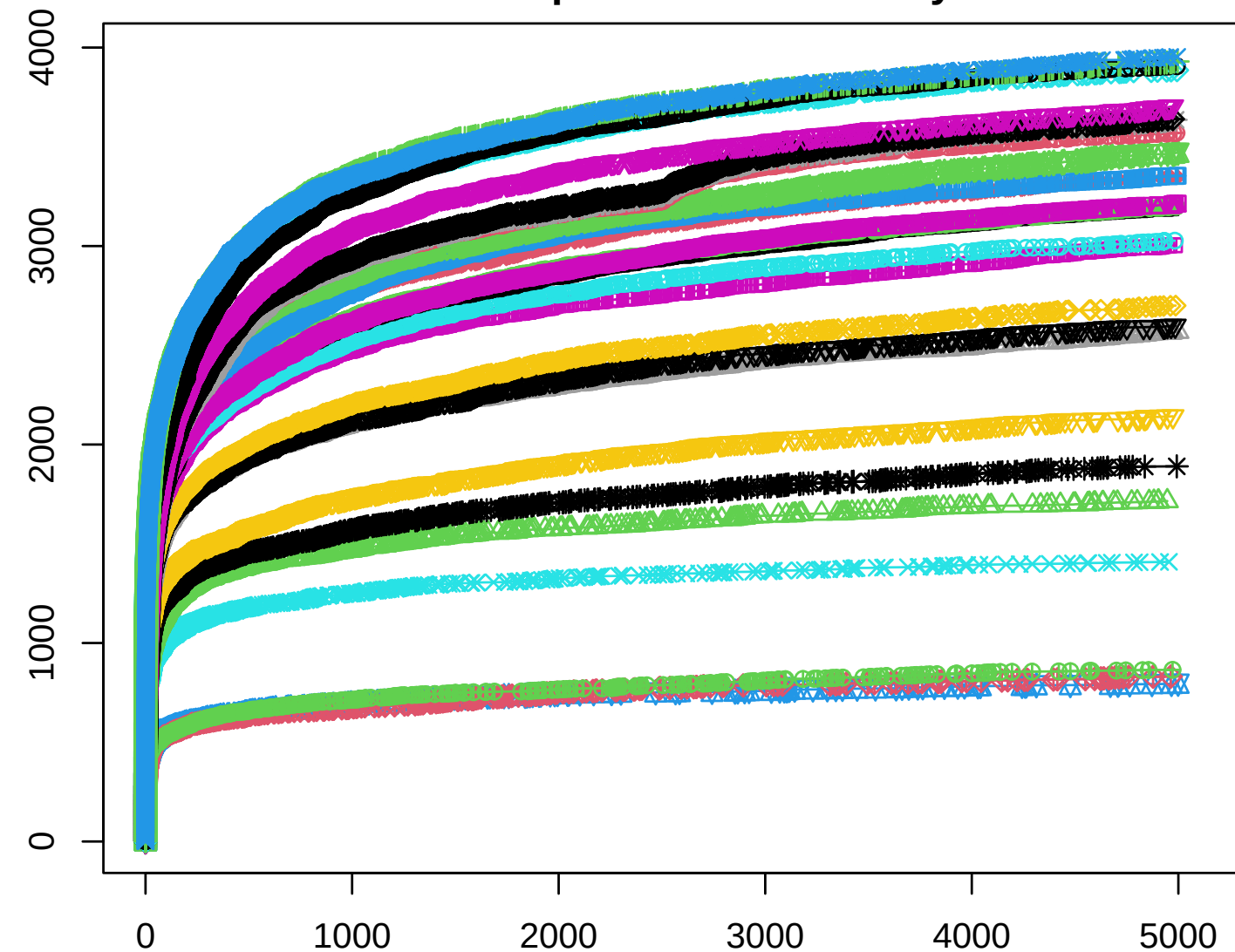


- × 284 kissat-mab-2021
- + 281 kissat-mab-hywalk-2022
- ◇ 276 kissat-2020
- 272 sbva-cadical-2023
- △ 266 cadical-2019
- ▽ 245 maple-lcm-disc-cb-dl-v3-2019
- ◆ 237 maple-lcm-dist-cb-2018
- * 237 maple-lcm-dist-2017
- 237 maple-comsps-drup-2016
- 222 abcdsat-2015
- ▣ 208 glucose-2016
- ▤ 205 lingeling-2014
- ◆ 202 lingeling-2013
- 201 glucose-2012
- ▣ 191 glucose-2011
- 190 minisat-2008
- 184 lingeling-2011
- ▲ 183 cryptominisat-2010
- 181 lingeling-2010
- ▣ 173 precosat-2009
- ▽ 148 satellite-gti-2005
- ◇ 147 minisat-2006
- △ 141 rsat-2007
- 135 minisat-2005
- ◇ 112 picosat-2007
- ▽ 77 berkmin-2003
- + 56 siege-2003
- × 49 limmat-2002
- △ 47 chaff-2001
- ▣ 44 march-2011
- ▣ 34 zchaff-2007
- * 32 zchaff-2004
- 24 posit-1995
- ◆ 14 boehm1-1992
- × 7 grasp-1997

Legacy Solvers — SAT Competition 2022

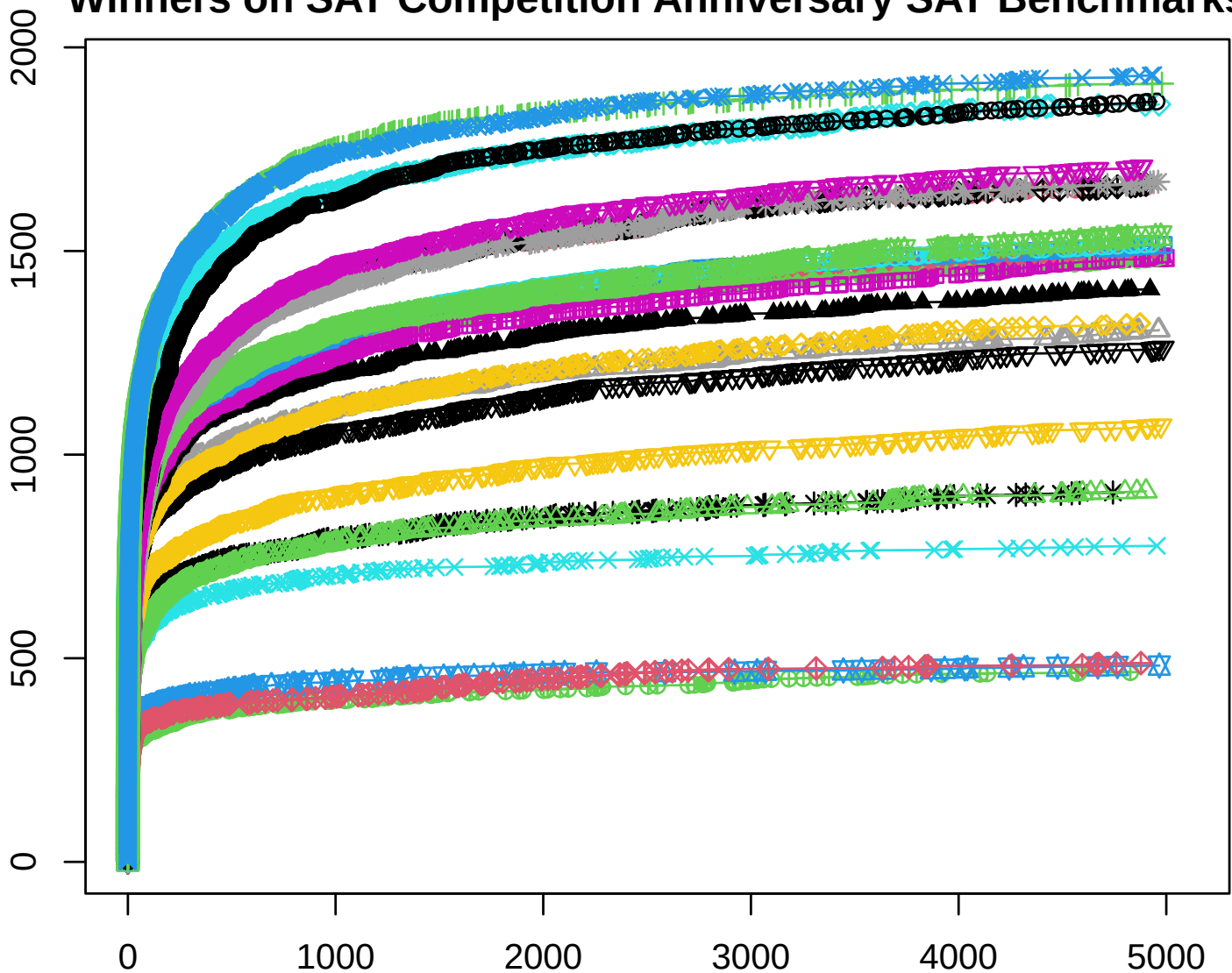
	solver	ok	sat	uns	fld	to	s11	s6	unk	time	space	max	best	uniq
	kissat-mab-2021	284	138	146	116	116	0	0	0	265782	150888	8560	23	0
	kissat-mab-hywalk-2022	281	141	140	119	119	0	0	0	243481	144848	5074	23	2
	kissat-2020	276	133	143	124	124	0	0	0	250172	140684	5800	29	3
	sbva-cadical-2023	272	139	133	128	128	0	0	0	237023	863369	40021	26	1
	cadical-2019	266	130	136	134	134	0	0	0	226275	338834	15287	36	1
	maple-lcm-disc-cb-dl-v3-2019	245	114	131	155	155	0	0	0	240050	252515	15342	3	0
	maple-lcm-dist-cb-2018	237	107	130	163	163	0	0	0	278238	241274	15342	14	1
	maple-lcm-dist-2017	237	109	128	163	157	6	0	0	282569	232392	15342	10	0
	maple-comsps-drup-2016	237	109	128	163	163	0	0	0	296217	254699	13707	27	0
	abcsat-2015	222	102	120	178	175	1	2	0	218955	160324	11921	17	0
	glucose-2016	208	93	115	192	192	0	0	0	220600	150531	11923	1	0
	lingeling-2014	205	98	107	195	195	0	0	0	229105	153486	6317	2	0
	lingeling-2013	202	86	116	198	198	0	0	0	249622	124551	6233	4	0
	glucose-2012	201	88	113	199	198	0	0	1	225987	112212	5424	8	0
	glucose-2011	191	85	106	209	209	0	0	0	189747	109528	7737	17	0
	minisat-2008	190	91	99	210	210	0	0	0	210046	194259	11139	12	0
	lingeling-2011	184	89	95	216	211	1	0	4	227743	92008	4111	5	0
	cryptominisat-2010	183	78	105	217	215	0	0	2	197523	209314	13620	8	0
	lingeling-2010	181	82	99	219	211	0	0	8	173349	98203	6965	2	0
	precosat-2009	173	85	88	227	226	0	0	1	211820	258453	21011	10	0
	satellite-gti-2005	148	72	76	252	252	0	0	0	191724	180730	18383	1	0
	minisat-2006	147	64	83	253	253	0	0	0	131637	100257	11749	4	0
	rsat-2007	141	68	73	259	259	0	0	0	164560	155831	18925	2	1
	minisat-2005	135	60	75	265	254	0	0	11	118366	110412	11838	6	0
	picosat-2007	112	57	55	288	273	0	0	15	146944	37585	3879	0	0
	berkmin-2003	77	36	41	323	304	0	0	19	77844	17913	4066	0	0
	siege-2003	56	42	14	344	242	0	0	102	82966	15819	3385	2	0
	limmat-2002	49	24	25	351	324	0	27	0	61160	119707	15146	7	0
	chaff-2001	47	26	21	353	353	0	0	0	63674	91987	20260	0	0
	march-2011	44	15	29	356	355	1	0	0	22220	14652	12284	17	0
	zchaff-2007	34	24	10	366	281	0	0	85	41662	9359	995	3	0
	zchaff-2004	32	23	9	368	283	0	0	85	32304	7984	875	0	0
	posit-1995	24	5	19	376	234	0	0	142	27943	830	270	1	0
	boehm1-1992	14	11	3	386	381	5	0	0	21429	38911	35939	0	0
	grasp-1997	7	6	1	393	393	0	0	0	4156	90404	83832	1	0

Winners on SAT Competition Anniversary Benchmarks



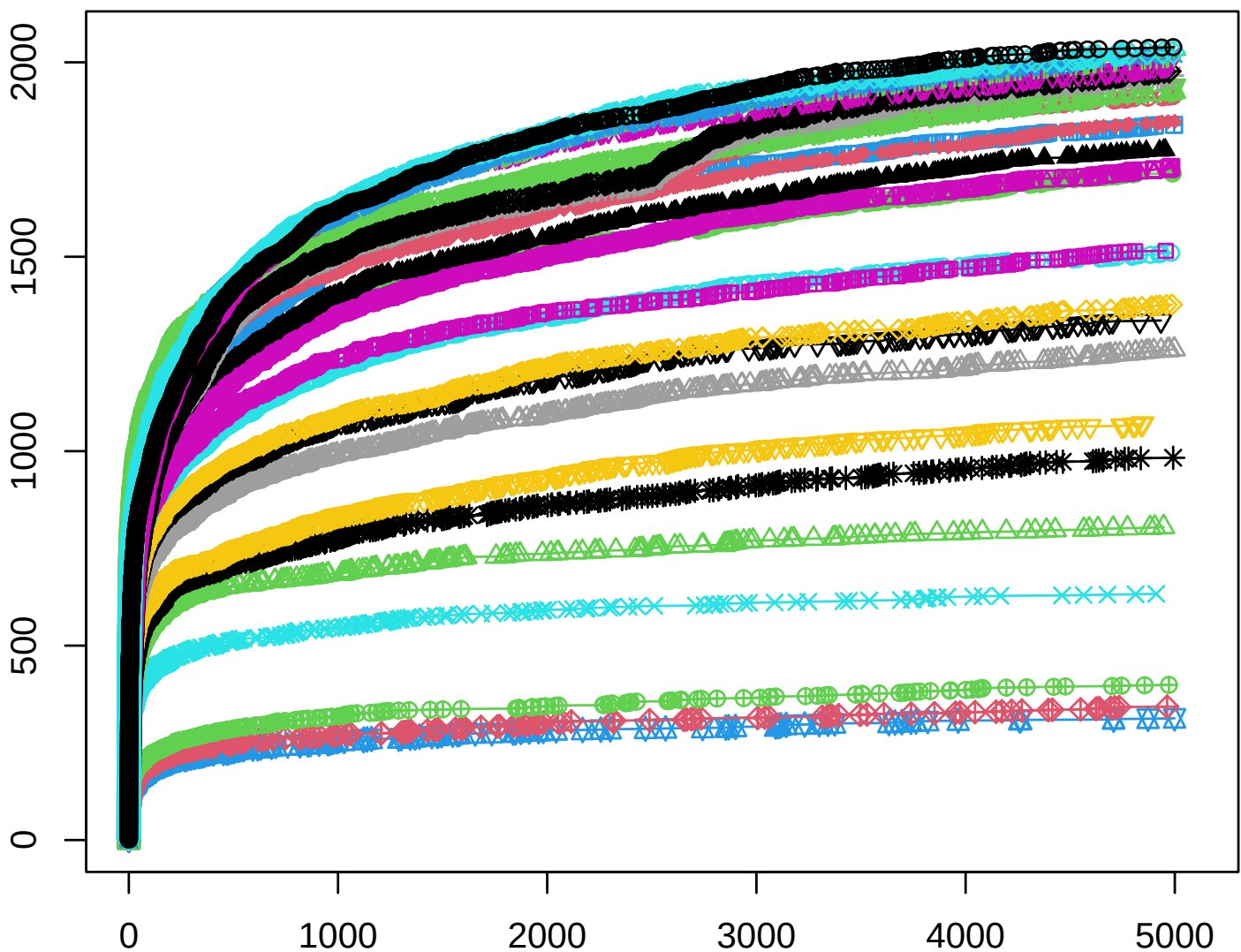
- × 3953 kissat-mab-2021
- + 3930 kissat-mab-hywalk-2022
- 3906 sbva-cadical-2023
- ◇ 3886 kissat-2020
- ▽ 3703 maple-lcm-disc-cb-dl-v3-2019
- ◆ 3640 maple-lcm-dist-cb-2018
- * 3636 maple-lcm-dist-2017
- ⊕ 3570 maple-comsps-drup-2016
- ⊗ 3470 lingeling-2014
- ⊠ 3354 abcdsat-2015
- ♦ 3347 lingeling-2013
- ⊞ 3214 glucose-2011
- 3199 glucose-2012
- ▲ 3181 cryptominisat-2010
- 3027 minisat-2008
- ⊞ 3004 precosat-2009
- ◇ 2700 minisat-2006
- ▽ 2598 satellite-gti-2005
- △ 2568 rsat-2007
- ▽ 2142 berkmin-2003
- * 1890 zchaff-2004
- △ 1715 chaff-2001
- × 1409 limmat-2002
- ⊕ 865 posit-1995
- ⊞ 831 boehm1-1992
- ⊠ 795 grasp-1997

Winners on SAT Competition Anniversary SAT Benchmarks



- × 1932 kissat-mab-2021
- + 1911 kissat-mab-hywalk-2022
- 1867 sbva-cadical-2023
- ◇ 1860 kissat-2020
- ▽ 1707 maple-lcm-disc-cb-dl-v3-2019
- * 1670 maple-lcm-dist-2017
- ◆ 1663 maple-lcm-dist-cb-2018
- ⊕ 1657 maple-comsps-drup-2016
- ⊗ 1538 lingeling-2014
- 1517 minisat-2008
- ⊠ 1515 abcdsat-2015
- ◆ 1499 lingeling-2013
- 1489 precosat-2009
- 1484 glucose-2012
- ⊠ 1483 glucose-2011
- ▲ 1406 cryptominisat-2010
- ◇ 1323 minisat-2006
- △ 1306 rsat-2007
- ▽ 1262 satellite-gti-2005
- ▽ 1071 berkmin-2003
- △ 910 chaff-2001
- * 907 zchaff-2004
- × 776 limmat-2002
- ⊕ 488 boehm1-1992
- ⊗ 482 grasp-1997
- ⊕ 466 posit-1995

Winners on SAT Competition Anniversary UNSAT Benchmarks

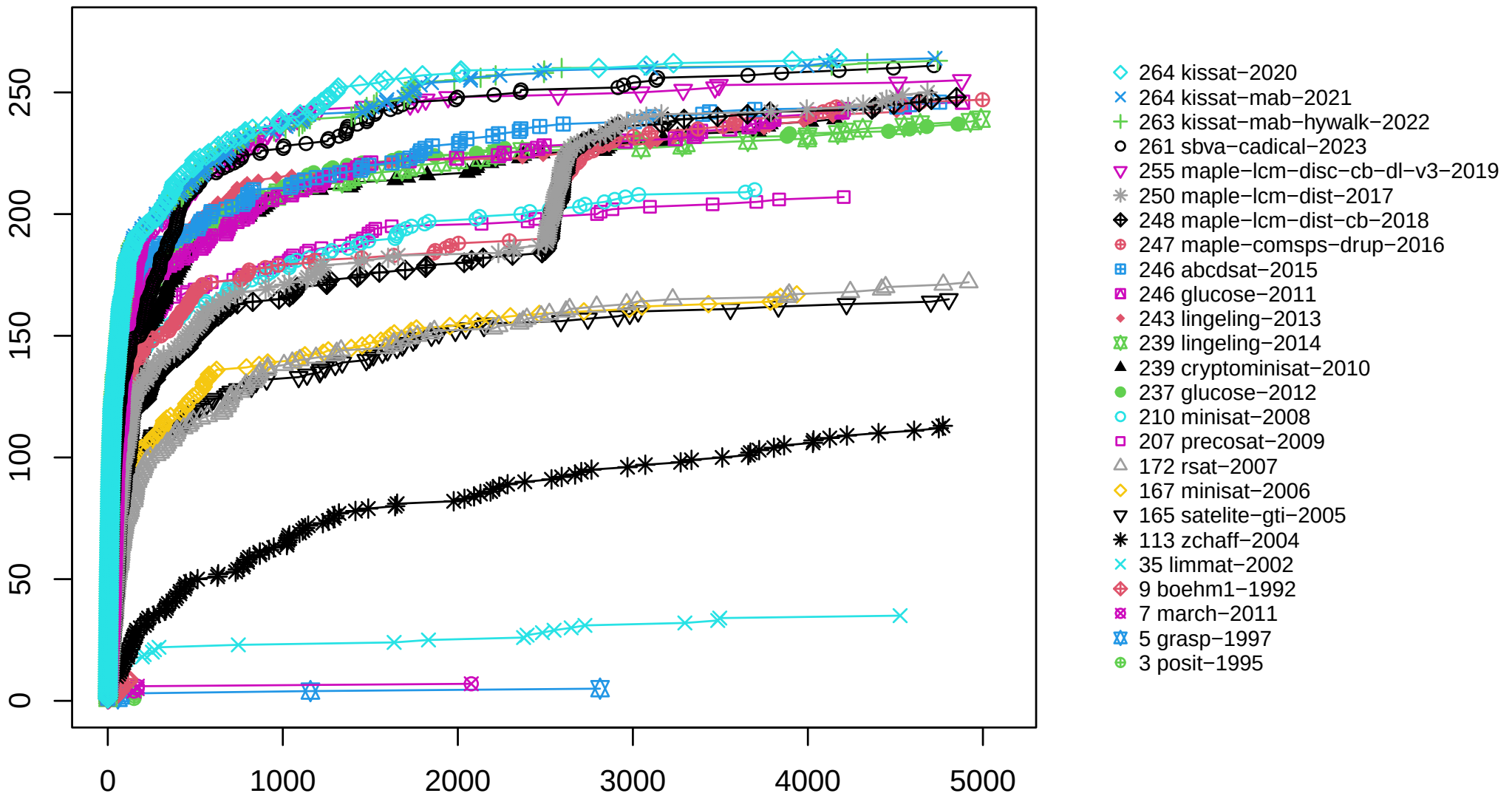


- 2039 sbva-cadical-2023
- ◇ 2026 kissat-2020
- × 2021 kissat-mab-2021
- + 2019 kissat-mab-hywalk-2022
- ▽ 1996 maple-lcm-disc-cb-dl-v3-2019
- ◆ 1977 maple-lcm-dist-cb-2018
- * 1966 maple-lcm-dist-2017
- ⋈ 1932 lingeling-2014
- ⊕ 1913 maple-comsps-drup-2016
- ♦ 1848 lingeling-2013
- ⊠ 1839 abcdsat-2015
- ▲ 1775 cryptominisat-2010
- ⊞ 1731 glucose-2011
- 1715 glucose-2012
- ◻ 1515 precosat-2009
- 1510 minisat-2008
- ◇ 1377 minisat-2006
- ▽ 1336 satellite-gti-2005
- △ 1262 rsat-2007
- ▽ 1071 berkmin-2003
- * 983 zchaff-2004
- △ 805 chaff-2001
- × 633 limmat-2002
- ⊕ 399 posit-1995
- ♦ 343 boehm1-1992
- ⊠ 313 grasp-1997

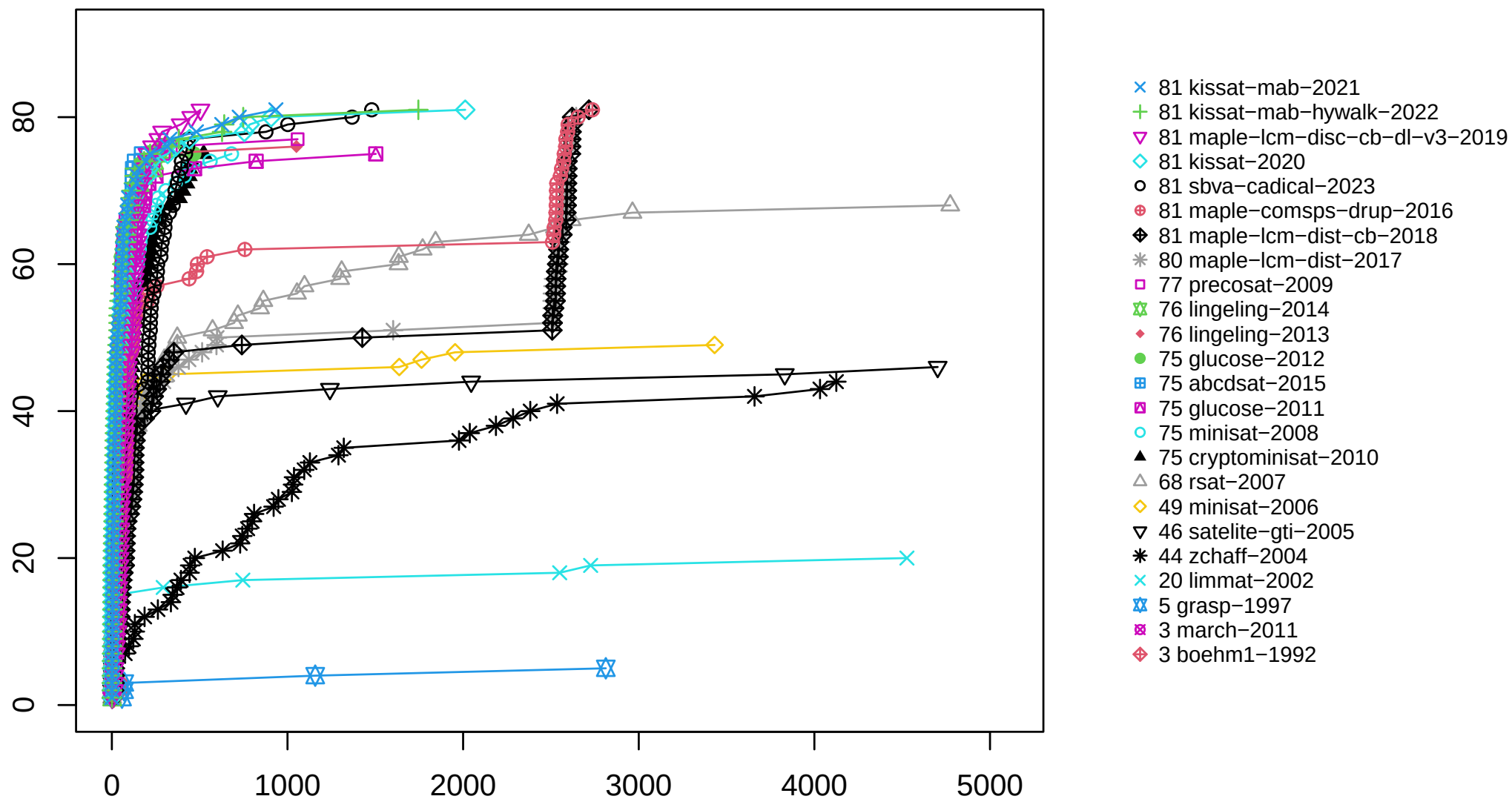
Winners & Legacy Solvers — Anniversary Track 2022

	solver	solved	ok	sat	uns	fld	to	s11	s6	unk	time	space	max	best	uniq
	kissat-mab-2021	5355	3953	1932	2021	1402	1402	0	0	0	1886768	406404	4560	541	1
	kissat-mab-hywalk-2022	5355	3930	1911	2019	1425	1425	0	0	0	1775006	394170	4575	560	9
	sbva-cadical-2023	5355	3906	1867	2039	1449	1449	0	0	0	2035326	4520049	56239	253	34
	kissat-2020	5355	3886	1860	2026	1469	1469	0	0	0	1843877	396874	5114	696	12
	cadical-2019	5355	3784	1833	1951	1571	1571	0	0	0	2055980	952138	15523	465	9
	maple-lcm-disc-cb-dl-v3-2019	5355	3703	1707	1996	1652	1652	0	0	0	2010562	921348	8922	184	5
	maple-lcm-dist-cb-2018	5355	3640	1663	1977	1715	1715	0	0	0	2194373	985951	15926	169	2
	maple-lcm-dist-2017	5355	3636	1670	1966	1719	1719	0	0	0	2250358	946213	14827	141	0
	maple-comsps-drup-2016	5355	3570	1657	1913	1785	1785	0	0	0	2023442	680829	8097	381	3
	lingeling-2014	5355	3470	1538	1932	1885	1885	0	0	0	1896595	460637	5250	308	32
	abcsat-2015	5355	3354	1515	1839	2001	1920	25	51	5	1733447	631787	8631	275	13
	lingeling-2013	5355	3347	1499	1848	2008	2006	0	0	2	1781063	454257	5234	290	4
	glucose-2011	5355	3214	1483	1731	2141	2141	0	0	0	1822397	534038	5969	171	2
	glucose-2012	5355	3199	1484	1715	2156	2155	0	0	1	1717315	534518	16696	208	0
	cryptominisat-2010	5355	3181	1406	1775	2174	2152	18	0	4	1777587	872932	8152	323	3
	minisat-2008	5355	3027	1517	1510	2328	2327	0	0	1	1531637	640045	10264	393	4
	precosat-2009	5355	3004	1489	1515	2351	2339	0	0	12	1675424	705878	16700	162	3
	minisat-2006	5355	2700	1323	1377	2655	2655	0	0	0	1500193	428616	10698	173	2
	satelite-gti-2005	5355	2598	1262	1336	2757	2757	0	0	0	1415601	501358	11756	80	1
	rsat-2007	5355	2568	1306	1262	2787	2787	0	0	0	1420626	584035	9673	30	0
	berkmin-2003	5355	2142	1071	1071	3213	3105	0	0	108	1215151	101164	3272	289	0
	zchaff-2004	5355	1890	907	983	3465	3230	0	0	235	952059	214999	1850	111	0
	chaff-2001	5355	1715	910	805	3640	3640	0	0	0	737517	359021	6075	113	0
	limmat-2002	5355	1409	776	633	3946	3617	0	329	0	485063	370990	8681	167	0
	posit-1995	5355	865	466	399	4490	3312	0	0	1178	468815	25690	2826	86	1
	boehm1-1992	5355	831	488	343	4524	4461	63	0	0	441046	22143	2391	149	5
	grasp-1997	5355	795	482	313	4560	4533	0	0	27	311569	246436	10636	69	0

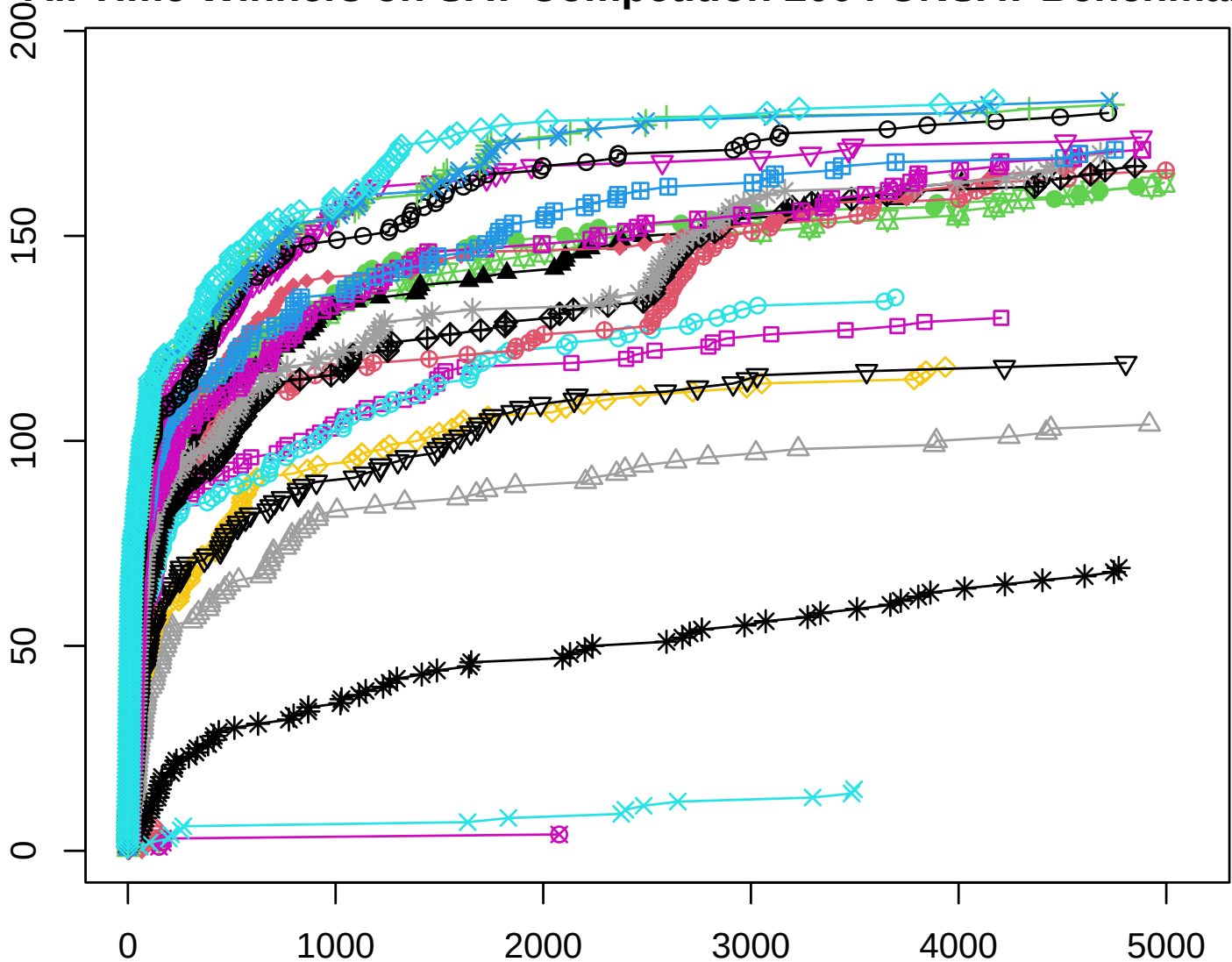
All Time Winners on SAT Competition 2004 Benchmarks



All Time Winners on SAT Competition 2004 SAT Benchmarks



All Time Winners on SAT Competition 2004 UNSAT Benchmarks



- ◇ 183 kissat-2020
- × 183 kissat-mab-2021
- + 182 kissat-mab-hywalk-2022
- 180 sbva-cadical-2023
- ▽ 174 maple-lcm-disc-cb-dl-v3-2019
- ▣ 171 abcdsat-2015
- ▣ 171 glucose-2011
- * 170 maple-lcm-dist-2017
- ◆ 167 lingeling-2013
- ◆ 167 maple-lcm-dist-cb-2018
- ⊕ 166 maple-comsps-drup-2016
- ▲ 164 cryptominisat-2010
- ⋈ 163 lingeling-2014
- 162 glucose-2012
- 135 minisat-2008
- ▣ 130 precosat-2009
- ▽ 119 satellite-gti-2005
- ◇ 118 minisat-2006
- △ 104 rsat-2007
- * 69 zchaff-2004
- × 15 limmat-2002
- ◆ 6 boehm1-1992
- ⊗ 4 march-2011
- ⊗ 3 posit-1995

Winners & Legacy Solvers — SAT Competition 2004

	solver	solved	sat	uns	fld	to	s11	s6	unk	time	space	max	best
	kissat-2020	264	81	183	60	60	0	0	0	75191	18465	556	50
	kissat-mab-2021	264	81	183	60	60	0	0	0	87769	18772	567	10
	kissat-mab-hywalk-2022	263	81	182	61	61	0	0	0	84277	17661	566	7
	sbva-cadical-2023	261	81	180	63	63	0	0	0	110245	261	1	25
	maple-lcm-disc-cb-dl-v3-2019	255	81	174	69	69	0	0	0	80546	41661	976	6
	cadical-2019	255	81	174	69	69	0	0	0	82649	52058	1512	20
	maple-lcm-dist-2017	250	80	170	74	70	0	0	4	234531	46386	1065	1
	maple-lcm-dist-cb-2018	248	81	167	76	76	0	0	0	240135	45183	1054	2
	maple-comsps-drup-2016	247	81	166	77	77	0	0	0	213356	39869	949	6
	abcdsat-2015	246	75	171	78	74	1	3	0	104889	48068	891	31
	glucose-2011	246	75	171	78	78	0	0	0	130584	738	3	12
	lingeling-2013	243	76	167	81	81	0	0	0	109644	24631	440	7
	glucose-2016	242	75	167	82	82	0	0	0	90814	35547	892	15
	lingeling-2014	239	76	163	85	85	0	0	0	110667	24205	387	2
	cryptominisat-2010	239	75	164	85	85	0	0	0	118264	62470	2001	3
	glucose-2012	237	75	162	87	87	0	0	0	88988	711	3	14
	lingeling-2010	224	77	147	100	100	0	0	0	90080	19525	419	5
	minisat-2008	210	75	135	114	114	0	0	0	89652	30065	770	8
	precosat-2009	207	77	130	117	117	0	0	0	77107	48002	1471	7
	picosat-2007	172	77	95	152	152	0	0	0	85781	13302	426	0
	rsat-2007	172	68	104	152	152	0	0	0	115798	191	2	0
	minisat-2006	167	49	118	157	153	0	0	4	82457	22838	942	5
	satelite-gti-2005	165	46	119	159	159	0	0	0	92584	165	1	2
	minisat-2005	163	51	112	161	156	0	0	5	118436	25692	4106	7
	siege-2003	131	52	79	193	178	0	0	15	122529	131	1	19
	zchaff-2004	113	44	69	211	208	0	0	3	144657	24406	500	0
	zchaff-2007	113	44	69	211	208	0	0	3	144829	24558	524	0
	limmat-2002	35	20	15	289	256	0	11	22	35744	18693	2633	1
	boehm1-1992	9	3	6	315	315	0	0	0	615	549	178	4
	march-2011	7	3	4	317	317	0	0	0	2596	351	123	0
	grasp-1997	5	5	0	319	319	0	0	0	4168	2010	427	0
	posit-1995	3	0	3	321	189	0	0	132	456	19	7	0

Related Work

- comparing SAT solvers for bit-vector solving [Duterte-SMT'20]
- incremental SAT for MaxSAT [KochemazovIgnatievMarques-Silva-SAT'21]
- SAT Heritage [AudemardPaulevéSimon-SAT'20]
- Hardware vs. Software progress in SAT solving [FichteHecherSzeider-CP'20]

We patched solvers to remove bugs / discrepancies and run them on the same platform on 7 years of competition benchmarks!

- we are missing some historic solvers: SATO, Satz, RelSAT, ...
- potential threats to validity that solvers are getting faster and faster

Threats to Validity

- authors stakeholders in the competition
 - either as organizers or submitters
 - showing that solvers improved serves their agenda
 - careful experiment on 7 years of competition benchmarks
- previous competition benchmark bias
 - solvers are trained on past competition benchmarks
 - running old solvers on new benchmarks
 - progress also on unseen benchmarks

Thanks go to ...

- Contributors to and supporters of the SAT competitions and POS workshops
majority of the SAT solvers is available through competition webpages
- Colleagues who helped us to resurrect solvers:
Jingchao Chen (abcdsat-2015); Eugene Goldberg, Yakov Novikov (berkmin-2003);
Lintao Zhang, Matthew Moskewicz, Sharad Malik (chaff-2001); Hans Kleine Büning,
Theodor Lettmann (boehm1-1992); João Marques-Silva (grasp-1997).
- Funding
 - Austrian Science Fund (FWF), NFN S11408-N23 (RiSE)
 - LIT AI Lab funded by the State of Upper Austria
- Karem Sakallah for his infinite patience in discussing progress in SAT solving
- Daniel Le Berre for coining the term “SAT Museum” in 2009
- organizers and participants of the POS’23 workshop at SAT’23 and ...
- ... the Shonan Seminar **The ART of SAT**

Conclusion

- SAT solvers improved tremendously in the last three decades
- empirically there are quantum leaps every 3-5 years
- features develop independently and excel when merged

SAT solvers do get Faster and Faster

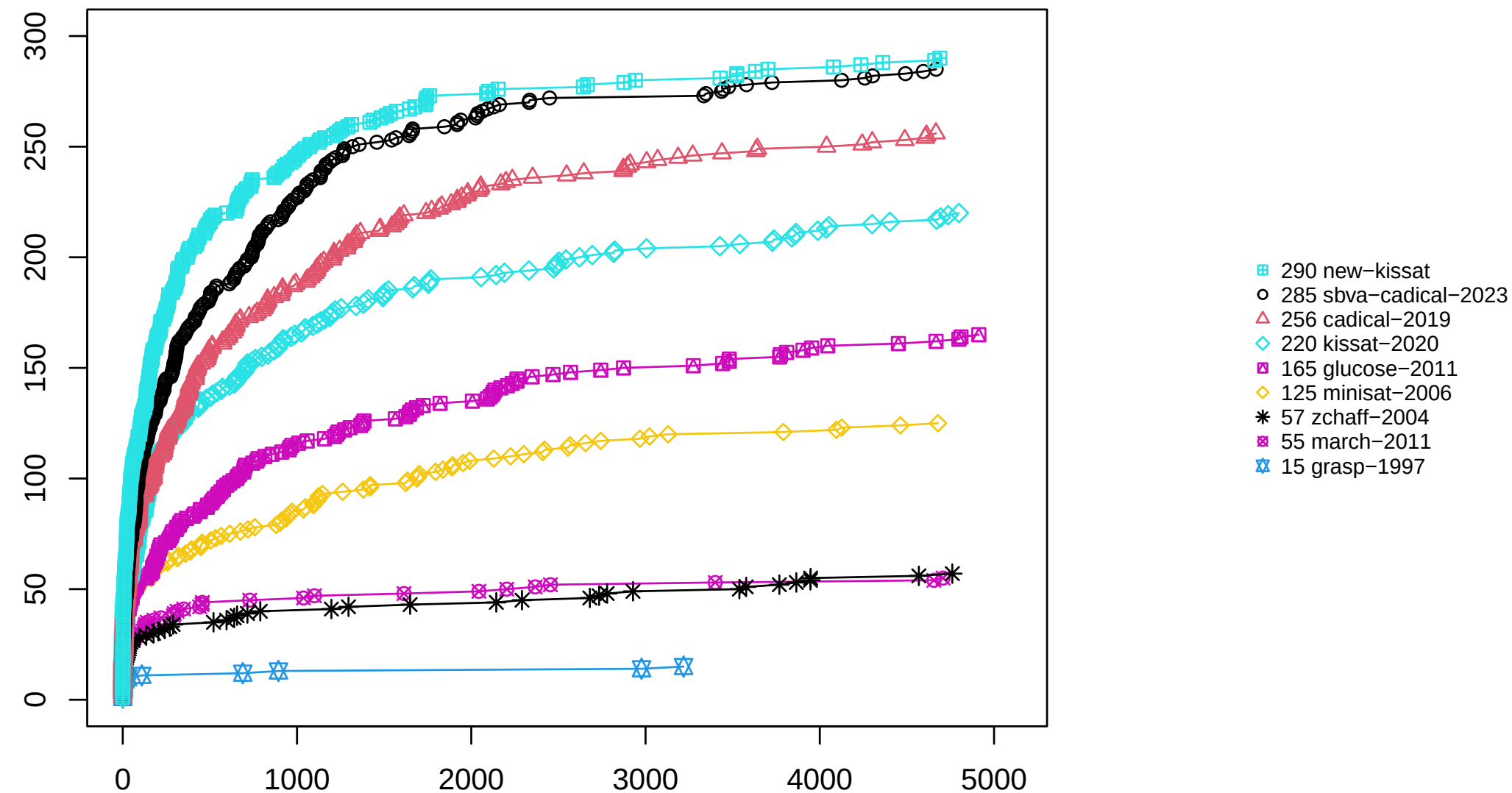
- partial understanding of the impact of solver features
- need to reassess their interaction and impact $\Rightarrow$ TabularaSAT
[with Karem, Mathias, Marijn, ...]
- what about improvement in other scenarios?
 - Model Checking (BMC, k -induction, IC3), MaxSAT, etc.
 - for backbones and SMT see our SAT'23 papers

[20??] Episode IV: A New Hope

[2023] Episode V: CaDiCaL strikes back

[2024] Episore VI: The Return of the ???

Some Solvers on SAT Competition 2023 Benchmarks



Some Solvers on SAT Competition 2022 Benchmarks

