

Herbrand Award Talk



Armin Biere

universität freiburg

International Joint Conference on Automated Reasoning

IJCAR'2024

July 4, 2024, Nancy, France

Dean back at JKU asked for a slide what I am doing ...



Grid Print Copy Paste Undo Redo Find Text Color Background Color Align Sort Filter Zoom Help

Arial

12 pt

B

I

U

T

C32

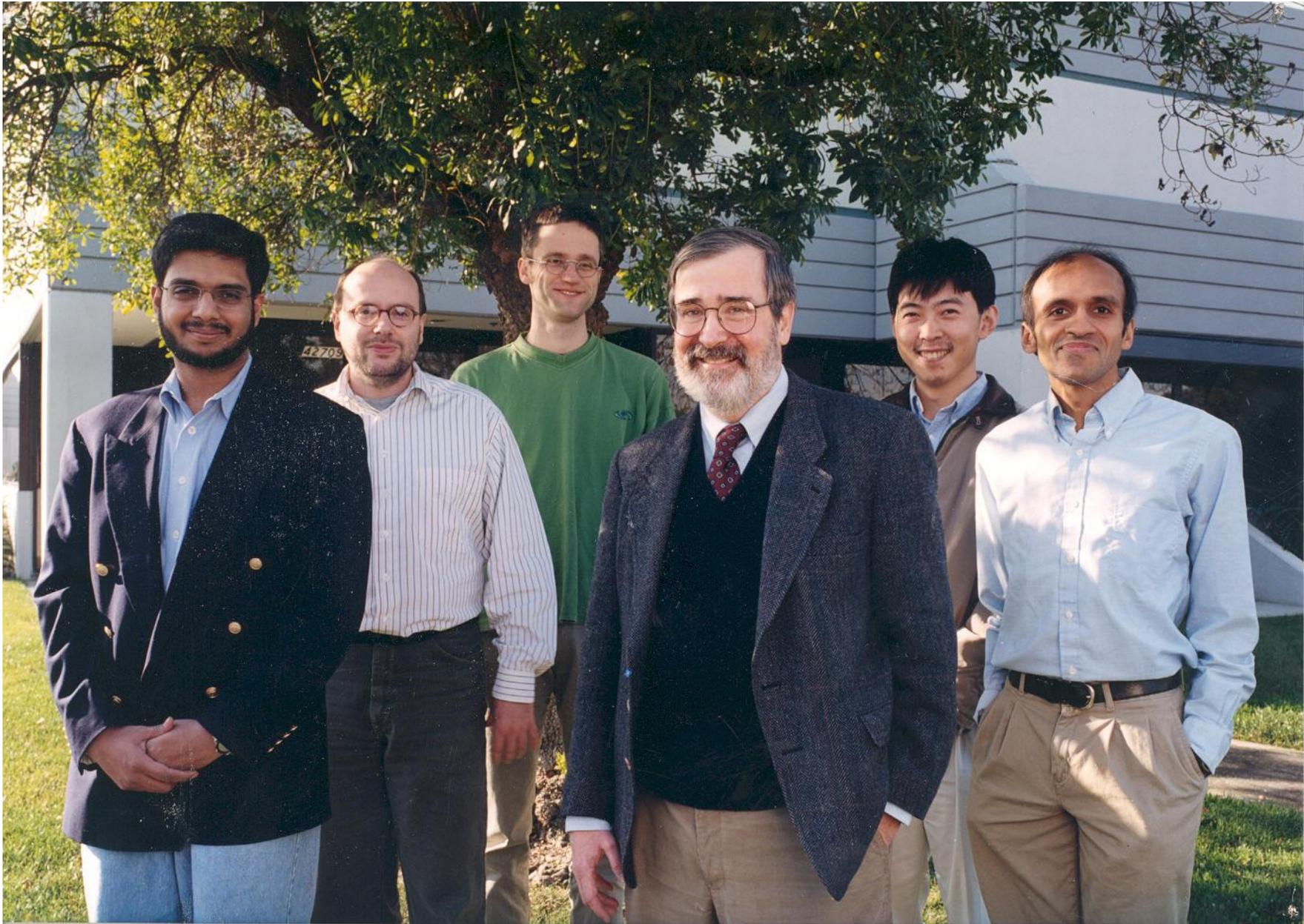
f_x Σ = =SUM(C1:C31)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	MEDALS	SAT'23	2	1		MEDALS	SAT'23		2						
2	MEDALS	SAT'22	4	1		MEDALS	SAT'22	4	1						
3	MEDALS	SAT'21	2	0		MEDALS	SAT'21	2	0						
4	MEDALS	SAT'20	7	3		MEDALS	SAT'20	7	3						
5	MEDALS	SAT'19	2	1		MEDALS	SAT'19	2	1						
6	MEDALS	SMT'19	10	7											
7	MEDALS	SAT'18	4	2		MEDALS	SAT'18	4	2						
8	MEDALS	SMT'18	6	5											
9	MEDALS	SAT'17	4	2		MEDALS	SAT'17	4	2						
10	MEDALS	SMT'17	6	3											
11	MEDALS	SAT'16	4	1		MEDALS	SAT'16	4	1						
12	MEDALS	SMT'16	3	3											
13	MEDALS	SAT'15	3	0		MEDALS	SAT'15	3	0						
14	MEDALS	SMT'15	3	3											
15	MEDALS	SMT'14	2	2		MEDALS	SMT'14								
16	MEDALS	SAT'14	9	4											
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18	MEDALS	SAT'13	7	4		MEDALS	SAT'13	7	4						
19	MEDALS	CFG'13	3	1		MEDALS	CFG'13	3	1						
20	MEDALS	SAT'12	1	0		MEDALS	SAT'12	1	0						
21	MEDALS	SMT'12	2	2											
22	MEDALS	SMT'11	2	1											
23	MEDALS	SAT'11	2	1		MEDALS	SAT'11	2	1						
24	MEDALS	QBF'10	1	1											
25	MEDALS	SAT'10	2	1		MEDALS	SAT'10	2	1						
26	MEDALS	SMT'09	2	1											
27	MEDALS	SAT'09	3	1		MEDALS	SAT'09	3	1						
28	MEDALS	SMT'08	2	2											
29	MEDALS	QBF'08	1	1											
30	MEDALS	SAT'07	2	1		MEDALS	SAT'07	2	1						
31	MEDALS	SAT'02	1	1		MEDALS	SAT'02	1	1						
32			104	57				53	23						
33															
34															

My Journey from CADE to CAV and SAT to IJCAR!

- CAV in the 90ies was the “new kid on the block”
- Symbolic Model Checking with BDDs [Clarke..., McMillan] at CMU
 - Binary Decision Diagrams [Bryant] saved the day
 - renaissance of formal methods / automated reasoning
 - from the theory perspective: boring finite systems (10^{20} states)
 - was the first to do **model checking** in the group (of *Deussen*, Karlsruhe)
Institut für Logik, Komplexität und Deduktionssysteme
- 1997 PhD on BDD based μ -calculus model checking *μcke* in C++
 - first paper at CAV’97 in Haifa (looking for Post-Doc opportunities)
 - invited talk by Arne Borälv on Stålmarch’s Method
 - Post-Doc with Ed Clarke at CMU, i.e., BMC
 - got into SAT afterwards at ETH and Linz *reluctantly and sceptically*
- 25 years later FLOCC’22 in Haifa
 - with SAT + IJCAR + CP + CAV: *Shankar* presenting the Herbrand Award
- Herbrand Award on SAT Applications and contributions in SAT at IJCAR’24

Verysys Design Automation



Symbolic model checking without BDDs

Authors Armin Biere, Alessandro Cimatti, Edmund Clarke, Yunshan Zhu

Publication date 1999

Conference Tools and Algorithms for the Construction and Analysis of Systems: 5th International Conference, TACAS'99 Held as Part of the Joint European Conferences on Theory and Practice of Software, ETAPS'99 Amsterdam, The Netherlands, March 22–28, 1999 Proceedings 5

Pages 193-207

Publisher Springer Berlin Heidelberg

Description Symbolic Model Checking [3], [14] has proven to be a powerful technique for the verification of reactive systems. BDDs [2] have traditionally been used as a symbolic representation of the system. In this paper we show how boolean decision procedures, like Stålmarck's Method [16] or the Davis & Putnam Procedure [7], can replace BDDs. This new technique avoids the space blow up of BDDs, generates counterexamples much faster, and sometimes speeds up the verification. In addition, it produces counterexamples of minimal length. We introduce a *bounded model checking* procedure for LTL which reduces model checking to propositional satisfiability. We show that bounded LTL model checking can be done without a tableau construction. We have implemented a model checker BMC, based on bounded model checking, and preliminary results are presented.

Total citations [Cited by 3431](#)

TACAS'14 Most Influential Paper in 25 Years of TACAS





ETAPS Test of Time Award 2017
was awarded to

*Armin Biere, Alessandro Cimatti,
Edmund M. Clarke and Yunshan Zhu*

for their ground-breaking TACAS 1999 paper
Symbolic model-checking without BDDs

ETAPS 2017 Uppsala, Sweden April 24 - 28, 2017





CAV 2018 Award

SAT-based and Bounded Model Checking

- Armin Biere
- Alessandro Cimatti
- Edmund M. Clarke
- Daniel Kroening
- Flavio Lerda
- Yunshan Zhu

Short Citation

For their outstanding contribution to the enhancement and scalability of model checking by introducing Bounded Model Checking based on Boolean Satisfiability (SAT) for hardware (BMC) and software (CBMC).



Symbolic model checking using SAT procedures instead of BDDs

Authors Armin Biere, Alessandro Cimatti, Edmund M Clarke, Masahiro Fujita, Yunshan Zhu

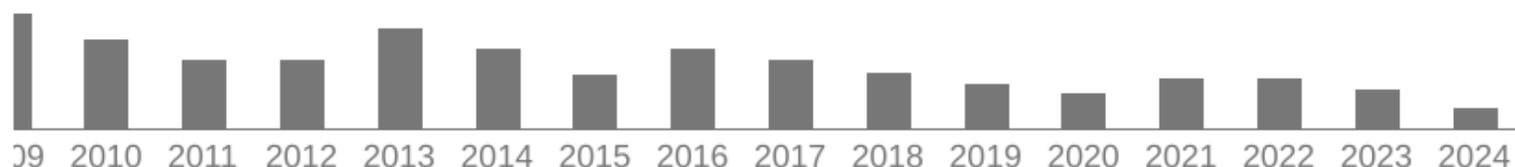
Publication date 1999/6/1

Book Proceedings of the 36th annual ACM/IEEE Design Automation Conference

Pages 317-320

Description In this paper, we study the application of propositional decision procedures in hardware verification. In particular, we apply bounded model checking, as introduced in [1], to equivalence and invariant checking. We present several optimizations that reduce the size of generated propositional formulas. In many instances, our SAT-based approach can significantly outperform BDD-based approaches. We observe that SAT-based techniques are particularly efficient in detecting errors in both combinational and sequential designs.

Total citations [Cited by 1064](#)

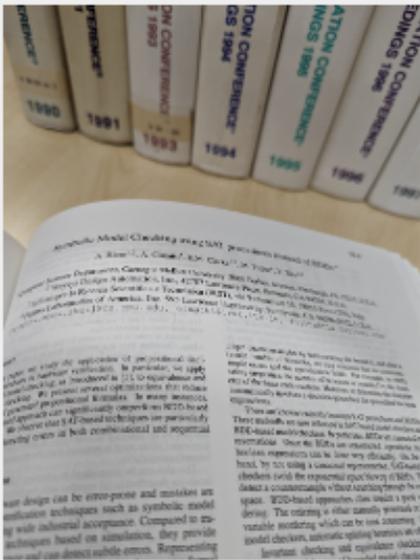
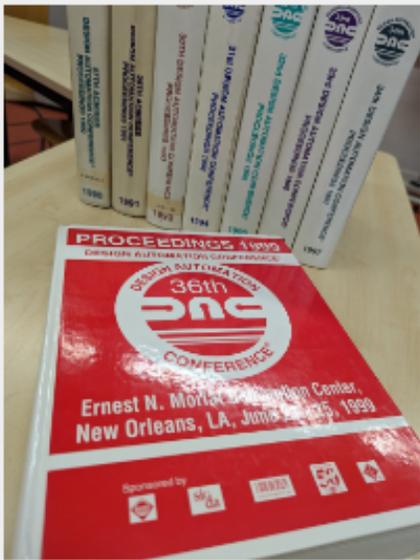
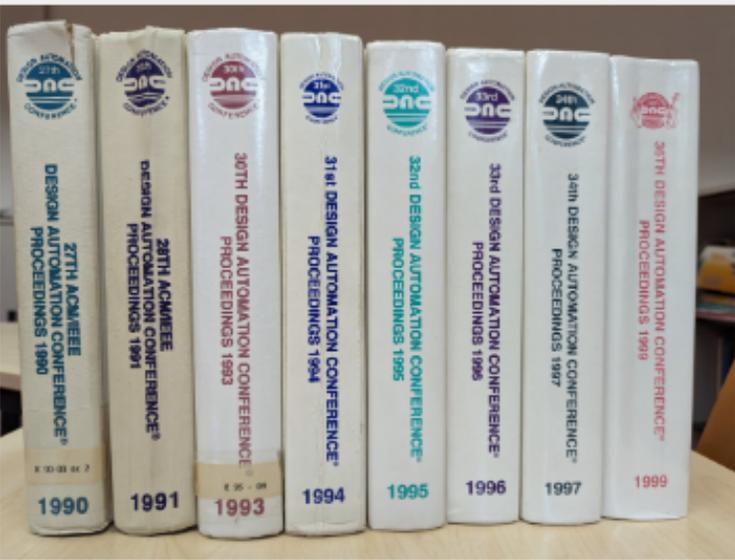


At 60th DAC'23 Most Impact Award (MIP) 1990ies DAC paper

1990s: DAC Most Influential Paper (MIP) Award

```
procedure best-to-cl(f, v)  
  case  
    cached(f, v)  
      return classify == v;  
    memoized(f)  
      return classify == v;  
    f := k.g.  
    C1 := best-to-cl(f, v1);  
    C2 := best-to-cl(f, v2);  
    assert cached(f, v1);  
    return classify == (v1 == v2) ? C1 : C2;  
  end
```

"Symbolic Model Checking Using SAT Procedures Instead of BDDs"
by A. Biere, A. Cimatti, E.M. Clarke, M. Fujita, Y. Zhu, 36th DAC, 1999.



2024 DAC MOST INFLUENTIAL PAPER (MIP) AWARD WINNERS

2000's "Chaff: Engineering an Efficient SAT Solver" by Matthew W. Moskewicz, Conor F. Madigan, Ying Zhao, Lintao Zhang, and Sharad Malik, 2001.

2023 DAC MOST INFLUENTIAL PAPER (MIP) AWARD WINNERS

1960s "Sketch pad a man-machine graphical communication system" by Ivan E. Sutherland, 1964.

1970s "A logic design structure for LSI testability" by E.B. Eichelberger, T.W. Williams, 14th DAC, 1977.

1980s "Dagon: technology binding and local optimization by DAG matching" by K. Keutzer, 24th DAC, 1987.

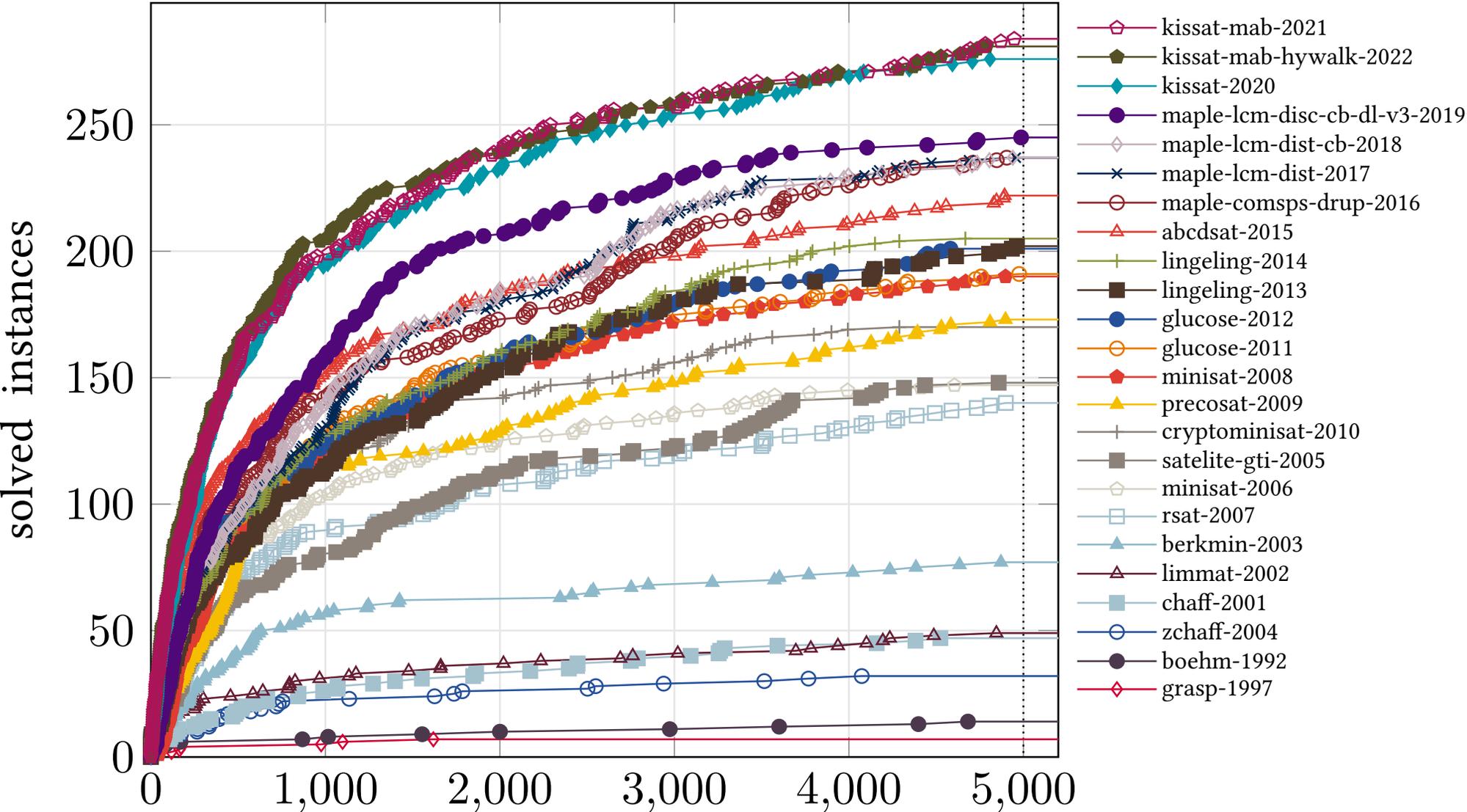
1990s "Symbolic Model Checking Using SAT Procedures Instead of BDDs" by A. Biere, A. Cimatti, E.M. Clarke, M. Fujita, Y. Zhu, 36th DAC, 1999.

My **SAT**, **QBF** and **SMT** Solvers

- QDDP 1998 at CMU
- DoISAT 1999 at Verysys
- Limmat 2000 - 2002 ETH
- CompSAT 2002 - 2005 ETH / JKU
- FunEx 2002 - 2004 ETH
- Quantor 2003 - 2004 ETH, **QBF**
- NanoSAT 2003 - 2004 ETH
- eBDDRes 2005 - 2007 JKU, BDD
- BooleForce 2005 - 2006 JKU
- PicoSAT 2006 (JSAT'08)
2012 (Knuth comments)
- Boolector 2008 - 2019 JKU, **SMT**
- PrecoSAT 2009 JKU in C++
- Lingeling, Plingeling, Treengeling
2010 - 2018 in C
- Cleaneling 2012 (Summer School)
- YaISAT 2014 JKU Local-Search
- Splatz 2015-2016 JKU
- **CaDiCaL** 2016 (Fields) JKU in C++
inc++ 2024 UFR V 2.0.0 (CAV'24)
- **Kissat** 2019 - 2024 JKU / UFR in C
- Satch 2021 JKU (Simons) JKU
- TabularaSAT 2022-2024 UFR
- Gimsatul 2022 - 2024 UFR

and many more I started but at the end did not see the light of the day

SAT Competition All Time Winners on SAT Competition 2022 Benchmarks



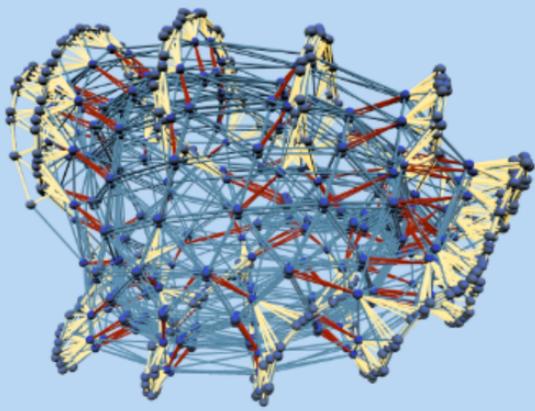
time in seconds

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.

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

[paper - bibtex - data - zenodo - ceur - workshop - proceedings]



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

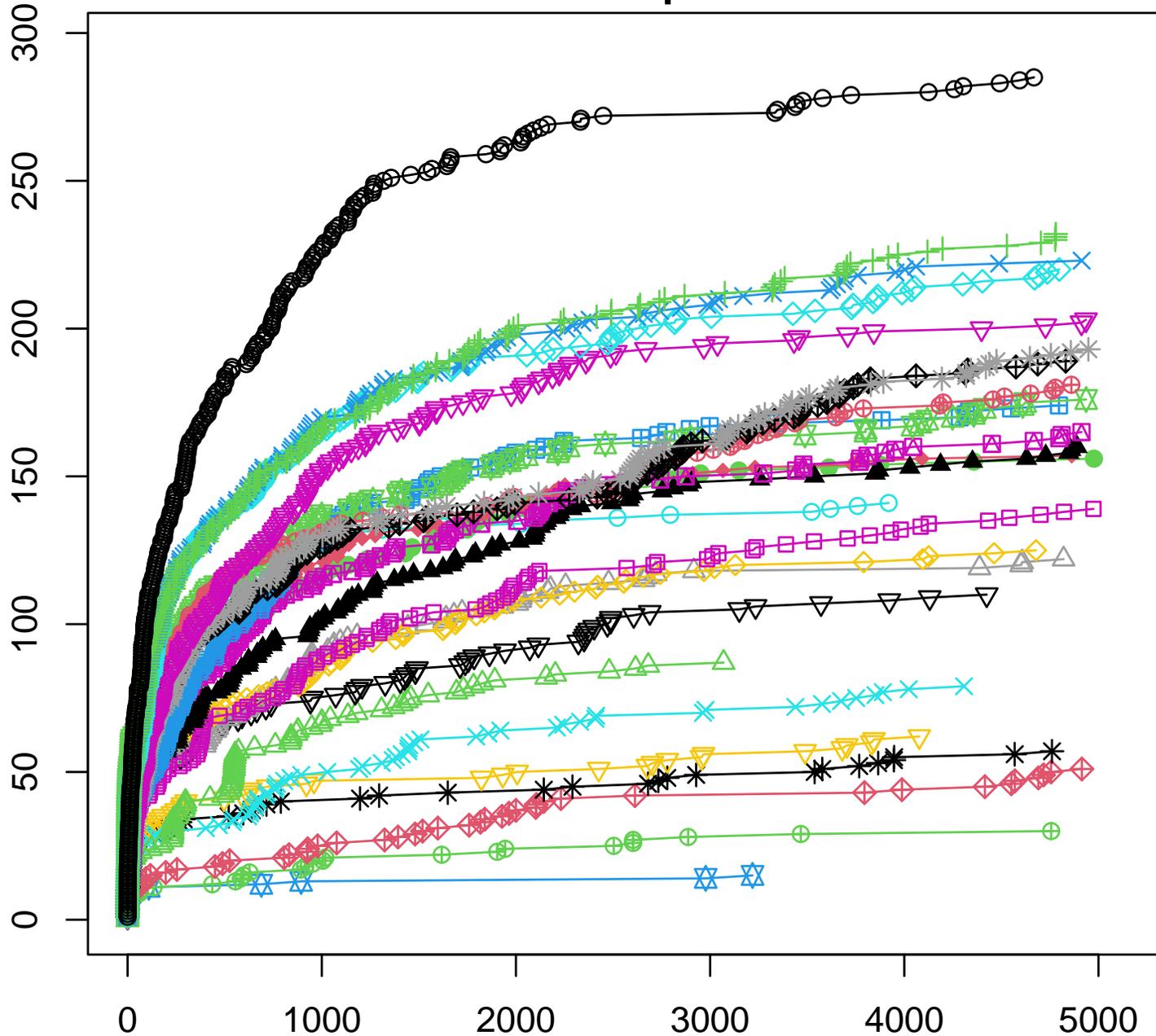
A New Hope
... Strikes Back
The Return of ...

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

SAT 2023 Conference, Alghero (Italy)

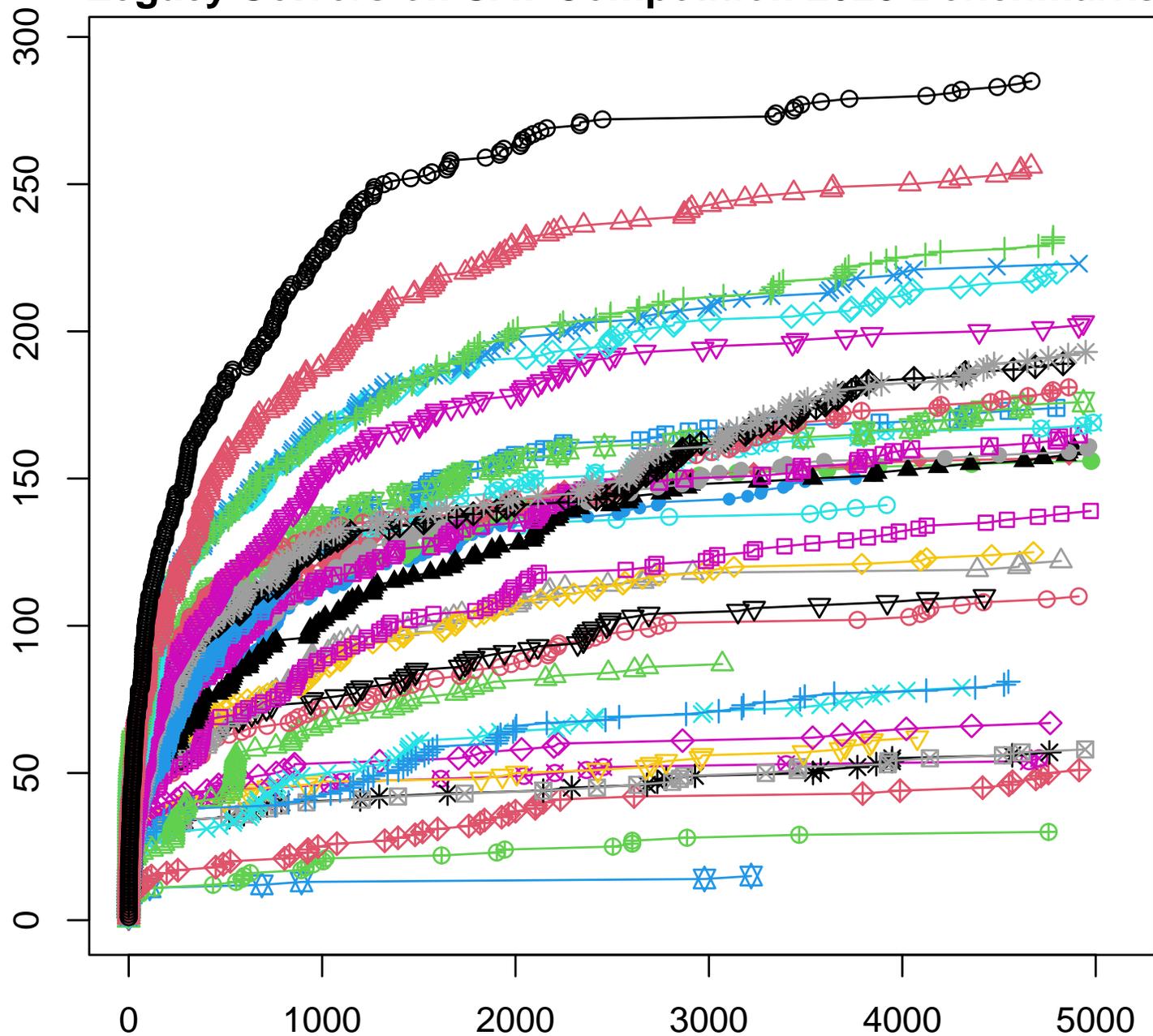
July 7, 2023

All Time Winners on SAT Competition 2023 Benchmarks



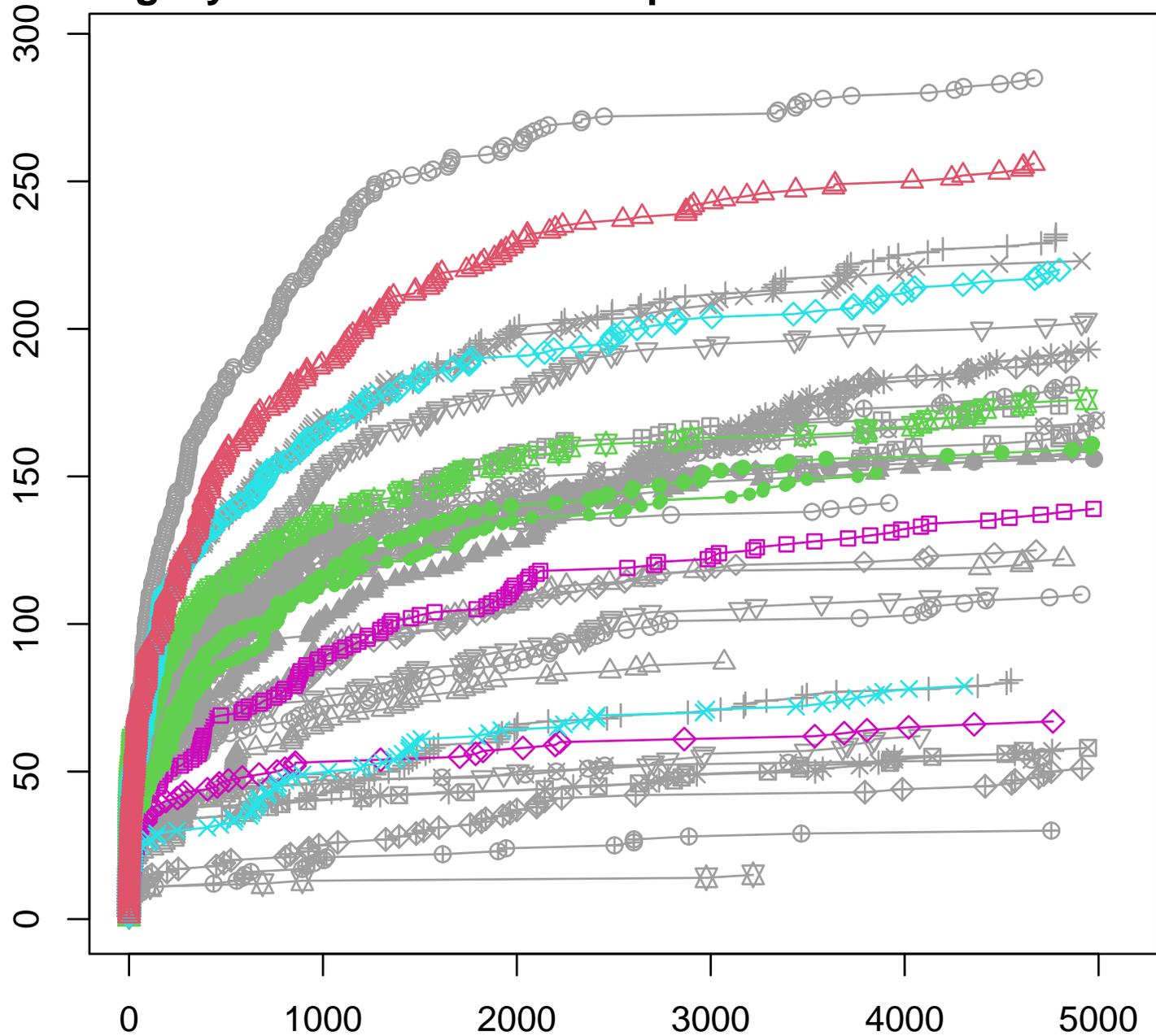
- sbva-cadical-2023
- + kissat-mab-hywalk-2022
- × kissat-mab-2021
- ◇ kissat-2020
- ▽ maple-lcm-disc-cb-dl-v3-2019
- * maple-lcm-dist-2017
- ◆ maple-lcm-dist-cb-2018
- ⊕ maple-comsps-drup-2016
- ⊗ lingeling-2014
- ⊠ abcdsat-2015
- ⊡ glucose-2011
- ▲ cryptominisat-2010
- ◆ lingeling-2013
- glucose-2012
- minisat-2008
- precosat-2009
- ◇ minisat-2006
- △ rsat-2007
- ▽ satelite-gti-2005
- △ chaff-2001
- × limmat-2002
- ▽ berkmin-2003
- * zchaff-2004
- ◇ boehm1-1992
- ⊕ posit-1995
- ⊗ grasp-1997

Legacy Solvers on SAT Competition 2023 Benchmarks



- sbva-cadical-2023
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- ◇ minisat-2006
- △ rsat-2007
- ▽ satellite-gti-2005
- minisat-2005
- △ chaff-2001
- + siege-2003
- × limmat-2002
- ◇ picosat-2007
- ▽ berkmin-2003
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Legacy Solvers on SAT Competition 2023 Benchmarks



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- ⊗ grasp-1997

Lessons under a Survivor Bias

- “Recommendations” I did **NOT** follow:
 - “You will not succeed (earn a PhD) if you continue programming!”
 - “We all know that SAT does not work, so why bother?”
- “Recommendations” I do follow:
 - “You only understand an algorithm after you have implemented it!”
 - review, review and review again
 - until one round went through without any changes
- My “Recommendations”
 - classification (problem complexity) results can be useful
 - do not take classification results too serious
 - EXPSpace approximation of PSPACE hard problem using an NP oracle
 - fuzz first (might also give you a theorem)
 - be curious, search for the unexpected