

State-of-the Art in Numerical Optimization Software

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DECISION TREE FOR OPTIMIZATION SOFTWARE

BENCHMARKS FOR OPTIMIZATION SOFTWARE

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END OF A BENCHMARKING ERA

For many years our benchmarking effort had included the solvers CPLEX, Gurobi, and XPRESS. Through an [action](#) by Gurobi at the 2018 INFORMS Annual Meeting this has come to an end. IBM and [FICO](#) demanded that results for their solvers be removed and then we decided to temporarily remove those of Gurobi as well. CPLEX was in fifteen of the benchmarks, Gurobi and XPRESS in thirteen. See [here](#) for more details. In late November 2019 selected benchmarks for Gurobi were added.

A partial record of previous benchmarks can be obtained from [this webpage](#) and some additional [older benchmarks](#)

What is on top of the Benchmark Page?

- ▶ Links to history and older benchmarks
- ▶ Especially the 2018 event eliminating CPLEX and XPRESS
- ▶ Hint that full solver logfiles are provided
- ▶ Explanation why performance profiles are not used
- ▶ Link to Matt Miltenberger's visualization tool

Visualizations of Mittelmann benchmarks

Interactive plots showing pairwise time differences for every instance and every solver

[View On GitHub](#)

- Benchmark of Simplex LP solvers (31 Aug 2022)
- Benchmark of Barrier LP solvers (29 Aug 2022)
- Large Network-LP Benchmark (commercial vs free) (24 Aug 2022)
- The MIPLIB2017 Benchmark Instances - 8 threads (30 Jun 2022)
- MILP cases that are slightly pathological (25 Jul 2022)
- Infeasibility Detection for MILP Problems (24 Jul 2022)
- Several SDP-codes on sparse and other SDP problems (29 Aug 2022)
- Large Second Order Cone Benchmark (29 Aug 2022)
- Mixed-integer SOCP Benchmark (31 Aug 2022)
- Binary Non-Convex QPLIB

Interactive charts comparing the results of [Hans Mittelmann's benchmarks](#). Each solver can be selected to show pairwise running time factors for every other solver in the respective benchmark. These plots should make browsing the results easier. The score ([scaled shifted geometric mean](#)) is recomputed using the reported solving times. We also calculate a "virtual best" or "ensemble" solver that picks the best performance over all solvers for every single problem instance. This might reveal how much potential the individual solvers still have. [Please let me know](#) if you have a question or if there is an error.

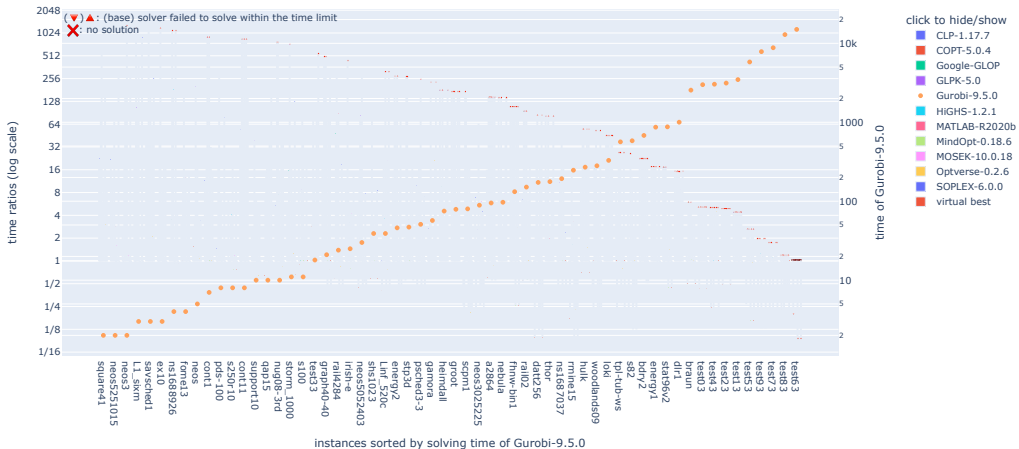
Benchmark of Simplex LP solvers (31 Aug 2022)

Choose base solver for comparison:

solver	score (as reported)	solved of 60
★ virtual best	0.74	100%
🏆 COPT-5.0.4	1.00 (1.00)	100%
🏆 MindOpt-0.18.6	1.16 (1.16)	100%
🏆 Gurobi-9.5.0	1.70 (1.70)	98%

Benchmark of Simplex LP solvers

shifted time ratios (shift=10 seconds) using Gurobi-9.5.0 as base solver (31 Aug 2022) - mattmilten.github.io/mittelmann-plots



History and Scope of the Benchmarks

- ▶ Start about 1998
- ▶ Summary presented at INFORMS Annual starting 2002
- ▶ 21 benchmarks in these areas
 - ▶ TSP, (MI)LP, (MI)SOCP, SDP, (MI)QP, (MI)QCP, (MI)NLP, MPEC
- ▶ Codes evaluated: 44, of those 25 actively developed, 13 commercial
- ▶ Running times per code: up to 3 weeks

Selected Benchmarks

These 7 benchmarks follow next:

- ▶ **convex**: Simplex LP, Barrier LP, MILP, SDP
- ▶ **nonconvex**: BQCP, QCP, MINLP
- ▶ remember: "the **great watershed** in optimization isn't between linearity and nonlinearity, but convexity and nonconvexity"

Benchmark of Simplex LP Solvers

Top of benchmark table shown

- ▶ Total of 60 instances (20 hidden)
- ▶ Sizes up to 20m/20m/20m rows/cols/nonzeros
- ▶ Intel i7-11700K, 3.6GHz, 64GB, 15,000 secs wall clock
- ▶ Own instance selection

60 probs	10.0	1.70	1.02	1	2.55	16.0	13.6	26.5	42.4	78.9	15.6
solved	43	59	60	59	53	46	47	32	34	28	44
=====											
probs	CLP	Gurob	COPT	MDOPT	OPTV	MOSEK	HiGHS	GLOP	SPLX	GLPK	MATL
=====											

Benchmark of Barrier LP Solvers

Top of benchmark table shown

- ▶ Total of 51 instances (all provided)
- ▶ Sizes up to 30m/30m/95m rows/cols/nonzeros
- ▶ Intel i7-11700K, 3.6GHz, 64GB, 15,000 secs wall clock
- ▶ Own instance selection

51 probs	4.00	34.3	1.31	69.1	52.4	1	2.39	14.4	18.6	12.1
solved	47	35	50	35	32	51	49	39	42	44
=====										
problem	MOSEK	MATLAB	Gurobi	CLP	TULIP	COPT	MDOPT	KNITRO	HiGHS	PDLP\$
=====										

The MIPLIB2017 Benchmark Instances

Top of benchmark table shown

- ▶ Total of 240 instances
- ▶ Sizes up to 1.5m/1m/43m rows/cols/nonzeros
- ▶ Intel i7-11700K, 3.6GHz, 64GB, 7,200 secs wall clock
- ▶ Instances from MIPLIB

	CBC	Gurobi	COPT	SCIP	SCIPC	HiGHS
mean	14.5	1	2.34	9.72	7.95	9.15
solved	107	224	195	137	152	150

Several SDP-codes on sparse and other SDP problems

Top of benchmark table shown

- ▶ Total of 75 instances (all provided)
- ▶ Sizes up to 100k/100k/450m variables/constraints/nonzeros
- ▶ AMD Ryzen 9 5900X, 12 cores, 128GB , 40,000 secs wall clock
- ▶ Own instance selection

	1	3.06	2.31	6.14	3.02	17.0	4.98	1.18
count of "a"	7	5	0	17	13	2	11	10
solved of 75	74	70	72	61	69	62	70	74
problem	COPT	CSDP	MOSEK	SDPA	SDPT3	SeDuMi	HDSDP	MDOPT

"a": reduced accuracy

Binary Non-Convex QPLIB Benchmark

Top of benchmark table shown

- ▶ Total of 128 instances
- ▶ Sizes up to 9k/13k/80k variables/constraints/nonzeros
- ▶ AMD Ryzen 9 5900X, 12 cores, 128GB , 3,600 secs wall clock
- ▶ Instances from QPLIB

mean	6.65	33.8	68.4	81.4	1.65	1
solved	55	35	16	6	92	89

=====						
prob#	BARON	SCIP	ANTIGONE	COUENNE	OCTERACT&	GUROBI

Continuous Non-Convex QPLIB Benchmark

Top of benchmark table shown

- ▶ Total of 102 instances
- ▶ Sizes up to 200k/140k/1m variables/lin constraints/nonlin constraints
- ▶ Intel Xeon E5-4657L, 48 cores, 512GB, 8 threads, 10,800 secs wall clock
- ▶ Instances from QPLIB

mean	4.90	5.76	11.2	6.95	9.85	1.25	1
solved	28	19	8	15	13	49	42

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prob#	ANTIGONE	BARON	COUENNE	MINOTAUR	SCIP	OCTERACT&	GUROBI
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Mixed Integer Nonlinear Programming Benchmark

Top of benchmark table shown

- ▶ Total of 87 instances
- ▶ Sizes up to 100k/100k/5k variables/lin constraints/nonlin constraints
- ▶ Intel i7-11700K, 3.6GHz, 64GB, 7,200 secs wall clock
- ▶ Instances from MINLPLib

	ANTIGONE	BARON	COUENNE	LINDO	OCTERACT	SCIP
geom mean	3.43	1	7.77	4.51	0.85	0.91
solved	53	69	24	37	67	64

Conclusions

Some Takeaways

- ▶ Gurobi and BARON have **serious** competition
- ▶ SDP code development has picked up again
- ▶ HiGHS is strong in MILP
- ▶ SCIP is strong in MINLP
- ▶ Global optimization is now standard but **challenges** remain

THANK YOU

Questions?

Slides of talk at
<http://plato.asu.edu/talks/informs2022.pdf>