

# **Benchmarks of Commercial and Noncommercial Optimization Software**

23rd International Symposium  
on  
Mathematical Programming

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## Services we provide

- Guide to Software: "**Decision Tree**"
- <http://plato.asu.edu/guide.html>
- Software Archive
- Software Evaluation: "**Benchmarks**"
- Archive of Testproblems
- Web-based Solvers (**1/3 of NEOS**)

We maintain the following NEOS solvers in 9 categories

Combinatorial Optimization \* CONCORDE [TSP Input]

Global Optimization \* ICOS [AMPL Input]

\* scip [AMPL Input][LP Input][MPS Input][OSIL Input][ZIMPL Input]

Linear Programming

\* bmpd [AMPL Input][LP Input][MPS Input][QPS Input]

\* SoPlex80bit [LP Input][MPS Input]

Mixed Integer Linear Programming

\* feaspump [AMPL Input][LP Input][MPS Input]

\* proxy [LP Input][MPS Input]

\* qsopt\_ex [AMPL Input][LP Input][MPS Input]

\* scip [AMPL Input][LP Input][MPS Input] [ZIMPL Input][OSIL Input]

Nondifferentiable Optimization \* condor [AMPL Input]

Semi-infinite Optimization \* nsips [AMPL Input]

## Mixed Integer Nonlinearly Constrained Optimization

\* scip [AMPL Input][LP Input][MPS Input][OSIL Input][ZIMPL Input]

## Semidefinite (and SOCP) Programming (also discrete)

\* csdp [MATLAB\_BINARY Input][SPARSE\_SDPA Input]

\* mosek [MATLAB\_BINARY Input][SPARSE\_SDPA Input]

\* penbmi [MATLAB Input][MATLAB\_BINARY Input][YALMIP Input]

\* pensdp [MATLAB\_BINARY Input][SPARSE\_SDPA Input]

\* scipsdp [SPARSE\_SDPA Input]

\* sdpa [MATLAB\_BINARY Input][SPARSE\_SDPA Input]

\* sdplr [MATLAB\_BINARY Input][SDPLR Input][SPARSE\_SDPA Input]

\* sdpt3 [MATLAB\_BINARY Input][SPARSE\_SDPA Input]

\* sedumi [MATLAB\_BINARY Input][SPARSE\_SDPA Input]

## Stochastic Linear Programming

\* bnbs [SMPS Input]

\* DDSIP [LP Input][MPS Input]

\* SD [SMPS Input]

# Overview of Talk

- **Current and Selected Benchmarks**
  - **Benchmarks of Continuous Optimization Software**
    - \* **Simplex/Barrier LP/QP/SOCP, SDP, NLP, MPEC**
  - **Benchmarks of Discrete Optimization Software**
    - \* **MILP, MIQP, MIQCP, MISOCP, MINLP**
- **Observations and Conclusions**

## **COMBINATORIAL OPTIMIZATION**

Concorde-TSP with different LP solvers (12-20-2017)

## **LINEAR PROGRAMMING**

\* Benchmark of Simplex LP solvers (6-19-2018)

\* Benchmark of commercial LP solvers (6-1-2018)

Parallel Barrier Solvers on Large LP/QP problems (5-28-2018)

Large Network-LP Benchmark (commercial vs free) (5-28-2018)

## **SEMIDEFINITE/SQL PROGRAMMING**

SQL problems from the 7th DIMACS Challenge (8-8-2002)

\* Several SDP codes on sparse and other SDP problems (6-6-2018)

Infeasible SDP Benchmark (5-9-2018)

\* Large SOCP Benchmark (6-19-2018)

\* MISOCP Benchmark (5-28-2018)

## **PROBLEMS WITH EQUILIBRIUM CONSTRAINTS**

MPEC Benchmark (4-17-2018)

## **MIXED INTEGER LINEAR PROGRAMMING**

- \* MILP Benchmark - MIPLIB2010 (6-15-2018)
- \* The Solvable MIPLIB Instances (6-21-2018) (MIPLIB2010)
- MILP cases that are slightly pathological (6-18-2018)
- Feasibility Benchmark (5-28-2018) (MIPLIB2010)
- Infeasibility Detection for MILP Problems (6-14-2018) (MIPLIB2010)

## **NONLINEAR PROGRAMMING**

AMPL-NLP Benchmark (6-20-2018)

## **MIXED INTEGER QPs and QCPS**

- \* Non-commercial convex QP Benchmark (6-12-2018)
- \* Binary QPLIB Benchmark (6-8-2018)
- \* QPLIB-QCQP Benchmark (6-11-2018)
- \* Convex Discrete QPLIB Benchmark (6-12-2018)

## **MIXED INTEGER NONLINEAR PROGRAMMING**

- \* MINLP Benchmark (6-14-2018)

## Important features of all our benchmarks

- NO PERFORMANCE PROFILES! (unreliable, TOMS 43)
- Statistics of problems (dimensions etc)
- Links to codes, problems and logfiles given
- Same selection for commercial/free codes
- many benchmark talks on personal webpage to  
TRACK PERFORMANCE OVER TIME



## Reasons for updates

- New versions of commercial software
  - CPLEX-12.8, GUROBI-8.0, XPRESS-8.5, SAS-OR-14.3
  - KNITRO-11.0, MOSEK-8.1
  - MATLAB-2018a (linprog, intlinprog, fmincon)
  - GAMS-25.1 (for MINLP)
- New versions of free software
  - MIPCL, SCIP, IPOPT, GALAHAD-CQP

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- Observations and Conclusions

16 Jun 2018 =====  
 Benchmark of Simplex LP solvers  
 =====  
 H. Mittelmann (mittelmann@asu.edu)

This benchmark was run on a Linux-PC (i7-4790K, 4.0GHz, 32GB).

CPLEX-12.8.0 CPLEX  
 GUROBI-8.0.0 www.gurobi.com/  
 MOSEK-8.1.0.49 www.mosek.com  
 XPRESS-8.5.1 XPRESS (1/8 threads)  
 CLP-1.16.10 projects.coin-or.org/Clp (with openblas)  
 Google-GLOP LP with Glop  
 SOPLEX-3.1.0 soplex.zib.de/  
 LP\_SOLVE-5.5.2 lpsolve.sourceforge.net/  
 GLPK-4.64 www.gnu.org/software/glpk/glpk.html  
 MATLAB-R2018a mathworks.com (dual-simplex)  
 SAS-OR-14.3 SAS optimization

Unscaled and scaled shifted (by 10 sec) geometric mean of runtimes

	49.3	26.2	137	26.2	49.0	292	474	5068	1180	298	147
	1.88	1	5.24	1.07	1.87	11.2	18.1	194	45	11.4	5.61
solved	40	40	39	40	40	36	36	23	31	32	38
=====											
40 probs	CPXS	GRBS	MSKS	XPRS	CLP	GLOP	SOPLX	LPSLV	GLPK	MATL	SAS
=====											

```

1 Jun 2018  =====
            Benchmark of commercial LP solvers
            =====
            H. Mittelmann (mittelmann@asu.edu)

```

This benchmark was run on a Linux-PC (i7-4790K, 4GHz, 32GB).

The barrier(B) and deterministic automatic/concurrent(A) methods were tested of:

```

CPLEX-12.8.0    CPLEX
GUROBI-8.0.0    www.gurobi.com/
MOSEK-8.1.0.49  www.mosek.com
XPRESS-8.2.1    XPRESS
MATLAB-R2018a   mathworks.com (interior-point, NO CROSSOVER!)
SAS-OR-14.3     SAS

```

Unscaled and scaled shifted (by 10 sec) geometric mean of runtimes

	28.8	17.8	43.5	16.3	47.7	18.9	22.5	179	174
46 probs	1.78	1.10	2.69	1	2.95	1.17	1.39	11.0	10.7
solved	46	46	44	46	45	46	46	42	41

```

=====
problem    CPXB  GRBB  MSKB  XPRB  CPXC  GRBC  XPRC  MATB  SASB
=====

```

12 Jun 2018

```
=====
Benchmark of noncommercial QP solvers
=====
H. Mittelmann (mittelmann@asu.edu)
```

Logiles at [plato.asu.edu/ftp/qpbench\\_logs/](http://plato.asu.edu/ftp/qpbench_logs/)  
Codes run in default mode on a 4.20 GHz Intel i7-7700K (32GB, Linux, 64 bits)  
BPMPD-2.21: [neos-server.org/neos/solvers/lp:bpmpd/MPS.html](http://neos-server.org/neos/solvers/lp:bpmpd/MPS.html) (run locally, QPS input)  
IPOPT-3.12.10: [projects.coin-or.org/Ipopt](http://projects.coin-or.org/Ipopt) (AMPL input)  
OOQP-0.99.19: [www.cs.wisc.edu/~swright/ooqp](http://www.cs.wisc.edu/~swright/ooqp) (QPS input)  
CLP-1.16.11: [projects.coin-or.org/Clp](http://projects.coin-or.org/Clp) (Barrier, QPS input)  
OSQP-0.3.0: [github.com/oxfordcontrol/osqp](https://github.com/oxfordcontrol/osqp) (Matlab input)  
Galahad-3: [www.galahad.rl.ac.uk](http://www.galahad.rl.ac.uk) (QPS input, CQP solver)

on the following convex continuous QPs Maros-Mezzaros collection in various formats

Given below is the number of successful runs. B: dir BRUNEL (46 cases), C: dir CUTE (76 cases), M:

```
=====
dir BPMPD  IPOPT   OOQP   CLP   OSQP  CQP
=====
```

B	46	44	44	44	9	45
C	76	76	76	74	56	76
M	16	15	14	14	2	14

```
=====
```

12 Jun 2018

```
=====
Benchmark of noncommercial QP solvers
=====
H. Mittelmann (mittelmann@asu.edu)
```

(continued)

Given below are some sample elapsed times in seconds. "f": fail, "t": 1hr exceeded

```
=====
problem  BPMPD IPOPT  OOQP   CLP   OSQP   CQP
=====
```

BOYD1	1	7	t	60	f	f
BOYD2	7	138	t	f	f	f
CONT-201	2	15	95	591	f	2
CONT-300	6	31	380	t	f	4
CVXQP1_L	7	4	187	345	f	13
CVXQP2_L	5	2	62	81	f	4
CVXQP3_L	10	7	795	t	f	246
EXDATA	4	10	15	69	f	39

```
=====
```

6 Jun 2018 =====  
 Several SDP-codes on sparse and other SDP problems  
 =====

Hans D. Mittelmann (mittelmann@asu.edu)

CSDP-6.2.0: [www.nmt.edu/~borchers/csdp.html](http://www.nmt.edu/~borchers/csdp.html)  
 DSDP-5.8: [www.mcs.anl.gov/hs/software/DSDP/](http://www.mcs.anl.gov/hs/software/DSDP/)  
 MOSEK-8.1.0.53: [mosek.com](http://mosek.com)  
 SDPA-7.3.8: [sdpa.sourceforge.net](http://sdpa.sourceforge.net)  
 SDPT3-4.0: [www.math.nus.edu.sg/~mattohkc/sdpt3.html](http://www.math.nus.edu.sg/~mattohkc/sdpt3.html)  
 SeDuMi-1.32: [github.com/sqlp/sedumi/](https://github.com/sqlp/sedumi/)  
 PENSDP-2.2: [www.penopt.com/pensdp.html](http://www.penopt.com/pensdp.html)  
 SDPNAL-0: [www.math.nus.edu.sg/~mattohkc/SDPNAL.html](http://www.math.nus.edu.sg/~mattohkc/SDPNAL.html)

The codes were run in default mode on an Intel i7-2600 (16GB) under Linux. Given are total CPU seconds

Scaled shifted geometric means of runtimes ("1" is fastest solver)

	1.60	4.67	1	2.24	1.51	6.90	3.87	10.3
count of "a"	7	22	2	21	10	6	4	13
solved of 90	83	73	87	83	84	79	81	56
problem	CSDP	DSDP	MOSEK	SDPA	SDPT3	SeDuMi	PENSDP	SDPNAL

"a": insufficient accuracy (DIMACS errors)

19 Jun 2018 =====  
 Large Second Order Cone Benchmark  
 =====  
 Hans D. Mittelmann (mittelmann@asu.edu)

Logfiles for these runs are at: [plato.la.asu.edu/ftp/socp\\_logs/](http://plato.la.asu.edu/ftp/socp_logs/)

MOSEK-8.1.0.38 MOSEK  
 CPLEX-12.8.0 CPLEX  
 GUROBI-8.0.0 GUROBI  
 XPRESS-8.5.1 XPRESS

These codes were tested on a selection of the SOCP problems from CBLIB2014.  
 The codes were run in default mode on an Intel i7-4790K (4.0 GHz, 32GB). Time limit 1 hr.

	3.21	1.01	1	1.35
-----				
problem	CPLEX	GUROBI	MOSEK	XPRESS
solved of 18	18	18	18	18
-----				



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- Observations and Conclusions

28 May 2018      =====  
                  Mixed-integer SOCP Benchmark  
                  =====

Hans D. Mittelmann (mittelmann@asu.edu)

Logfiles for these runs are at: [plato.la.asu.edu/ftp/misocp\\_logs/](http://plato.la.asu.edu/ftp/misocp_logs/)

MOSEK-8.1.0.38 MOSEK  
CPLEX-12.8.0 CPLEX  
GUROBI-8.0.0 GUROBI  
XPRESS-8.5.1 XPRESS  
SCIP-5.0.1 SCIP

These codes were tested on a selection of the MISOCP problems from CBLIB2014 and from here.  
The codes were run in default mode (except mipgap=0) on an Intel i7-4790K (4.0 GHz, 32GB).  
Time limit 2 hrs.

Scaled shifted geometric means of runtimes (t/m counted as maxtime)

	3.50	1	9.12	1.22	28.7
=====					
problem	CPLEX	GUROBI	MOSEK	XPRESS	SCIP
solved of 47	37	46	32	45	31
-----					

15 Jun 2018 =====  
Mixed Integer Linear Programming Benchmark (MIPLIB2010)  
=====

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The following codes were run with a limit of 2 hours on the MIPLIB2010 benchmark set with the MIPLIB2010 scripts (exc Matlab) on two platforms.

1/4 threads: Intel i7-4790K, 4 cores, 32GB, 4GHz, available memory 24GB;

12 threads: Intel Xeon X5680, 12 cores, 32GB, 3.33Ghz, available memory 24GB

CPLEX-12.8.0: CPLEX

GUROBI-8.0.0 GUROBI

ug[SCIP/cpx/spx]-5.0.0: Parallel development version of SCIP (SCIP+CPLEX/SOPLEX on 1 thread)

CBC-2.9.8: CBC

GLKP-4.65: GLPK

LP\_SOLVE-5.5.2: LPSOLVE

XPRESS-8.4.0: XPRESS

MATLAB-2017a: MATLAB (intlprog)

MIPCL-1.5.2: MIPCL

SAS-OR-14.3: SAS

Table for single thread, Result files per solver, Log files per solver

Table for 4 threads, Result files per solver, Log files per solver

Table for 12 threads, Result files per solver, Log files per solver

Statistics of the problems can be obtained from the MIPLIB2010 webpage.

The third line lists the number of problems (86 total) solved.

1 thr	CBC	CPLEX	GUROBI	SCIPC	SCIPS	XPRESS	MATLB	SAS	MIPCL	GLPK	LP_SOL
unscal	1639	72.2	47.8	281	329	83.1	2667	120	477	6925	5616
scaled	34	1.51	1	5.88	6.87	1.74	55.8	2.52	10.0	121	117
solved	53	87	87	83	76	86	39	84	74	2	7

FSCIP to be updated to version 5.0:

4 thr	CBC	CPLEX	FSCIPC	FSCIPS	GUROBI	XPRESS	MIPCL	SAS
unscal	843	36.4	278	355	23.1	40.3	191	72.6
scaled	36.5	1.58	12.0	15.4	1	1.75	8.28	3.15
solved	66	86	74	74	87	87	83	85

12 thr	CBC	CPLEX	FSCIPC	FSCIPS	GUROBI	XPRESS	MIPCL	SAS
unscal	668	37.5	276	350	26.1	38.0	150	85.4
scaled	26	1.44	10.6	13.4	1	1.46	5.74	3.27
solved	69	87	74	73	87	87	84	82

21 Jun 2018

=====  
The Solvable MIPLIB Instances (MIPLIB2010)  
=====

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The following codes were run on the "green" problems from MIPLIB2010 with the MIPLIB2010 scripts on an Intel Xeon X5680 (32GB, Linux, 64 bits, 2\*6 cores) and with 40 threads on an Intel Xeon Gold 6138, 40 cores, 256GB, 2.00GHz.

CBC-2.9.8, CPLEX-12.8.0, GUROBI-8.0.0, XPRESS-8.5.1, FiberSCIP[cpx]-4.0.0, ODH-3.3.6, SAS-OR-14.3

no. of probs	CBC	CPLEX	GUROBI	XPRESS	FSCIP	SAS
12 threads	1266	73.4	60.9	95.3	746	256
220	20.8	1.20	1	1.56	12.2	4.21
solved	119	211	213	207	140	171

no. of probs	CPLEX	GUROBI	XPRESS	SAS	ODH
40 threads	54.0	44.2	64.7	197	54.9
220	1.22	1	1.46	4.46	1.24
solved	211	216	208	183	212

8 Jun 2018

=====  
Binary QPLIB Benchmark  
=====

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Logfiles at [plato.asu.edu/ftp/qplib\\_logs/](http://plato.asu.edu/ftp/qplib_logs/)

CPLEX-12.8.0	CPLEX
GUROBI-8.0.0	GUROBI
Baron-18.5.8	BARON
ug[spx,4.0.0]	FSCIP-SOPLEX (only open source code included)
ANTIGONE-1.1	ANTIGONE
XPRESS-8.5.1	XPRESS

The above solvers were run on a 3 GHz Intel i7-5960X (8 cores, 48GB) on the binary nonconvex problems (128 total) from QPLIB.

Times given are elapsed times in seconds. Mipgap is zero, time limit 1hr; 8 threads, except SCIP.

Only those instances are shown for which at least one solver succeeded.

Shifted and scaled geometric mean of runtimes:

mean	1.61	1.30	10.8	18.1	26.5	1
solved	71	73	27	20	11	75
=====						
prob#	CPLEX	GUROBI	BARON	FSCIP	ANTIGONE	XPRESS
-----						

11 Jun 2018

=====  
QPLIB-QCQP Benchmark  
=====

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Logfiles at [plato.asu.edu/ftp/qcqp\\_logs/](http://plato.asu.edu/ftp/qcqp_logs/)

Baron-18.5.8	BARON
ANTIGONE-1.1	ANTIGONE
SCIP-5.0.0/1	SCIP/CPLEX
COUENNE-0.5	COUENNE
CPLEX-12.8.0	CPLEX

The above solvers were run on a 3 GHz Intel i7-5960X (8 cores, 48GB) on the (nonconvex) QCQPs (37 total) with quadratic objective and the continuous QCQPs (52 total) with linear objective as well as the nonbinary QPs (19 total) from QPLIB. Times given are elapsed times in seconds. Mipgap is zero, time limit 3hrs. Only those instances are shown for which at least one solver succeeded. Shifted and scaled geometric mean of runtimes:

mean	2.36	1	2.38	4.54
solved	19	29	17	9
=====				
prob#	BARON	ANTIGONE	SCIP	COUENNE
-----				

11 Jun 2018

=====  
QPLIB-QCQP Benchmark  
=====

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(continued, nonbinary QPs)

prob#	BARON	ANTIGONE	SCIP	COUENNE	CPLEX
0018	t	6552	9	t	779
0031	3526	t	t	t	2666
0343	t	7682	8	t	771
2702	41	t	82	3762	71
2712	f	t	4530	t	t
3060	106	t	120	t	68
3122	2853	t	1804	t	206
3523	1119	t	2391	t	189
3554	t	t	t	t	14
3790	336	t	t	t	2
3870	t	t	t	t	2896
8505	t	135	t	1410	18
8777	t	t	t	t	6679
9030	t	t	t	t	1
9048	922	t	t	t	t



12 Jun 2018

```

=====
Convex Discrete QPLIB Benchmark
=====
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```

Logfiles at [plato.asu.edu/ftp/convex\\_logs/](http://plato.asu.edu/ftp/convex_logs/)

```

CPLEX-12.8.0    CPLEX
GUROBI-8.0.0    GUROBI
MOSEK-8.1.0.53 MOSEK
XPRESS-8.5.1    XPRESS
KNITRO-11.0     KNITRO
Baron-18.5.8    BARON
SCIP-5.0.0      SCIP with CPLEX-12.8.0
Bonminh-1.8     BONMIN

```

The above solvers were run on a 3 GHz Intel i7-5960X (8 cores, 48GB) on the 31 discrete convex problems from QPLIB. Times given are elapsed times in seconds. Mipgap zero, time limit 2hrs, 8 threads; SCIP 1 thread  
 Shifted and scaled geometric mean of runtimes:

mean	2.74	1	8.08	2.90	13.3	8.72	12.6	10.2
solved	20	22	11	14	8	14	14	9
=====								
prob#	CPLEX	GUROBI	MOSEK	XPRESS	KNITRO	BARON	SCIP	BONMIN
-----								

14 Jun 2018 =====  
Mixed Integer Nonlinear Programming Benchmark (MINLPLib2)  
=====

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The following codes were run through GAMS-25.1 with a limit of 2 hours on these instances from MINLPLIB2 and with one thread on an Intel i7-4790K, 32GB, 4GHz, available memory 20GB.

Description of selection process of benchmark instances. Statistics of the instances.

ANTIGONE-1.1, BARON-18.5.8, COUENNE-0.5, LINDO-11.0, SCIP-5.01/Soplex

++++  
Scaled and shifted geometric means of run times

Feasibility tolerance set to 1e-6. All non-successes are counted as max-time.  
The second line lists the number of problems (72 total) solved.

The geometric mean is computed on the 49 instances for which no solver failed.

	ANTIGONE	BARON	COUENNE	LINDO	SCIP
geom mean	5.27	1	10.1	8.58	2.87
solved	39	55	24	22	38

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=====  
Commercial Solver Strengths  
=====

ANTIGONE	nonconvex MIQCP
BARON	nonconvex MINLP
CPLEX	MILP, nonconvex MIQP
Gurobi	LP/Simplex, LP/Barrier, SOCP, MILP, convex MIQCP
KNITRO	NLP
XPRESS	LP/Simplex, LP/Barrier, MISOCP, binary QP,
MOSEK	SDP, SOCP

=====  
Noncommercial Solver Strengths  
=====

BONMIN	convex MIQCP
BPMPD	QP
CSDP, SDPT3	SDP
CLP	LP/Simplex
IPOPT	NLP
SCIP	convex MIQCP, nonconvex MINLP

**coming soon:**

**MIPLIB2017, QPLIB-final, more MINLP etc**

**slides at:** <http://plato.asu.edu/talks/>

*Thank you!*