Latest Benchmark Results

INFORMS Annual Conference

virtual

9 Nov 2020

H. D. Mittelmann
School of Mathematical and Statistical Sciences
Arizona State University
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)
Overview of Talk

• Current and Selected (*) Benchmarks (as of 10-12-20)
  – Benchmarks of Continuous Optimization Software
    * Simplex/Barrier QPLIB, [SOCP, SDP, NLP]
  – Benchmarks of Discrete Optimization Software
    * MILP, QPLIB, [MISOCP, MINLP]

• Observations and Conclusions
COMBINATORIAL OPTIMIZATION

Concorde-TSP with different LP solvers (12-11-2019)

LINEAR PROGRAMMING

* Benchmark of Simplex LP solvers (11-2-2020)
* Benchmark of Barrier LP solvers (11-2-2020)
Large Network-LP Benchmark (commercial vs free) (11-2-2020)

SEMIDEFINITE/SQL PROGRAMMING

SQL problems from the 7th DIMACS Challenge (8-8-2002)
Several SDP codes on sparse and other SDP problems (6-6-2020)
Infeasible SDP Benchmark (10-12-2020)
Large SOCP Benchmark (9-24-2020)
MISOCP Benchmark (6-14-2020)

PROBLEMS WITH EQUILIBRIUM CONSTRAINTS

MPEC Benchmark (6-3-2020)
MIXED INTEGER LINEAR PROGRAMMING

* MILP Benchmark – MIPLIB2017 (10-2-2020)
MILP cases that are slightly pathological (10-11-2020)

NONLINEAR PROGRAMMING

AMPL-NLP Benchmark (6-3-2020)

MIXED INTEGER QPs and QCPs

Non-commercial convex QP Benchmark (11-1-2019)
* Binary Non-Convex QPLIB Benchmark (10-7-2020)
* Discrete Non-Convex QPLIB Benchmark (non-binary) (10-8-2020)
* Continuous Non-Convex QPLIB Benchmark (10-10-2020)
* Convex Continuous QPLIB Benchmark (9-27-2020)
* Convex Discrete QPLIB Benchmark (10-8-2020)

MIXED INTEGER NONLINEAR PROGRAMMING

MINLP Benchmark (10-16-2020)
Overview of Talk

• Selected Benchmarks
  
  – Benchmarks of Continuous Optimization Software
    * Simplex/Barrier QPLIB, [SOCP, SDP, NLP]
  
  – Benchmarks of Discrete Optimization Software
    * MILP, QPLIB, [MISOCP, MINLP]

• Observations and Conclusions
2 Nov 2020  ============================
Benchmark of Simplex LP solvers
==================================
H. Mittelmann (mittelmann@asu.edu)

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

MOSEK-9.2.20  www.mosek.com
CLP-1.17.6    projects.coin-or.org/Clp
Google-GLOP   LP with Glop
SOPLEX-5.0.0  soplex.zib.de/
Gurobi-9.1.0  gurobi.com
GLPK-4.65     www.gnu.org/software/glpk/glpk.html
MATLAB-R2020a mathworks.com (dual-simplex)
COPT-1.4.3    [Cardinal Optimization]
MindOpt-0.10.0 [alibabaUS]
HiGHS-1.0.0: HiGHS [ERGO-Code]
SAS-OR-15.1: SAS (dual-simplex)

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

<table>
<thead>
<tr>
<th></th>
<th>MSK</th>
<th>CLP</th>
<th>GLOP</th>
<th>SPLX</th>
<th>Gurob</th>
<th>GLPK</th>
<th>MATL</th>
<th>COPT</th>
<th>MDOPT</th>
<th>HiGHS</th>
<th>SAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>428</td>
<td>201</td>
<td>836</td>
<td>1105</td>
<td>50.0</td>
<td>3094</td>
<td>926</td>
<td>59.3</td>
<td>84.3</td>
<td>811</td>
<td>432</td>
</tr>
<tr>
<td></td>
<td>8.55</td>
<td>4.01</td>
<td>16.7</td>
<td>22.1</td>
<td>1</td>
<td>61.9</td>
<td>18.5</td>
<td>1.19</td>
<td>1.68</td>
<td>16.2</td>
<td>8.63</td>
</tr>
<tr>
<td>solved</td>
<td>38</td>
<td>40</td>
<td>34</td>
<td>36</td>
<td>40</td>
<td>27</td>
<td>32</td>
<td>40</td>
<td>37</td>
<td>33</td>
<td>36</td>
</tr>
</tbody>
</table>

40 probs  MSK  CLP  GLOP  SPLX  Gurob  GLPK  MATL  COPT  MDOPT  HiGHS  SAS
This benchmark was run on a Linux-PC (i7-4790K, 4GHz, 32GB).

The barrier methods were tested of:

- **MOSEK-9.2.21**  www.mosek.com
- **MATLAB-R2020a**  mathworks.com (interior-point, NO CROSSOVER!)
- **Gurobi-9.1.0**  gurobi.com
- **CLP-1.17.6**  projects.coin-or.org/Clp
- **SAS-OR-15.1**  SAS
- **Tulip-0.5.1**  [Tulip at Github]
- **COPT-1.4.3**  [Cardinal Optimization]

Unscaled (w/o first 5) and scaled shifted (by 10 sec) geometric mean of runtimes

<table>
<thead>
<tr>
<th></th>
<th>33.8</th>
<th>514</th>
<th>16.3</th>
<th>786</th>
<th>106</th>
<th>558</th>
<th>36.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 probs</td>
<td>2.36</td>
<td>30.7</td>
<td>1</td>
<td>47.4</td>
<td>5.26</td>
<td>36.2</td>
<td>2.39</td>
</tr>
<tr>
<td>solved</td>
<td>44</td>
<td>34</td>
<td>45</td>
<td>37</td>
<td>43</td>
<td>35</td>
<td>45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>problem</th>
<th>MOSEK</th>
<th>MATLAB</th>
<th>Gurobi</th>
<th>CLP</th>
<th>SAS</th>
<th>TULIP</th>
<th>COPT</th>
</tr>
</thead>
</table>

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

The barrier methods were tested of:

- **MOSEK-9.2.21**  www.mosek.com
- **MATLAB-R2020a**  mathworks.com (interior-point, NO CROSSOVER!)
- **Gurobi-9.1.0**  gurobi.com
- **CLP-1.17.6**  projects.coin-or.org/Clp
- **SAS-OR-15.1**  SAS
- **Tulip-0.5.1**  [Tulip at Github]
- **COPT-1.4.3**  [Cardinal Optimization]

Unscaled (w/o first 5) and scaled shifted (by 10 sec) geometric mean of runtimes

<table>
<thead>
<tr>
<th></th>
<th>33.8</th>
<th>514</th>
<th>16.3</th>
<th>786</th>
<th>106</th>
<th>558</th>
<th>36.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 probs</td>
<td>2.36</td>
<td>30.7</td>
<td>1</td>
<td>47.4</td>
<td>5.26</td>
<td>36.2</td>
<td>2.39</td>
</tr>
<tr>
<td>solved</td>
<td>44</td>
<td>34</td>
<td>45</td>
<td>37</td>
<td>43</td>
<td>35</td>
<td>45</td>
</tr>
</tbody>
</table>
Continuous Non-Convex QPLIB Benchmark

H. Mittelmann (mittelmann@asu.edu)

Logiles at plato.asu.edu/ftp/cnconv_logs/

Baron-20.4.14   BARON
ANTIGONE-1.1    ANTIGONE
SCIP-7.0.0      SCIP/SOPLEX
COUENNE-0.5     COUENNE [projects.coin-or.org/Couenne]
MINOTAUR-0.2.1  MINOTAUR
Octeract-1.07.29 OCTERACT
Gurobi-9.0.3    GUROBI

The above solvers were run on an Intel Xeon E5-4657L (48 cores, 512GB) on the continuous non-convex problems (102 total) from QPLIB. Time times given are elapsed times in seconds. Time limit 3hrs. Only those instances are shown for which at least one solver succeeded. Shifted and scaled geometric mean of runtimes:

| mean  | 1.59 | 1.83 | 4.39 | 4.63 | 3.55 | 2.47 | 1 |
| solved| 29   | 25   | 8    | 6    | 12   | 16   | 28*|

prob#   ANTIGONE  BARON  COUENNE  MINOTAUR  SCIP  OCTERACT  GUROBI

---------------------------------
Convex Continuous QPLIB Benchmark

H. Mittelmann (mittelmann@asu.edu)

Logiles at plato.asu.edu/ftp/cconvex_logs/

MOSEK-9.2.24  MOSEK
KNITRO-12.2  KNITRO
IPOPT-3.13.0  [Ipopt at Github]
Gurobi-9.0.3  GUROBI

The above solvers were run on a 3 GHz Intel i7-5960X (8 cores, 48GB) on
the 32 continuous convex problems from QPLIB. Times given are elapsed
times in seconds; time limit 2hrs, 8 threads
Shifted and scaled geometric mean of runtimes:

<table>
<thead>
<tr>
<th>mean</th>
<th>1</th>
<th>1.56</th>
<th>3.64</th>
<th>1.31</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>29</td>
<td>30</td>
<td>28</td>
<td>30</td>
</tr>
</tbody>
</table>

prob#  MOSEK  KNITRO  IPOPT  Gurobi

--------------------------------------
Overview of Talk

• Selected Benchmarks
  – Benchmarks of Continuous Optimization Software
    * Simplex/Barrier QLIB, [SOCP, SDP, NLP]
  – Benchmarks of Discrete Optimization Software
    * MILP, QPLIB, [MISOCP, MINLP]

• Observations and Conclusions
The following codes were run with a limit of 2 hours on the MIPLIB2017 benchmark set on two platforms.

1 thread: Intel i7-4790K, 4 cores, 32GB, 4GHz;
8 threads: Intel i7-5960X, 8 cores, 48GB, 3Ghz;

CBC-2.10.5: projects.coin-or.org/Cbc
GLPK-4.65: www.gnu.org/software/glpk/glpk.html
LP_SOLVE-5.5.2: lpsolve.sourceforge.net/
MATLAB-2020a: MATLAB (intlinprog)
SAS-OR-15.1: SAS
(F)SCIP/spx]-7.0.0: FiberSCIP (SCIP+SOPLEX on 1 thread)
Gurobi-9.0.3: Gurobi
The third line lists the number of problems (240 total) solved.

<table>
<thead>
<tr>
<th>1 thr</th>
<th>CBC</th>
<th>GLPK</th>
<th>LP_SOL</th>
<th>MATLAB</th>
<th>SAS</th>
<th>SCIP</th>
<th>Gurobi</th>
</tr>
</thead>
<tbody>
<tr>
<td>unscal</td>
<td>2107</td>
<td>5032</td>
<td>5335</td>
<td>3301</td>
<td>743</td>
<td>1100</td>
<td>260</td>
</tr>
<tr>
<td>scaled</td>
<td>8.10'</td>
<td>19.4</td>
<td>20.5</td>
<td>12.7</td>
<td>2.86</td>
<td>4.23</td>
<td>1</td>
</tr>
<tr>
<td>solved</td>
<td>89</td>
<td>23</td>
<td>20</td>
<td>63</td>
<td>147</td>
<td>125</td>
<td>205</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8 thr</th>
<th>CBC</th>
<th>SAS</th>
<th>FSCIP</th>
<th>Gurobi</th>
</tr>
</thead>
<tbody>
<tr>
<td>unscal</td>
<td>1723</td>
<td>580</td>
<td>1065</td>
<td>151</td>
</tr>
<tr>
<td>scaled</td>
<td>11.4</td>
<td>3.85</td>
<td>7.06</td>
<td>1</td>
</tr>
<tr>
<td>solved</td>
<td>98</td>
<td>157</td>
<td>138</td>
<td>219</td>
</tr>
</tbody>
</table>
7 Oct 2020

Binary Non-Convex QPLIB Benchmark

H. Mittelmann (mittelmann@asu.edu)

Logiles at plato.asu.edu/ftp/qplib_logs/

<table>
<thead>
<tr>
<th>prob#</th>
<th>BARON</th>
<th>SCIP</th>
<th>ANTIGONE</th>
<th>MINOTAUR</th>
<th>OCTERACT</th>
<th>GUROBI</th>
<th>FSCIP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>53</td>
<td>65</td>
<td>87</td>
<td>21</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>solved</td>
<td>42</td>
<td>26</td>
<td>23</td>
<td>7</td>
<td>36</td>
<td>81</td>
<td>34</td>
</tr>
</tbody>
</table>

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&Minotaur. Only those instances are shown for which at least one solver succeeded. Shifted and scaled geometric mean of runtimes:
8 Oct 2020

Discrete Non-Convex QPLIB Benchmark (non-binary)

H. Mittelmann (mittelmann@asu.edu)

Logiles at plato.asu.edu/ftp/nonbinary_logs/

Baron-20.4.14   BARON
ANTIGONE-1.1    ANTIGONE
SCIP-7.0.0      SCIP/SOPLEX
COUENNE-0.5     projects.coin-or.org/Couenne
MINOTAUR-0.2.1  MINOTAUR
OCTERACT-1.07.29 OCTERACT
Gurobi-9.0.3    Gurobi

The above solvers were run on an Intel Xeon E5-4657L (48 cores, 512GB) on the discrete non-convex problems (160 total) with not only binary variables from QPLIB. Time limit 3hrs. Only those instances are shown for which at least one solver succeeded. Shifted and scaled geometric mean of runtimes:

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>17.2</th>
<th>14.3</th>
<th>7.31</th>
<th>37.5</th>
<th>43.0</th>
<th>11.9</th>
<th>31.8</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>29</td>
<td>31</td>
<td>32</td>
<td>8</td>
<td>4</td>
<td>30</td>
<td>8</td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>prob#</th>
<th>ANTIGONE</th>
<th>BARON</th>
<th>FSCIP</th>
<th>COUENNE</th>
<th>MINOTAUR</th>
<th>SCIP</th>
<th>OCTERACT</th>
<th>Gurobi</th>
</tr>
</thead>
</table>

==============================================================================

---

8 Oct 2020

Discrete Non-Convex QPLIB Benchmark (non-binary)

H. Mittelmann (mittelmann@asu.edu)

Logiles at plato.asu.edu/ftp/nonbinary_logs/

Baron-20.4.14   BARON
ANTIGONE-1.1    ANTIGONE
SCIP-7.0.0      SCIP/SOPLEX
COUENNE-0.5     projects.coin-or.org/Couenne
MINOTAUR-0.2.1  MINOTAUR
OCTERACT-1.07.29 OCTERACT
Gurobi-9.0.3    Gurobi

The above solvers were run on an Intel Xeon E5-4657L (48 cores, 512GB) on the discrete non-convex problems (160 total) with not only binary variables from QPLIB. Time limit 3hrs. Only those instances are shown for which at least one solver succeeded. Shifted and scaled geometric mean of runtimes:

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>17.2</th>
<th>14.3</th>
<th>7.31</th>
<th>37.5</th>
<th>43.0</th>
<th>11.9</th>
<th>31.8</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>29</td>
<td>31</td>
<td>32</td>
<td>8</td>
<td>4</td>
<td>30</td>
<td>8</td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>

==============================================================================
8 Oct 2020

Convex Discrete QPLIB Benchmark

H. Mittelmann (mittelmann@asu.edu)

Logiles at plato.asu.edu/ftp/convex_logs/

<table>
<thead>
<tr>
<th>solver</th>
<th>version</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSEK</td>
<td>9.2.18</td>
<td>MOSEK</td>
</tr>
<tr>
<td>KNITRO</td>
<td>12.2</td>
<td>KNITRO</td>
</tr>
<tr>
<td>Baron</td>
<td>20.4.14</td>
<td>BARON</td>
</tr>
<tr>
<td>Bonmin</td>
<td>1.8.7</td>
<td>BONMIN (with CBC and Ipopt)</td>
</tr>
<tr>
<td>SCIP</td>
<td>7.0.0</td>
<td>SCIP with SOPLEX-5.0.0</td>
</tr>
<tr>
<td>ANTIGONE</td>
<td>1.1</td>
<td>ANTIGONE</td>
</tr>
<tr>
<td>MINOTAUR</td>
<td>0.2.1</td>
<td>MINOTAUR</td>
</tr>
<tr>
<td>Gurobi</td>
<td>9.0.3</td>
<td>Gurobi</td>
</tr>
<tr>
<td>Shot</td>
<td>1.0</td>
<td>SHOT with CBC</td>
</tr>
<tr>
<td>OCTERACT</td>
<td>1.07.29</td>
<td>OCTERACT</td>
</tr>
</tbody>
</table>

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, Minotaur 1 thread

Shifted and scaled geometric mean of runtimes:

<table>
<thead>
<tr>
<th>mean</th>
<th>13.2</th>
<th>19.8</th>
<th>7.99</th>
<th>19.3</th>
<th>15.5</th>
<th>50.8</th>
<th>32.0</th>
<th>1</th>
<th>59.5</th>
<th>36.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>11</td>
<td>9</td>
<td>16</td>
<td>10</td>
<td>11</td>
<td>2</td>
<td>11</td>
<td>25</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>
Overview of Talk

• Selected Benchmarks
  – Benchmarks of Continuous Optimization Software
    * Simplex/Barrier QPLIB, [SOCP, SDP, NLP]
  – Benchmarks of Discrete Optimization Software
    * MILP, QPLIB, [MISOCP, MINLP]

• Observations and Conclusions
"TOP PERFORMERS"

LP-Simplex: COPT, MindOpt, Gurobi
LP-Barrier: Gurobi, MOSEK, SAS
Network-LP: SAS, Gurobi, COPT
MILP: Gurobi, SAS, (F)SCIP
SOCP: MOSEK, Gurobi
MISOCP: Gurobi, MOSEK, SCIP
nonc BQCP: Gurobi, BARON, FSCIP
nonc DQCP: Gurobi, FSCIP, BARON
nonc CQCP: Gurobi, ANTIGONE, BARON
conv DQCP: Gurobi, BARON, MOSEK
conv CQCP: MOSEK, Gurobi, KNITRO
MINLP: BARON, SCIP
Thank you!

slides at: http://plato.asu.edu/talks/

Expect updates soon!