The State-of-the-Art in Optimization Software

ISMP 2015
Pittsburgh, PA
15 July 2015

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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)
We maintain the following NEOS solvers in 9 categories

Combinatorial Optimization  * CONCORDE [TSP Input]
Global Optimization        * ICOS [AMPL Input]
ental Optimization         * scip [AMPL Input][CPLEX Input][MPS Input][OSIL Input][ZIMPL Input]
Linear Programming
     * bpmfd [AMPL Input][LP Input][MPS Input][QPS Input]
     * SoPlex80bit [LP Input][MPS Input]
Mixed Integer Linear Programming
     * feasmpd [AMPL Input][LP Input][MPS Input]
     * proxy [CPLEX 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]
We maintain the following NEOS solvers (cont.)

Mixed Integer Nonlinearly Constrained Optimization
* scip [AMPL Input][CPLEX Input][MPS Input][OSIL Input][ZIMPL Input]

Semidefinite (and SOCP) Programming
* csdp [MATLAB_BINARY Input][SPARSE_SDPA Input]
* penbmi [MATLAB Input][MATLAB_BINARY Input]
* pensdp [MATLAB_BINARY Input][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
  – Benchmark of Simplex and parallel LP solvers
  – Several SDP-codes on sparse and other SDP problems
  – MISOCOP and large SOCP Benchmark
  – MILP benchmarks (MIPLIB2010, EASY)
  – Feasibility/Infeasibility for MILP Problems

• Observations and Conclusions
COMBINATORIAL OPTIMIZATION

Concorde-TSP with different LP solvers (7-2-2015)

LINEAR PROGRAMMING

* Benchmark of Simplex LP solvers (7-3-2015)
* Benchmark of parallel LP solvers (7-9-2015)
Parallel Barrier Solvers on Large LP/QP problems (6-29-2015)
Large Network-LP Benchmark (commercial vs free) (6-28-2015)

SEMIDEFINITE/SQL PROGRAMMING

SQL problems from the 7th DIMACS Challenge (8-8-2002)
* Several SDP codes on sparse and other SDP problems (12-14-2014)
* MISOCP and large SOCP Benchmark (7-6-2015)
MIXED INTEGER LINEAR PROGRAMMING

* MILP Benchmark - MIPLIB2010 (7-8-2015)
* The EASY MIPLIB Instances (7-2-2015) (MIPLIB2010)
MILP cases that are slightly pathological (7-6-2015)
* Feasibility Benchmark (6-29-2015) (MIPLIB2010)

NONLINEAR PROGRAMMING
AMPL-NLP Benchmark (4-23-2015)

MIXED INTEGER QPs and QCPs
MIQ(C)P Benchmark (7-2-2015)

MIXED INTEGER NONLINEAR PROGRAMMING
MINLP Benchmark (1-9-2014)

PROBLEMS WITH EQUILIBRIUM CONSTRAINTS
MPEC Benchmark (6-1-2015)
Important features of all our benchmarks

• Statistics of problems (dimensions etc)

• Links to codes given

• Links to test problems given

• Links to full logfiles given

• Same selection for commercial/free codes
Reasons for updates

- New versions of commercial software
  - CPLEX, GUROBI, XPRESS, KNITRO, MOSEK, GOOGLE, MATLAB

- New versions of free software
  - CBC, CLP, SCIP
  - BONMIN, COUENNE, IPOPT

- More multicore hardware
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• Observations and Conclusions
This benchmark was run on a Linux-PC (i7-2600, 16GB).
The simplex methods were tested of the codes:

<table>
<thead>
<tr>
<th>Solver</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPLEX</td>
<td>CPLEX</td>
</tr>
<tr>
<td>GUROBI</td>
<td><a href="http://www.gurobi.com/">www.gurobi.com/</a></td>
</tr>
<tr>
<td>MOSEK</td>
<td><a href="http://www.mosek.com">www.mosek.com</a></td>
</tr>
<tr>
<td>XPRESS</td>
<td>XPRESS</td>
</tr>
<tr>
<td>CLP</td>
<td>CLP</td>
</tr>
<tr>
<td>Google</td>
<td>Google</td>
</tr>
<tr>
<td>SOPLEX</td>
<td>SOPLEX</td>
</tr>
<tr>
<td>LP_SOLVE</td>
<td>LPSOLVE</td>
</tr>
<tr>
<td>GLPK</td>
<td>GLPK</td>
</tr>
<tr>
<td>MATLAB</td>
<td>Matlab’s dual-simplex</td>
</tr>
</tbody>
</table>

Scaled shifted geometric mean of runtimes (40 instances)

<table>
<thead>
<tr>
<th>Problem</th>
<th>CPLEX</th>
<th>GUROBI</th>
<th>MOSEK</th>
<th>XPRESS</th>
<th>CLP</th>
<th>Google</th>
<th>SOPLEX</th>
<th>LP_SOLVE</th>
<th>GLPK</th>
<th>MATLAB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.94</td>
<td>1.18</td>
<td>2.37</td>
<td>1.12</td>
<td>1</td>
<td>11.8</td>
<td>9.67</td>
<td>93.9</td>
<td>40.7</td>
<td>14.7</td>
</tr>
</tbody>
</table>
9 Jul 2015

Benchmark of parallel LP solvers

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Sources of problems:

- miplib.zib.de/ [1]
- plato.asu.edu/ftp/lptestset/ [2]
- www.netlib.org/lp/data/ [3,7]
- www.sztaki.hu/~meszaros/public_ftp/lptestset/
  (MISC[4], PROBLEMATIC[5], STOCHLP[6], INFEAS[8])

The simplex, barrier, and deterministic automatic/concurrent methods were tested of:

- CPLEX-12.6.2  CPLEX
- GUROBI-6.0.0  www.gurobi.com/
- MOSEK-7.1.0.24  www.mosek.com
- XPRESS-7.9.0:  XPRESS

Scaled shifted (by 10 sec) geometric mean of runtimes (40 instances)

<table>
<thead>
<tr>
<th>Problem</th>
<th>CPXS</th>
<th>GRBS</th>
<th>MSKS</th>
<th>XPRS</th>
<th>CPXB</th>
<th>GRBB</th>
<th>MSKB</th>
<th>XPRB</th>
<th>CPXA</th>
<th>GRBA</th>
<th>MSKA</th>
<th>XPRA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.42</td>
<td>3.29</td>
<td>6.59</td>
<td>3.14</td>
<td>1.64</td>
<td>1.07</td>
<td>1.55</td>
<td>1.07</td>
<td>2.18</td>
<td>1.12</td>
<td>1.85</td>
<td>1.41</td>
</tr>
</tbody>
</table>
Overview of Talk

• Current and Selected(*) Benchmarks
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  – Feasibility/Infeasibility for MILP Problems

• Observations and Conclusions
Several SDP-codes on sparse and other SDP problems

Hans D. Mittelmann (mittelmann@asu.edu)

Logfiles for these runs are at: plato.asu.edu/ftp/sparse_logs/

<table>
<thead>
<tr>
<th></th>
<th>CSDP-6.1.1</th>
<th>DSDP-5.8</th>
<th>MOSEK-7.1.0.9</th>
<th>SDPA-7.3.8</th>
<th>SDPT3-4.0</th>
<th>SeDuMi-1.32</th>
<th>PENSDF-2.2</th>
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</table>

Scaled shifted geometric means of runtimes

<table>
<thead>
<tr>
<th></th>
<th>3.81</th>
<th>3.08</th>
<th>1.54</th>
<th>1.52</th>
<th>1</th>
<th>4.57</th>
<th>2.54</th>
</tr>
</thead>
<tbody>
<tr>
<td>count of &quot;a&quot;</td>
<td>6</td>
<td>22</td>
<td>18</td>
<td>21</td>
<td>10</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

"a": insufficient accuracy (DIMACS errors)
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• Observations and Conclusions
MISOCP and large SOCP Benchmark

Hans D. Mittelmann (mittelmann@asu.edu)

Logfiles for these runs are at: plato.la.asu.edu/ftp/socp_logs/

MOSEK-7.1.0.31 MOSEK
CPLEX-12.6.2 CPLEX
GUROBI-6.0.0 GUROBI
XPRESS-7.9.0 XPRESS
SCIP-3.2.0 SCIP

These codes were tested on a selection of the (MI)SOCP problems from CBLIB.

The codes were run in default mode (except mipgap=0 for the MISOCP problems) on an Intel i7-2600. Given are total CPU seconds. Time limit 2 hrs resp 1 hr.
MISOCP and large SOCP Benchmark

Scaled shifted geometric means of runtimes

<table>
<thead>
<tr>
<th></th>
<th>CPLEX</th>
<th>GUROBI</th>
<th>MOSEK</th>
<th>XPRESS</th>
<th>SCIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MISOCp problems solved of 42</td>
<td>42</td>
<td>41</td>
<td>29</td>
<td>35</td>
<td>34</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CPLEX</th>
<th>GUROBI</th>
<th>MOSEK</th>
<th>XPRESS</th>
<th>SCIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOCP problems solved of 18</td>
<td>18</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>1</td>
</tr>
</tbody>
</table>
Overview of Talk

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• Observations and Conclusions
The following codes were run on the MIPLIB2010 benchmark set with the MIPLIB2010 scripts on two platforms:
1/4 threads: Intel i7-2600, 4 cores, 16GB, 3.4GHz, available memory 12GB
12 threads: Intel Xeon X5680, 12 cores, 32GB, 3.33GHz, available memory 24GB

CPLEX-12.6.2: CPLEX
GUROBI-6.0.0: GUROBI
ug[SCIP/cpx/spx]-3.2.0: Parallel development version of SCIP (SCIP+CPLEX/SOPLEX/CLP on 1 thread)
CBC-2.9.4: CBC
XPRESS-7.9.0: XPRESS
MATLAB-2015a: MATLAB (intlinprog)

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.
Unscaled and scaled geometric means of times, 87 problems, Time limit 2 hrs

<table>
<thead>
<tr>
<th></th>
<th>1 thr</th>
<th>CBC</th>
<th>CPLEX</th>
<th>GUROBI</th>
<th>SCIPC</th>
<th>SCIPS</th>
<th>XPRESS</th>
<th>MATLAB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unscl</td>
<td>1925</td>
<td>105</td>
<td>117</td>
<td>541</td>
<td>642</td>
<td>97</td>
<td>3925</td>
<td></td>
</tr>
<tr>
<td>scaled</td>
<td>19.7</td>
<td>1.08</td>
<td>1.20</td>
<td>5.55</td>
<td>6.59</td>
<td>1</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>solved</td>
<td>48</td>
<td>85</td>
<td>84</td>
<td>72</td>
<td>70</td>
<td>86</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>4 thr</th>
<th>CBC</th>
<th>CPLEX</th>
<th>FSCIPC</th>
<th>FSCIPS</th>
<th>GUROBI</th>
<th>XPRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unscl</td>
<td>2401</td>
<td>121</td>
<td>133</td>
<td>600</td>
<td>1015</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>scaled</td>
<td>18</td>
<td>1</td>
<td>1.1</td>
<td>4.97</td>
<td>8.41</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>solved</td>
<td>36</td>
<td>83</td>
<td>80</td>
<td>69</td>
<td>60</td>
<td>81</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>12 thr</th>
<th>CBC</th>
<th>CPLEX</th>
<th>FSCIPC</th>
<th>FSCIPS</th>
<th>GUROBI</th>
<th>XPRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unscl</td>
<td>615</td>
<td>44</td>
<td>339</td>
<td>502</td>
<td>44</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>scaled</td>
<td>14</td>
<td>1.01</td>
<td>7.67</td>
<td>11</td>
<td>1</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>solved</td>
<td>69</td>
<td>87</td>
<td>72</td>
<td>71</td>
<td>86</td>
<td>86</td>
<td></td>
</tr>
</tbody>
</table>
8 Jul 2015

The EASY MIPLIB Instances (MIPLIB2010)

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CBC-2.9.4: CBC
CPLEX-12.6.2: CPLEX
GUROBI-6.0.0: GUROBI
XPRESS-7.9.0: XPRESS
FiberSCIP[cpx]-3.1.1: Parallel development version of SCIP

Table for all solvers, Result files per solver, Log files per solver

+------------------------------------------+
| Shifted geometric means of times          |
+------------------------------------------+

The fastest solver is scaled to 1. Max time 2 hours. Max memory 24GB. Non-successes counted as max-time.

<table>
<thead>
<tr>
<th>no. of probs</th>
<th>CBC</th>
<th>CPLEX</th>
<th>GUROBI</th>
<th>XPRESS</th>
<th>FSCIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>solved</td>
<td>115</td>
<td>194</td>
<td>194</td>
<td>170</td>
<td>139</td>
</tr>
</tbody>
</table>

205 solved
Overview of Talk

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- Observations and Conclusions
Feasibility Benchmark

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Logfiles for these runs are at: plato.asu.edu/ftp/feas_bench_logs/

MILP problems mostly from MIPLIB2010 were solved for a feasible point

The following codes were run on an Intel i7-4790K with 4 threads:
- CPLEX-12.6.2: CPLEX
- FEASPUMP2: as implemented for interactive use at NEOS (utilizes CPLEX)
- GUROBI-6.0.0: GUROBI
- XPRESS-7.9.0: XPRESS
- CBC-2.9.4: CBC

Times given are elapsed times in seconds. A time limit of 1 hr was imposed. Shifted geometric means of the times are listed. For objective values see logfiles.

<table>
<thead>
<tr>
<th>problem(33 tot)</th>
<th>CPLEX</th>
<th>FP2</th>
<th>GUROBI</th>
<th>XPRESS</th>
<th>CBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>geometric mean</td>
<td>1.07</td>
<td>3.62</td>
<td>1</td>
<td>4.46</td>
<td>78</td>
</tr>
<tr>
<td>problems solved</td>
<td>33</td>
<td>31</td>
<td>33</td>
<td>28</td>
<td>13</td>
</tr>
</tbody>
</table>
Infeasibility Detection for MILP Problems

H. Mittelmann (mittelmann@asu.edu)

CPLEX-12.6.2: CPLEX
GUROBI-6.0.0: GUROBI
ug[SCIP/spx/cpx]-3.2.0: Parallel development version of SCIP
CBC-2.9.4: CBC
XPRESS-7.9.0: XPRESS

Table for all solvers, Result files per solver, Log files per solver

Shifted scaled geometric means of times

All non-successes are counted as max-time (1 hr). The instance zib02 has been omitted due to memory issues.

<table>
<thead>
<tr>
<th>CBC</th>
<th>CPLEX</th>
<th>FSCIPC</th>
<th>FSCIPS</th>
<th>GUROBI</th>
<th>XPRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>84</td>
<td>1</td>
<td>10</td>
<td>14</td>
<td>1.20</td>
<td>1.60</td>
</tr>
</tbody>
</table>

solved of 18: 8 18 14 14 18 18
• Observations and Conclusions: **Declare Winners?**

  – **Simplex LP**: CLP, XPRESS, Gurobi, ....CPLEX

  – **parallel LP**: XPRB, GRBB, GRBA, MSKB, XPRRA, CPXB

  – **sparse SDP**: SDPT3, ...SDPA, MOSEK, ...PENNSDP, DSDP, CSDP

  – **MISOCP**: CPLEX, ...Gurobi, ...XPRESS, ...MOSEK, ...SCIP

  – **SOCP**: MOSEK, XPRESS, Gurobi, CPLEX, SCIP

  – **MIPLIB**: balanced; **FEASIBLE**: Gurobi, CPLEX, ...XPRESS

  – **INFEASIBLE**: CPLEX, Gurobi, ...XPRESS, ...FSCIP
Thank you!