Performance of Optimization Software - an Update

CREST Workshop
Chuo University, Tokyo
23 March 2012

H. D. Mittelmann
School of Math and Stat 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)
We maintain the following NEOS solvers (8 categories)

Combinatorial Optimization  * CONCORDE [TSP Input]
Global Optimization        * ICOS [AMPL Input]
Linear Programming
    * bpmpd [AMPL Input][LP Input][MPS Input][QPS Input]
Mixed Integer Linear Programming
    * FEASPUMP [AMPL Input][CPLEX Input][MPS Input]
    * SCIP [AMPL Input][CPLEX Input][MPS Input] [ZIMPL Input]
    * qsopt_ex [LP Input][MPS Input] [AMPL Input]
Nondifferentiable Optimization  * condor [AMPL Input]
Semi-infinite Optimization    * nsips [AMPL Input]
Stochastic Linear Programming * bnbs [SMPS Input]
    * DDSIP [LP Input][MPS Input]
We maintain the following NEOS solvers (cont.)

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]
Overview of Talk

• Current and Selected(*) Benchmarks
  – Parallel LP benchmarks
  – MILP benchmark (MIPLIB2010)
  – Feasibility/Infeasibility Detection benchmarks (MIPLIB2010)
  – slightly pathological MILP cases
  – MI(QC)QP benchmark

• Conclusions
COMBINATORIAL OPTIMIZATION
Concorde-TSP with different LP solvers (8-16-2011)

LINEAR PROGRAMMING
Benchmark of serial LP solvers (11-9-2011)
* Benchmark of parallel LP solvers (2-25-2012)
* Parallel Barrier Solvers on Large LP/QP problems (3-2-2012)
Large Network-LP Benchmark (commercial vs free) (2-25-2012)

MIXED INTEGER LINEAR PROGRAMMING
* MILP Benchmark - MIPLIB2010 (2-22-2012)
* MILP cases that are slightly pathological (2-29-2012)
* Feasibility Benchmark (12-10-2011) (MIPLIB2010)
SEMIDEFINITE/SQL PROGRAMMING

Several SDP-codes on SDP problems with free variables (4-1-2008)
Several SDP codes on problems from SDPLIB (4-10-2008)
SQL problems from the 7th DIMACS Challenge (8-8-2002)
Newer SDP/SOCP-codes on the 7th DIMACS Challenge problems (4-7-2008)
Several SDP codes on sparse and other SDP problems (6-22-2011)
SOCP (second-order cone programming) Benchmark (3-2-2012)

NONLINEAR PROGRAMMING

Benchmark of commercial and other (QC)QP Solvers (11-16-2011)
AMPL-NLP Benchmark, IPOPT, KNITRO, LOQO, PENNLP, SNOPT & CONOPT (11-9-2011)

MIXEDINTEGER NONLINEAR PROGRAMMING

* MI(QC)QP Benchmark (3-9-2012)

PROBLEMS WITH EQUILIBRIUM CONSTRAINTS

MPEC Benchmark (2-26-2012)
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 version of commercial software
  - CPLEX-12.4, GUROBI-4.6.1, KNITRO-7.2.1, MOSEK-6.0.0.126/135

- New versions of free software
  - CBC, CLP, SCIP, SYMPHONY
  - BONMIN, COUENNE, IPOPT, FEASPUMP2

- More multicore hardware
Solving the MIPLIB 2010 Problems

• In late 2010 we had solved a number of instances

• In early 2012 we decided to solve those problems that a commercial solver with default options could solve in a day or less. We solved 13 cases plus 4 feasible solves.

• We used three platforms
  – Intel Xeon X5680 (3.33 GHz, 32GB, 12 cores)
  – Intel Xeon X5690 (3.47 GHz, 48GB, 6 cores)
  – Intel i7-2600 (3.4 GHz, 16GB, 4 cores)
<table>
<thead>
<tr>
<th>instance</th>
<th>cores</th>
<th>time</th>
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<td>116575</td>
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<tr>
<td>buildingenergy</td>
<td>1/4</td>
<td>895</td>
<td>easy</td>
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<td>maxgasflow</td>
<td>6/6</td>
<td>66726</td>
<td>hard</td>
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<td>opm2-z10-s2</td>
<td>12/12</td>
<td>10131</td>
<td>hard</td>
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<tr>
<td>opm2-z11-s8</td>
<td>12/12</td>
<td>18286</td>
<td>hard</td>
</tr>
<tr>
<td>opm2-z12-s14</td>
<td>4/4</td>
<td>49164</td>
<td>hard</td>
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<td>opm2-z12-s7</td>
<td>12/12</td>
<td>72492</td>
<td>hard</td>
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<td>r80x800</td>
<td>12/12</td>
<td>283303</td>
<td>hard</td>
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<td>rmatr200-p10</td>
<td>4/4</td>
<td>19644</td>
<td>hard</td>
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<tr>
<td>satellites3-40-fs</td>
<td>4/6</td>
<td>32952</td>
<td>hard</td>
</tr>
<tr>
<td>satellites3-40</td>
<td>4/4</td>
<td>21205</td>
<td>hard</td>
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<td>transportmoment</td>
<td>12/12</td>
<td>30</td>
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<td>wnq-n100-mw99-14</td>
<td>12/12</td>
<td>28124</td>
<td>hard</td>
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</table>
Overview of Talk

• Current and Selected(*) Benchmarks
  – Parallel LP benchmarks
  – MILP benchmark (MIPLIB2010)
  – Feasibility/Infeasibility Detection benchmarks (MIPLIB2010)
  – slightly pathological MILP cases
  – MI(QC)QP benchmark

• Observations and Conclusions
This benchmark was run on a Linux-PC (2.67 GHz Intel Core 2 Quad). The MPS-datafiles for all testcases are in one of (see column "s")

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 (dual) simplex, barrier, and concurrent methods were tested of:

CPLEX-12.4.0.0  CPLEX
GUROBI-4.6.1 www.gurobi.com/
MOSEK-6.0.0.126 www.mosek.com
XPRESS-7.2.1: XPRESS

Scaled geometric mean of runtimes

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th>GRB-S</th>
<th>MSK-S</th>
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<th>XPR-B</th>
<th>CPX-A</th>
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</table>
Parallel Barrier Solvers on Large LP/QP problems

H. Mittelmann (mittelmann@asu.edu)

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

CPLEX-12.4.0.0: CPLEX
GUROBI-4.6.0: GUROBI
MOSEK-6.0.0.126: MOSEK
XPRESS-7.2.1: XPRESS
IPOPT-3.10.1: IPOPT

The barrier methods (w/o crossover) of the above solvers were run on a 3.47 GHz Intel Xeon X5690 (6 cores, 48GB) on large LP problems from here. Times given are elapsed times in seconds.
2 Mar 2012

Parallel Barrier Solvers on Large LP/QP problems

<table>
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<tr>
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<th>MOSEK</th>
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<th>IPOPT</th>
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<td>879</td>
<td>309</td>
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<td>pde_10</td>
<td>2271</td>
<td>747</td>
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<td>15906</td>
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<tr>
<td>pde_1</td>
<td>2516a</td>
<td>2033</td>
<td>6625</td>
<td>fail</td>
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<tr>
<td>pde_200</td>
<td>299a</td>
<td>528</td>
<td>1237</td>
<td>1528</td>
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<td>qap_2</td>
<td>slow</td>
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<td>slow</td>
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<tr>
<td>srd300</td>
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<td>fail</td>
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<td>&gt;60000</td>
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"a": reduced accuracy
Parallel Barrier Solvers on Large LP/QP problems

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<th>problem</th>
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<th>variables</th>
<th>nonzeros</th>
<th>MPS-file</th>
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<td>6813128</td>
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<td>80970001</td>
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<tr>
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<td>999306</td>
<td>9586066</td>
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</table>
Overview of Talk

- **Current and Selected(*) Benchmarks**
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  - Feasibility/Infeasibility Detection benchmarks (MIPLIB2010)
  - slightly pathological MILP cases
  - MI(QC)QP benchmark

- Conclusions
22 Feb 2012  Mixed Integer Linear Programming Benchmark (MIPLIB2010)

The following codes were run on the MIPLIB2010 benchmark set with the MIPLIB2010 scripts on an Intel Xeon X5680 (32GB, Linux, 64 bits, 2*6 cores), with one, four and twelve threads. (deterministically) and a time limit of 1 hour. These are updated and extended versions of the results produced for the MIPLIB2010 paper.

CPLEX-12.4.0.0: CPLEX
GUROBI-4.6.1: GUROBI
ug[SCIP/cpx/spx]: Parallel development version of SCIP (SCIP+CPLEX/SOPLEX/CLP on 1 thread)
CBC-2.7.6: CBC
XPRESS-7.2.1: XPRESS
GLPK-4.47: GLPK
LP_SOLVE-5.5.2: LP_SOLVE

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.
Geometric means of times

All non-successes are counted as max-time. The fastest solver is scaled to 1. The second line lists the number of problems (87 total) solved.

<table>
<thead>
<tr>
<th>threads</th>
<th>CBC</th>
<th>CPLEX</th>
<th>GLPK</th>
<th>GUROBI</th>
<th>LPSOLVE</th>
<th>SCIPC</th>
<th>SCIPL</th>
<th>SCIPS</th>
<th>XPRESS</th>
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<tr>
<td>1</td>
<td>10.3</td>
<td>1.45</td>
<td>22.11</td>
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<td>19.4</td>
<td>3.76</td>
<td>6.4</td>
<td>5.33</td>
<td>1.28</td>
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<td>73</td>
<td>3</td>
<td>77</td>
<td>5</td>
<td>63</td>
<td>52</td>
<td>57</td>
<td>74</td>
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<th>CBC</th>
<th>CPLEX</th>
<th>FSCIPC</th>
<th>FSCIPS</th>
<th>GUROBI</th>
<th>XPRESS</th>
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<tr>
<td>4</td>
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<td>1</td>
<td>5.83</td>
<td>8.43</td>
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<td>1.23</td>
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<tr>
<td>solved</td>
<td>52</td>
<td>84</td>
<td>66</td>
<td>63</td>
<td>85</td>
<td>79</td>
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</table>

<table>
<thead>
<tr>
<th>threads</th>
<th>CBC</th>
<th>CPLEX</th>
<th>FSCIPC</th>
<th>FSCIPS</th>
<th>GUROBI</th>
<th>XPRESS</th>
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<tbody>
<tr>
<td>12</td>
<td>12.3</td>
<td>1.1</td>
<td>8.64</td>
<td>12.7</td>
<td>1</td>
<td>1.33</td>
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<tr>
<td>solved</td>
<td>56</td>
<td>84</td>
<td>71</td>
<td>65</td>
<td>87</td>
<td>83</td>
</tr>
</tbody>
</table>
Overview of Talk

- **Current and Selected(*) Benchmarks**
  - Parallel LP benchmarks
  - MILP benchmark (MIPLIB2010)
  - Feasibility/Infeasibility Detection benchmarks (MIPLIB2010)
  - slightly pathological MILP cases
  - MI(QC)QP benchmark

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

MILP problems from MIPLIB2010 were solved for a feasible point

The following codes were run on an Intel i7-2600 (3.4 GHz, 16GB, Linux, 4 cores) with 4 threads:

CPLEX-12.4.0.0: CPLEX
FEASPUMP2: as implemented for interactive use at NEOS (utilizes CPLEX)
GUROBI-4.6.1: GUROBI
XPRESS-7.2.1: XPRESS
CBC-2.7.5: CBC

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

<table>
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<tr>
<th>problem(30 tot)</th>
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<th>GUROBI</th>
<th>XPRESS</th>
<th>CBC</th>
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<td>geometric mean</td>
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<td>14.3</td>
<td>1</td>
<td>14.85</td>
<td>50.9</td>
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<td>problems solved</td>
<td>22</td>
<td>17</td>
<td>27</td>
<td>19</td>
<td>11</td>
</tr>
</tbody>
</table>
26 Feb 2012  Infeasibility Detection for MILP Problems

The following codes were run on the infeasible problems from MIPLIB2010 with the MIPLIB2010 scripts:

CPLEX-12.4.0.0: CPLEX
GUROBI-4.6.1: GUROBI
ug[SCIP/spx/cpx]: Parallel development version of SCIP
CBC-2.7.4: CBC
XPRESS-7.2.1: XPRESS

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

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

+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Geometric means of times (19 instances)
All non-successes are counted as max-time. The fastest solver is scaled to 1.

<table>
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<tr>
<th></th>
<th>CBC</th>
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<th>FSCIPC</th>
<th>FSCIPS</th>
<th>GUROBI</th>
<th>XPRESS</th>
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<tbody>
<tr>
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<td>79.3</td>
<td>1.68</td>
<td>17.7</td>
<td>30.5</td>
<td>1.00</td>
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<td>solved</td>
<td>6</td>
<td>16</td>
<td>13</td>
<td>11</td>
<td>18</td>
<td>15</td>
</tr>
</tbody>
</table>
Overview of Talk

• Current and Selected(*) Benchmarks
  – Parallel LP benchmarks
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  – Feasibility/Infeasibility Detection benchmarks (MIPLIB2010)
  – slightly pathological MILP cases
  – MI(QC)QP benchmark

• Conclusions
MILP cases that are slightly pathological

H. Mittelmann (mittelmann@asu.edu)

CPLEX-12.4.0.0: CPLEX to be added
GUROBI-4.6.1: GUROBI
ug[SCIP/spx]: FSCIP-Parallel development version of SCIP
CBC-2.7.5: CBC
XPRESS-7.2.1: XPRESS
SCIP-2.1.1: serial SCIP with CPLEX

These codes were run with the MIPLIB2010 scripts in default mode on an Intel Xeon X5680 (32GB, Linux, 64 bits, 2*6 cores) on problems from here. Times given are elapsed CPU seconds. Time limit 3 hrs. Available memory 24GB. This benchmark is not giving a representative impression of the relative performance of the codes.

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

Scaled geometric mean of runtimes and problems solved (24 total)

<table>
<thead>
<tr>
<th>CBC</th>
<th>CPLEX</th>
<th>FSCIP</th>
<th>GUROBI</th>
<th>SCIP</th>
<th>XPRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1</td>
<td>5.15</td>
<td>1.38</td>
<td>7.4</td>
<td>3.39</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>13</td>
<td>20</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>
Overview of Talk

• **Current and Selected(*) Benchmarks**
  - Parallel LP benchmarks
  - MILP benchmark (MIPLIB2010)
  - Feasibility/Infeasibility Detection benchmarks (MIPLIB2010)
  - slightly pathological MILP cases
  - MI(QC)QP benchmark

• Conclusions
9 Mar 2012

Mixed Integer (QC)QP Benchmark

H. Mittelmann (mittelmann@asu.edu)

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

The MPS-datafiles are in plato.asu.edu/ftp/miqp/ and the AMPL files in plato.asu.edu/ftp/ampl_files/miqp_ampl/ and egon.cheme.cmu.edu/ibm/files/

The following codes were run in default mode on a 2.66GHz Intel Core2 Quad, For accuracy reached, see logfiles. In the last columns are results for the QCQPs obtained by rewriting the QPs as: min t, subject to quadratic obj <= t plus constraints. SCIP does this transformation itself. SCIP uses relgap=0;

CPLEX-12.4.0.0: CPLEX
Bonmin-1.5.3: projects.coin-or.org/Bonmin (Bonmin: hybrid algorithm. with Cbc)
Couenne-0.4.2: projects.coin-or.org/Couenne
FilMINT: currently only at NEOS, (run locally)
GUROBI-4.6.1: gurobi.com
SCIP-2.1.1: scip.zib.de (with CPLEX and IPOPT)
XPRESS-7.2.1: XPRESS
Times given are user times in seconds. Time limit 10,800 seconds.

\[
\begin{align*}
\text{QP} &= \quad \\
\text{Scaled geometric means of runtimes} &= \\
53.9 &\quad 239 &\quad 2.68 &\quad 261 &\quad 1 &\quad 14.8 &\quad 1.67 \\
\end{align*}
\]

\begin{align*}
\text{\text{problem} & Bonmin, Couenne, CPLEX, FilMINT, GUROBI, SCIP, XPRESS} \\
\end{align*}

\[
\begin{align*}
\text{QCQP} &= \quad \\
\text{Scaled geometric means of runtimes} &= \\
12.9 &\quad 18.7 &\quad 2.67 &\quad 32.7 &\quad 1 \\
\end{align*}
\]

\begin{align*}
\text{\text{problem} & Bonmin, Couenne, CPLEX, FilMINT, XPRESS} \\
\end{align*}
Observations and Conclusions

- Observation: TTB (Tuning To the Benchmarks)
  - CPLEX-12.3 -> CPLEX-12.4preview
    * better for MIPLIB benchmarks
    * worse for pathological ones
  - MOSEK-6.0.0.122 -> 6.0.0.126 Changelog
    * Improved the interior point optimizers for linear problems for certain hard problems.
Conclusions: Declare Winners?

- **MIPLIB-bench**: CPLEX/Gurobi-XPRESS
- **MIPLIB-feas**: Gurobi-CPLEX-XPRESS, FEASPUMP close
- **MIPLIB-infeas**: Gurobi, CPLEX close, XPRESS slow
- **Pathological**: Gurobi-CPLEX, SCIP,FSCIP respectable
- **MIQP**: Gurobi
- **MIQCQP**: XPRESS
- **LP**: CPLEX/Gurobi; **QP/QCQP**: XPRESS/MOSEK
Thank you!