Pierre Bonami
CPLEX Optimization – IBM Spain

CPLEX keeps getting better and Energy Optimization

COST workshop – Dublin – March 1st 2015

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News from IBM Optimization

- Two CPLEX releases in 2015
  - 12.6.2 (June)
  - 12.6.3 (December)
- Decision Optimization on the Cloud
  - CPLEX and CPO accessible as a service.
  - Support for OPL added June 2015.

- Docplex (developing)
  - Python modeling layer for CPLEX and CPO
  - Prepared to connect locally or to the cloud
  - Free and open source
  - Integrated with Python software ecosystem
  - Notebook-ready

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Everything CPLEX can handle

All variables continuous	LP Convex QP Convex QCP	
Some or all variables Integer	MIP Convex MIQP Convex MIQCP	

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Everything CPLEX can handle

All variables continuous	LP Convex QP Convex QCP	Nonconvex QP
Some or all variables Integer	MIP Convex MIQP Convex MIQCP	

Barrier (local) 2011

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Everything CPLEX can handle

All variables continuous	LP Convex QP Convex QCP	Nonconvex QP
Some or all variables Integer	MIP Convex MIQP Convex MIQCP	Nonconvex MIQP

Spatial B&B 2013

- Relax to convex QP
- Spatial branch-and-bound

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CPLEX Progress in 2015

All variables continuous	**LP** **Convex QP** **Convex QCP**	Nonconvex QP
Some or all variables Integer	MIP Convex MIQP Convex MIQCP	Nonconvex MIQP

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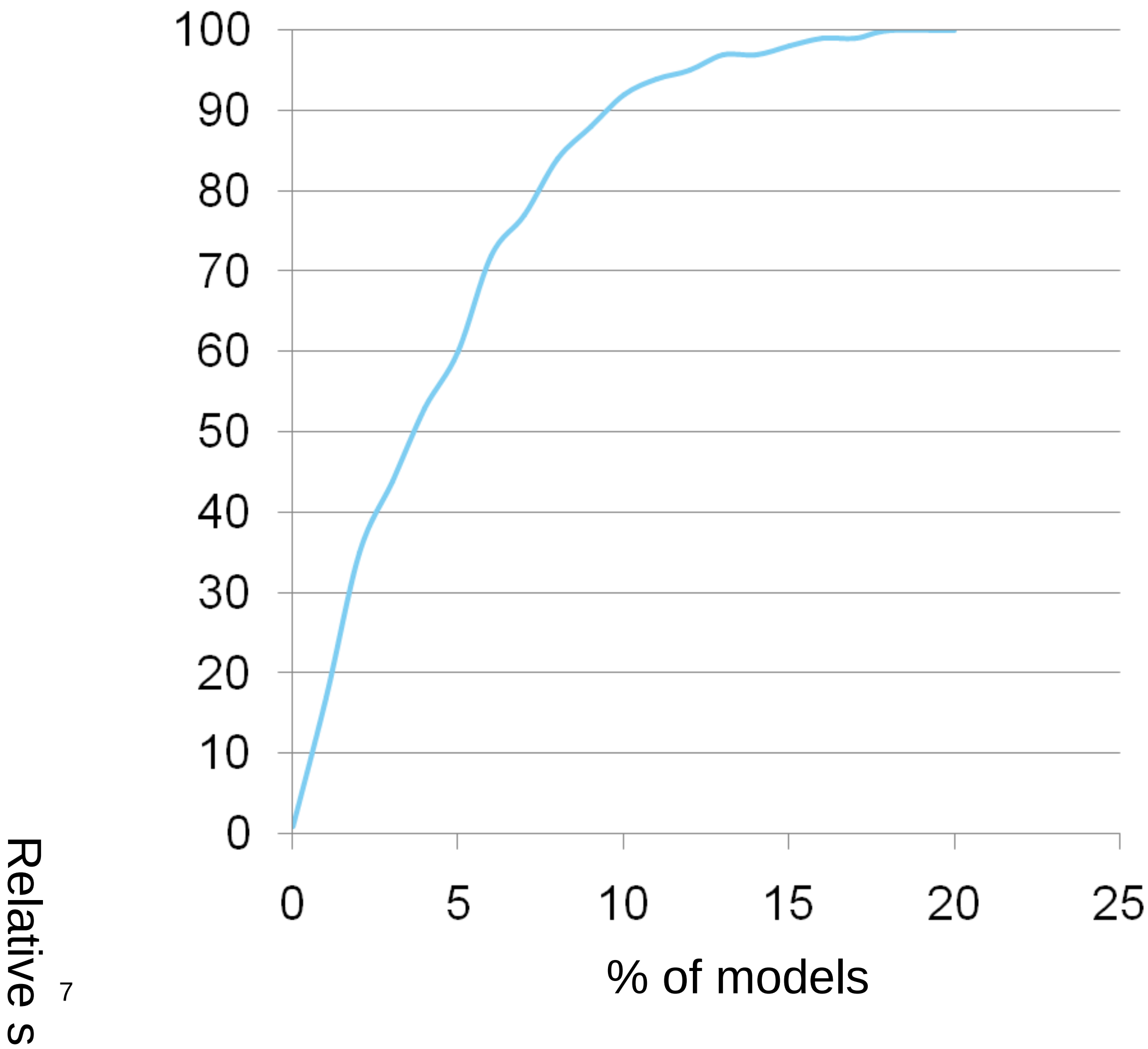
Symmetries in LPs



Using internal set of
2128 LP problem instances

- < 25% have symmetry
- ~ 5% considerable

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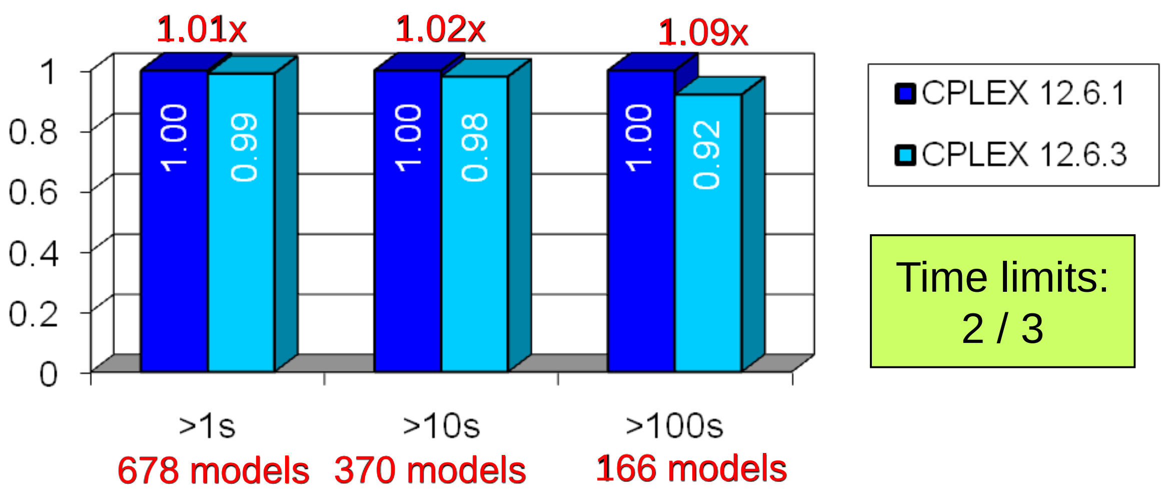
CPLEX 12.6.1 vs.12.6.3: LP performance improvement



Concurrent LP
(12 threads)

Main improvement come from exploiting the symmetry in the models:

Roland Wunderling, “Symmetry: What LP Can Learn from MIP”, INFORMS 2015
Available online

Date:	25 October 2015
Testset:	LP: 2271 models
Machine:	Intel X5650 @ 2.67GHz, 24 GB RAM, 12 threads, deterministic
Timelimit:	10,000 sec

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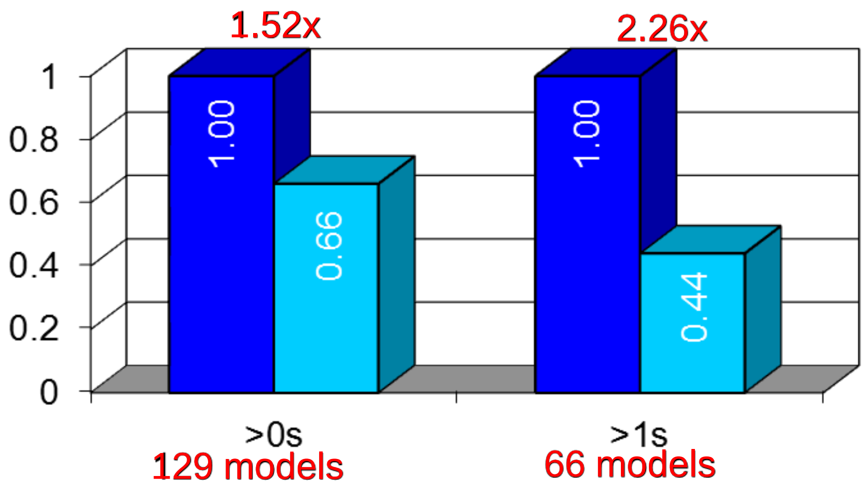
CPLEX 12.6.1 vs.12.6.3: QCP/SOCP performance improvement



Time limits:
8 / 0

SOCP barrier
(12 threads)

- Improved dense column handling
- Improved handling of short cones
- Excluding the 8 time outs for CPLEX 12.6.1:
  - Speed-up of 1.05x in “>0 secs”
  - Speed-up of 1.10x in “>1 secs”

Date:	25 October 2015
Testset:	SOCP: 142 models
Machine:	Intel X5650 @ 2.67GHz, 24 GB RAM, 12 threads, deterministic
Timelimit:	10,000 sec

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CPLEX Progress in 2015

All variables continuous	LP Convex QP Convex QCP	Nonconvex QP
Some or all variables Integer	**MIP** **Convex MIQP** **Convex MIQCP**	Nonconvex MIQP

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MILP performance improvement: summary

- Node presolve improvements (estimated performance improvement: 2%)
  - Improved handling of bound strengthening for continuous and general integer variables
  - Improved propagation of indicator constraints
    - Estimated performance impact on models with indicator constraints: 13%
    - But test set is too small

- Dynamic search improvement:
  - Estimated performance impact: 3%

- Node cuts improvements:
  - More aggressive separation
  - More aggressive filtering
  - Estimated performance improvement: 5%

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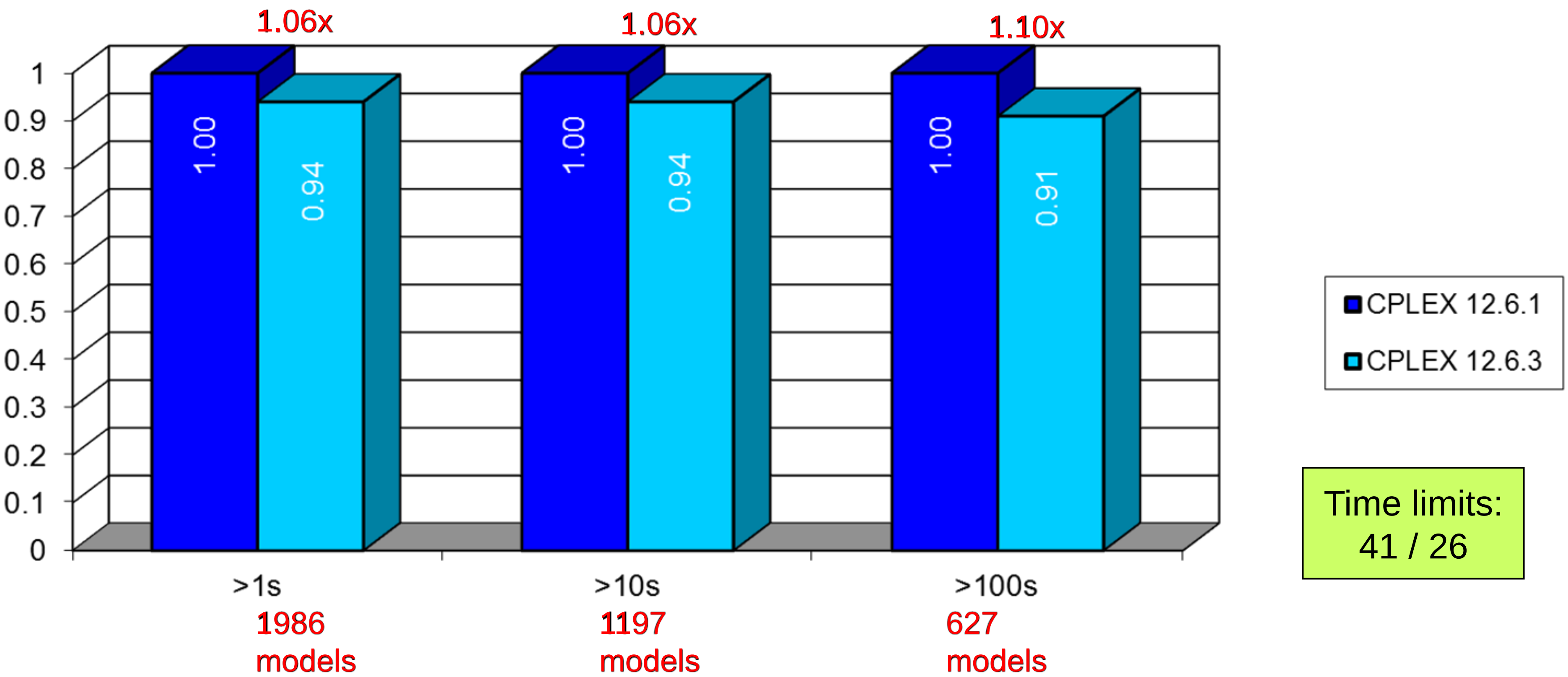
CPLEX 12.6.1 vs. 12.6.3: MILP performance improvement

Deterministic parallel MILP (12 threads)



Time limits: 41 / 26

Date:	25 October 2015
Testset:	MILP: 4245 models
Machine:	Intel X5650 @ 2.67GHz, 24 GB RAM, 12 threads, deterministic
Timelimit:	10,000 sec

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MISOCP performance improvements (CPLEX 12.6.2, June 2015)

▪Major improvements for Outer Approximation B&C

–Cone disaggregation

•Original idea in [Tawarmalani Sahinidis, 2005, Hijazi et al., 2013, Vielma et al., 2015]

–Cone strengthening by perspective reformulation

•Original idea in [Günlük and Linderoth, 2011]

–Lift-and-Project (L&P) cutting planes (available for MILP since CPLEX 12.5.1)

•Linear cuts that exploit non-linear constraints

•LP-based OA scheme from [Kilinç et al., 2011]

•Compact separation LP from [Bonami, 2011]

•Plus our own normalization to truncate the separation LP

▪Redesigned heuristic to choose algorithm to apply in view of these changes.

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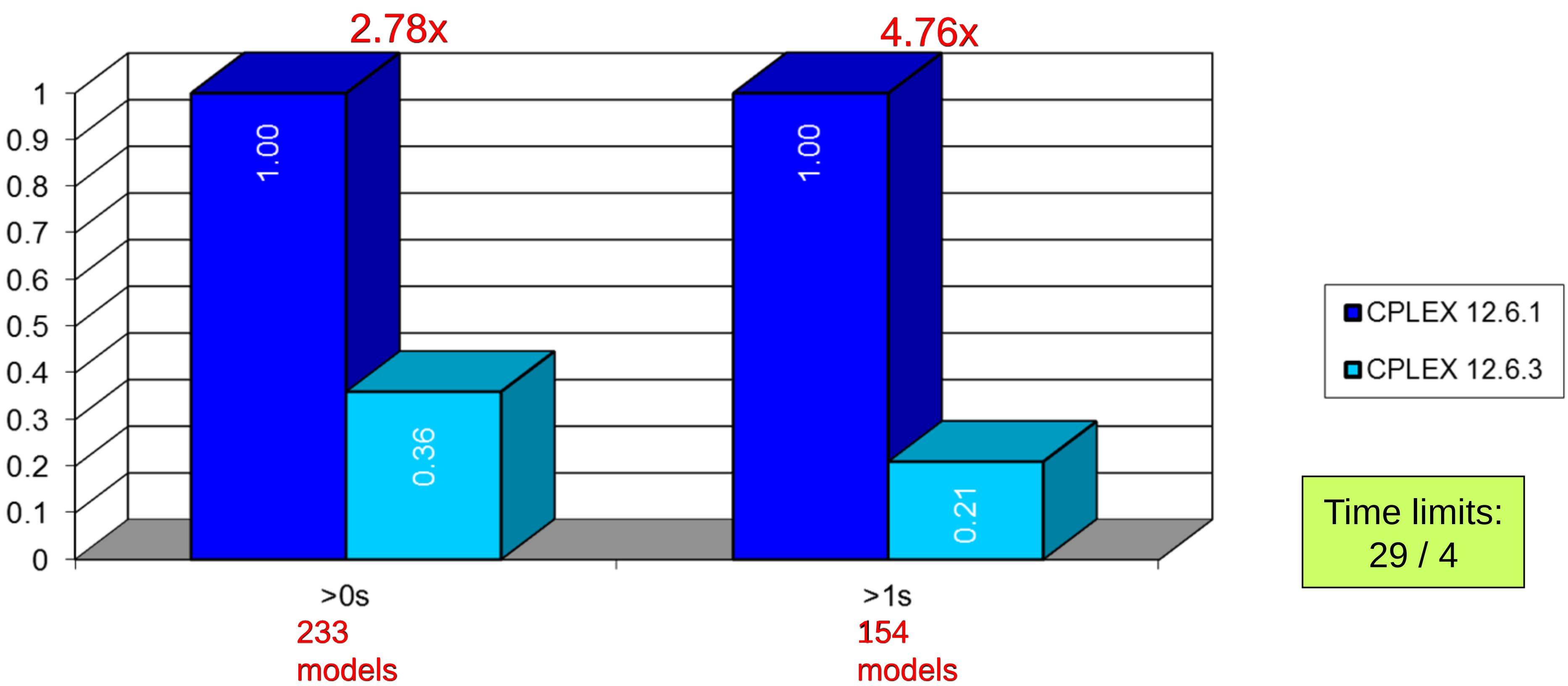
CPLEX 12.6.1 vs.12.6.3: Convex MIQCP performance improvement

Deterministic parallel MIQCP (12 threads)



Date:	25 October 2015
Testset:	MIQCP: 296 models
Machine:	Intel X5650 @ 2.67GHz, 24 GB RAM, 12 threads, deterministic
Timelimit:	10,000 sec

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CPLEX Progress in 2015

All variables continuous	LP Convex QP Convex QCP	**Nonconvex QP**
Some or all variables Integer	MIP Convex MIQP Convex MIQCP	**Nonconvex MIQP**

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BQP cuts for non-convex (MI)QPs

[joint project with IBM Research (Günlük and Linderoth)]

Box QP:

$$\max \frac{1}{2}x^T Q x + c^T x$$
$$s.t.$$
$$0 \le x \le 1$$

(box QP is a trivial relaxation of any non-convex QP with bounds)

Bin QP

$$\max \frac{1}{2}x^T \tilde{Q} x + c^T x$$
$$s.t.$$
$$x \in \{0,1\}^n$$

where $\tilde{q}_{ii} = 0$ if $q_{ii} < 0$, $\tilde{q}_{ij} = q_{ij}$ otherwise.

Bin QP is a relaxation of Box QP!

Any valid cut for Bin QP is valid for Box QP.

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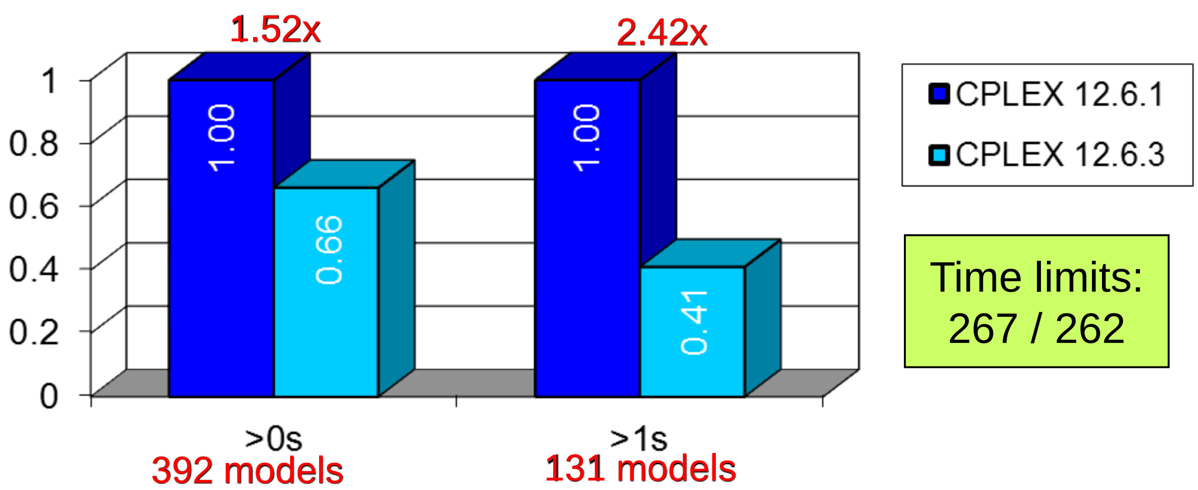
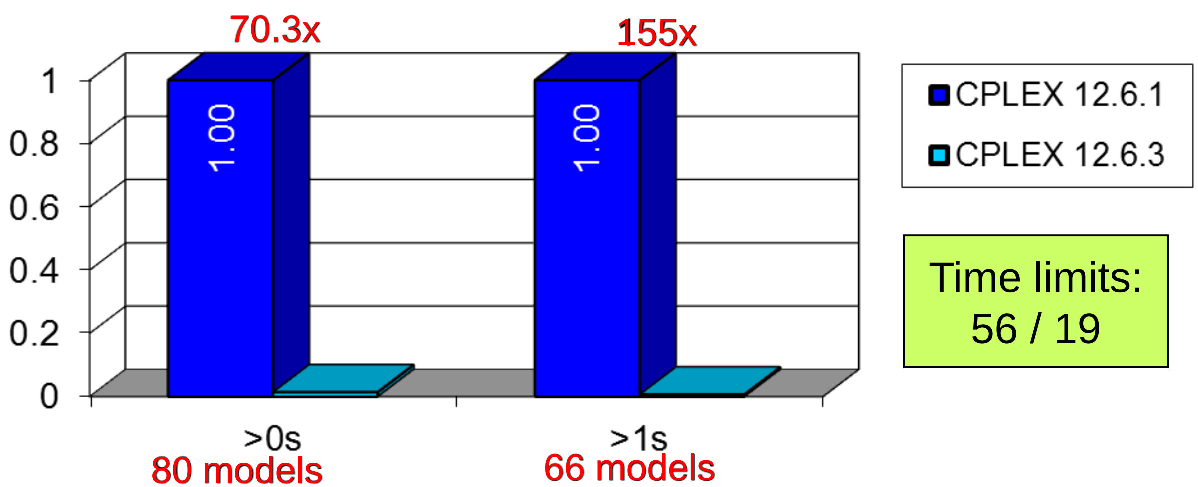
CPLEX 12.6.1 vs.12.6.3: Global (MI)QP performance improvement

CPLEX test bed



Box-QP test bed

[Vandenbussche & Nemhauser, ‘05,
Burer & Vandenbussche, ‘09]



Date:	25 October 2015
Testset:	CPLEX test bed: 675 models; Box-QP test bed: 99 models
Machine:	Intel X5650 @ 2.67GHz, 24 GB RAM, 12 threads, deterministic
Timelimit:	10,000 sec

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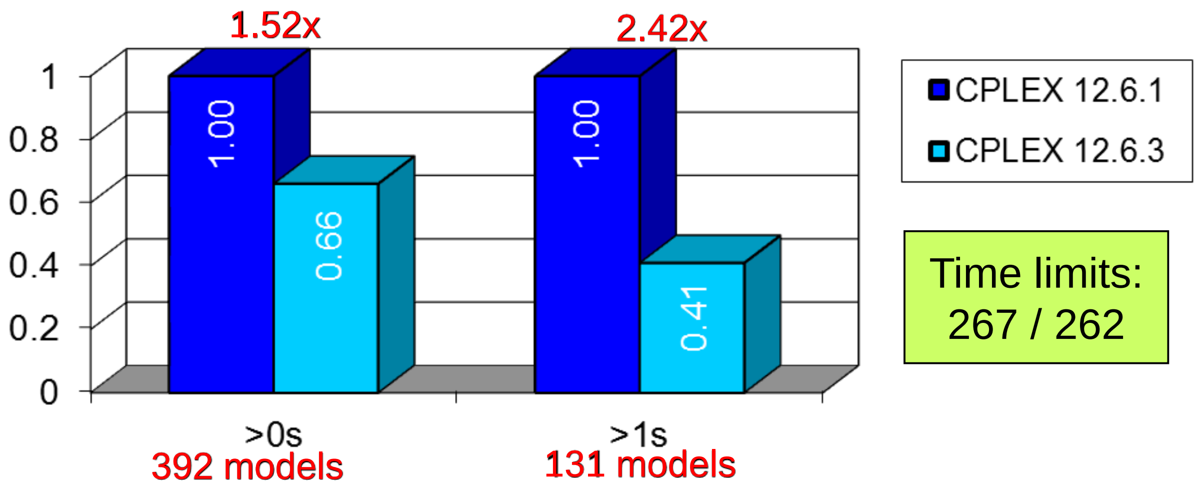
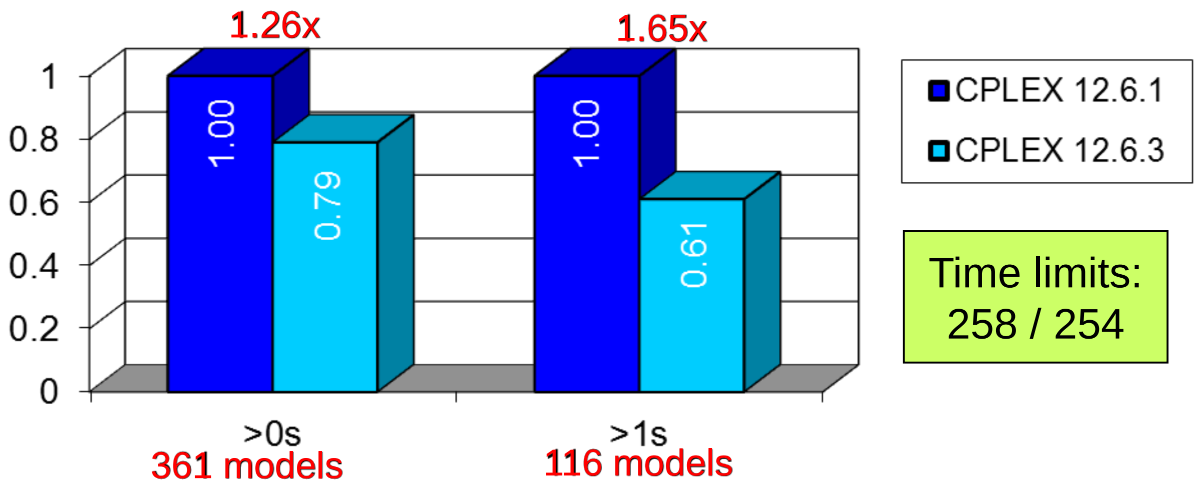
CPLEX 12.6.1 vs.12.6.3: Global (MI)QP performance improvement



Time limits: 267 / 262

CPLEX test bed



Time limits: 258 / 254

CPLEX test bed (without Box-QPs)

Date:	25 October 2015
Testset:	CPLEX test bed: 675 models; Box-QP test bed: 99 models
Machine:	Intel X5650 @ 2.67GHz, 24 GB RAM, 12 threads, deterministic
Timelimit:	10,000 sec

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CPLEX Progress in 2015

All variables continuous	LP Convex QP Convex QCP	Nonconvex QP
Some or all variables Integer	MIP Convex MIQP Convex MIQCP	Nonconvex MIQP

+9%

125%

+10%

240%

480%

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IBM ILOG Optimization for the Power Industry

Contact

- **Sofiane Oussedik, soussedik@fr.ibm.com**
- **Hermann Stolle, hfmstolle@de.ibm.com**

Presenter : Alex Fleischer
(Stolen by Pierre Bonami)

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Short Term Unit Commitment: the good MIP story

MISO Unlocks Billions in Savings Through the Application of Operations Research for Energy and Ancillary Services Markets. B. Carlson, Y. Chen et al. INFORMS Interfaces (2012), volume 42, No.1. (Edelman award finalist).

- Short Term Unit Commitment.
- Robust constraints on the transmission system to handle failures of a power plant.
- Solved daily with a hard time constraint of 20 minutes.
- Implemented in 2007
- Pure black box MIP approach (replacing a Lagrangian relaxation)

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Short Term Unit Commitment: a few years later

Overcoming Computational Challenges on Large Scale Security Constrained Unit Commitment (SCUC) Problem – MISO and Alstom's Experience with MIP Solver. Y. Chen et al. FERC Technical Conference. June 23-25, 2014

- 18,1474 rows, 48,9155 columns, and **10,585,477 nonzeros** and 54,245 binaries

CPLEX12.5	Root relaxation	MIP Gap with 1200s time limit
Thread=1	454s	40.18%
Thread=8	279s	99.99%

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Hot Topics: AC Optimal Power Flow problem

Classical non-linear problem with good conic relaxations with a continued tremendous activity.

In the past year, two groups in particular applying MINLP types of approaches with very good computational results:

- Coffin, Hijazi and Van Henterryck (3 papers in 2015)
- Kocuc, Dey and Sun (3 papers in 2015)

Derivation of new relaxation and new cutting planes based on:

- Convex envelope of arctangents
- McCormick Relaxation of cycles
- SDP
- ...

Coupling with bound tightening and constraint programming techniques.

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Hot problem: pooling problem

Most classical problem in petroleum industries.

On of the driving problems for progress in MINLP. In recent years:

- Apogee (Misener, Thompson and Floudas 2011), GloMIQO (Misener and Floudas 2013), ANTIGONE (Misener and Floudas, 2014).
- Pooling problems: relaxations and discretizations (Gupte, Ahmed Dey and Cheon 2013), make a MILP approximation of pooling problem derive cutting planes…

Still a huge gap between theory and practice. Industrial models can be challenging even for local optimality.

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Hot Topic: MINLP

MINLP has seen tremendous progress in the last 10 years:

- Solvers for Convex MINLP exploiting branch-and-cut: FilMINT, Bonmin, SCIP,…
- Solvers for non-convex MINLP or global optimization: Baron, Couenne, SCIP, ANTIGONE,…

According to Vigerske (2015) a speedup of nearly 15x in 4 years! (2011-2015).

Still, many applications out of reach (Gaz Network with SCIP is an exception).

Technologies are making their ways into commercial solvers.

Some problems in Energy Optimization have good potential to be next success story.

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