Automated Configuration of MIP solvers

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Parameters in Algorithms

Most algorithms have parameters

- Decisions that are left open during algorithm design
  - numerical parameters (e.g., real-valued thresholds)
  - categorical parameters (e.g., which heuristic to use)
- Set to optimize empirical performance
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Prominent parameters in MIP solvers

- Preprocessing
- Which type of cuts to apply
- MIP strategy parameters
- Details of underlying linear (or quadratic) programming solver
Example: IBM ILOG CPLEX

- 76 parameters that affect search trajectory
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  “Integer programming problems are more sensitive to specific parameter settings, so you may need to experiment with them.” [Cplex 12.1 user manual, page 235]
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- “Experiment with them”
  - Perform manual optimization in 76-dimensional space
  - Complex, unintuitive interactions between parameters
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▶ “Experiment with them”
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- “Experiment with them”
  - Perform manual optimization in 76-dimensional space
  - Complex, unintuitive interactions between parameters
  - Humans are not good at that

- CPLEX automated tuning tool (since version 11)
  - Saves valuable human time
  - Improves performance
Our work: automated algorithm configuration

Given:
- Runnable algorithm $A$, its parameters and their domains
- Benchmark set of instances $\Pi$
- Performance metric $m$

This paper: application study for MIP solvers

Use existing algorithm configuration tool ($ParamILS$)

Use different MIP solvers ($Cplex$, $Gurobi$, $lpsolve$)

Use six different MIP benchmark sets

Optimize different objectives (runtime to optimality/MIP gap)
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First to handle this with many categorical parameters
- E.g. 51/76 Cplex parameters are categorical
- $10^{47}$ possible configurations

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  - \( 10^{47} \) possible configurations \( \leadsto \) **algorithm configuration**
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Outline

1. Related work

2. Details about this study

3. Results

4. Conclusions
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Parameter Optimization Tools and Applications

- **Composer** [Gratch & Dejong, '92; Gratch and Chien, '96]
  - Spacecraft communication scheduling
- **Calibra** [Diaz and Laguna, '06]
  - Optimized various metaheuristics
- **F-Race** [Birattari et al., '04-present]
  - Iterated Local Search and Ant Colony Optimization
- **Paramils** [Hutter et al, '07-present]
  - SAT (tree & local search), time-tabling, protein folding, ...
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  - Optimized MIP solvers, including CPLEX
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  - We only found this work $\approx$ 1 month ago
  - Main problem: only optimized performance for single instances
  - Only used small subset of 10 *Cplex* parameters
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   - The automated configuration tool: PARAMILS
   - The MIP solvers: Cplex, Gurobi & lpsolve
   - Experimental Setup

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Simple manual approach for configuration

Start with some parameter configuration
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Start with some parameter configuration

Modify a single parameter
Simple manual approach for configuration

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Modify a single parameter

if results on benchmark set improve then
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How to evaluate each configuration?

- **BasicILS($N$)**: perform fixed number of $N$ runs to evaluate a configuration $\theta$
  - Variance reduction: use same $N$ instances & seeds for each $\theta$

- **FocusedILS**: choose $N(\theta)$ adaptively
  - Small $N(\theta)$ for poor configurations $\theta$
  - Large $N(\theta)$ only for good $\theta$
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Adaptive Choice of Cutoff Time

- Evaluation of poor configurations takes especially long

[Hutter et al., JAIR'09]
Adaptive Choice of Cutoff Time

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- Can terminate evaluations early
  - Incumbent solution provides bound
  - Can stop evaluation once bound is reached

Results
- Provably never hurts
- Sometimes substantial speedups

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Problems with some parameter configurations
- Segmentation faults & wrong results
- Detect such runs online, give worst possible score
- Local search avoids problematic parameter configurations
- Concise bug reports helped to fix 2 bugs in Gurobi (!)
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<td>MILP</td>
<td>2000</td>
<td>[Leyton-Brown et al., '00]</td>
</tr>
<tr>
<td>Mixed integer knapsack (MIK)</td>
<td>MILP</td>
<td>120</td>
<td>[Atamtürk, '03]</td>
</tr>
<tr>
<td>and 3 more ...</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Split benchmarks 50:50 into training and test sets

- Optimized parameters on the training set
- Reported performance on the test set
- Necessary to check for *over-tuning*
Setup of configuration experiments

Perform 10 independent runs of ParamILS

- Select configuration $\hat{\theta}^*$ of run with best training performance
Setup of configuration experiments

Perform 10 independent runs of ParamILS

- Select configuration $\hat{\theta}^*$ of run with best training performance

Compare test performance of:

- ParamILS’s configuration $\hat{\theta}^*$
- Default algorithm settings
- Cplex tuning tool
  - Gurobi and lpSolve: no tuning tool available
Outline

1. Related work

2. Details about this study

3. Results

4. Conclusions
Minimization of Runtime to Optimal Solution

▶ “Optimal”: relative optimality gap of 0.0001
   (CPLEX and GUROBI default)
Minimization of Runtime to Optimal Solution

- “Optimal”: relative optimality gap of 0.0001 (Cplex and Gurobi default)
- Ran ParamILS for 2 days on 10 machines
Minimization of Runtime to Optimal Solution

▶ “Optimal”: relative optimality gap of 0.0001
  (Cplex and Gurobi default)
▶ Ran ParamILS for 2 days on 10 machines
▶ Mean speedup (on test instances)
  – Cplex 2x to 50x

\[ \begin{array}{|c|c|}
\hline
\text{Default [CPU s]} & \text{Config. found by ParamILS [CPU s]} \\
\hline
\text{Train} & \times \\
\text{Test} & \cdot \\
\hline
\end{array} \]

Cplex on SUST instances (50x)
Minimization of Runtime to Optimal Solution

- “Optimal”: relative optimality gap of 0.0001 (Cplex and Gurobi default)
- Ran ParamILS for 2 days on 10 machines
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Cplex on SUST instances (50x)

Lpsolve on WDP instances (150x)
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Cplex on SUST instances (50x)  
Gurobi on SUST instances (2.3x)
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Gurobi on MIK instances (1.2x)

Gurobi on SUST instances (2.3x)
Comparison to Cplex tuning tool

- **Cplex** tuning tool
  - Evaluates predefined good configurations, returns best one
  - Required runtime varies (from $< 1h$ to weeks)
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<tr>
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</tr>
<tr>
<td>10^4</td>
<td>X</td>
</tr>
<tr>
<td>10^5</td>
<td></td>
</tr>
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**Cplex** on MIK instances
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**Cplex on MIK instances**

**Cplex on SUST instances**
Minimization of Optimality Gap

- Objective: minimal optimality gap within 10 seconds runtime
Minimization of Optimality Gap

- Objective: minimal optimality gap within 10 seconds runtime
- Ran PARAMILS for 5 hours on 10 machines
Minimization of Optimality Gap

- Objective: minimal optimality gap within 10 seconds runtime
- Ran $\text{PARAMILS}$ for 5 hours on 10 machines
- Reduction factors of average optimality gap (on test set)
  - $\text{Cplex}$ 1.3x to 8.6x
  - $\text{Lpsolve}$ 1x (no reduction) to 46x
  - $\text{Gurobi}$ 1.1x to 2.2x
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Conclusions

MIP solvers can be configured automatically

- Configuration tool *PARAMILS* available online:
  - [http://www.cs.ubc.ca/labs/beta/Projects/ParamILS/](http://www.cs.ubc.ca/labs/beta/Projects/ParamILS/)
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Requirements

- Representative instance set
  - 100 instances sometimes not enough
  - If you generate instances, please make more (e.g., 2000)!
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Requirements

- Representative instance set
  - 100 instances sometimes not enough
  - If you generate instances, please make more (e.g., 2000)!
- CPU time (here: $10 \times 2$ days per domain)
Future Work

▶ Model-based techniques
  – Fit a model that predicts performance of a given configuration on a given instance
Future Work

- Model-based techniques
  - Fit a model that predicts performance of a given configuration on a given instance
  - Use that model to quantify
    - Importance of each parameter
    - Interaction of parameters
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Future Work

- Model-based techniques
  - Fit a model that predicts performance of a given configuration on a given instance
  - Use that model to quantify
    + Importance of each parameter
    + Interaction of parameters
    + Interaction of parameters and instance characteristics

- Per-instance approaches for heterogeneous benchmarks
  - Given a new unseen instance:
    + Compute instance characteristics (fast)
    + Use parameter config. predicted to be best for the instance
Thanks to:

- Providers of instance benchmark sets
  - Louis-Martin Rousseau
  - Bistra Dilkina
  - Berkeley Computational Optimization Lab

- Commercial MIP solvers for free full academic license
  - IBM (Cplex)
  - Gurobi

- LPSOLVE developers for their solver

- Compute clusters
  - Westgrid
  - CFI-funded arrow cluster

- Funding agencies
  - Postdoc fellowship from CBIE
  - MITACS
  - NSERC
Backup slides
**Differences to STOP** [Baz et al, ’09]

Baz et al optimized for single instances

“In practice, users would typically be tuning for a family of related instances rather than for an individual instance”

- Generalization to sets of instances is nontrivial
  - Cannot afford to run all instances for each configuration
  - \textit{FocusedILS} adapts \# runs per configuration

**Further differences**

- Baz et al used older \texttt{Cplex} version (9.0)
  - defaults improved in newer \texttt{Cplex} versions
- Baz et al considered (only) 10 \texttt{Cplex} parameters
  - and also not all possible values for each parameter
  - in order to improve \texttt{STOP}’s performance
  - requires domain knowledge
Configuration of MIP Solvers: Optimality Gap

> Objective: minimal optimality gap within 10 seconds runtime
Configuration of MIP Solvers: Optimality Gap

- Objective: minimal optimality gap within 10 seconds runtime
- Ran PARAMILS for 5 hours on 10 machines
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Cplex on MIK instances (8.6x)
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![Graph showing optimality gap reduction for CPLEX and LPSOLVE](image)

**CPLEX** on MIK instances (8.6x)  
**LPSOLVE** on MIK instances (46x)