BOBILib: Bilevel Optimization (Benchmark) Instance Library

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A Brief History of Computational Bilevel Optimization

First computations using small continuous linear-linear or linear-quadratic bilevel problems

- Fortuny-Amat and McCarl (1981)
- Bialas and Karwan (1984)
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Survey of mixed-integer techniques for bilevel optimization

- Kleinert, Labbé, Ljubić, S. (2021)

> In addition to the mathematical aspects mentioned so far, computational bilevel optimization still suffers from the absence of a broad variety of well-curated instance libraries that can be used to test and tune specific implementations of newly developed algorithms. Although some instance sets are already publicly available (Paulavičius and Adjiman, 2019; Ralphs, 2020; Sinnl, 2020; Zhou et al., 2020), the community of computational bilevel optimization would greatly benefit from more, and in particular more diverse, instance sets.

Instance Libraries in Other Fields

MIPLIB

- Bixby et al. (1998)
- Koch et al. (2011b)
- Gleixner et al. (2019)
- `https://miplib.zib.de`

QPLIB

- Furini et al. (2019)
- `https://qplib.zib.de`

MINLPLIB

- `https://www.minlplib.org`

… and in bilevel optimization?

BASBLib

- Paulavicius and Adjiman (2017)
- `https://github.com/basblsolver/BASBLib`
- “Only” continuous bilevel instances
- Based on AMPL

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Very recently: solver package by Jungen et al. (2023)

- `https://git.rwth-aachen.de/avt-svt/public/libdips?`
- Also contains a rather large set of test instances

We teamed up in 2017 (... or 2018?)





What do we have in 2024?

BOBILib: Bilevel Optimization (Benchmark) Instance Library

- More than 2500 instances of mixed-integer linear bilevel problems
- New instance data format
- New solution format
- Numerical results for all instances
- Benchmark instance subset
- Feasibility checker

Agenda

1. Instance Subsets
2. Data Formats
3. Numerical Results
4. Benchmark Instance Set

Instance Subsets

Overview of MILP-MILP Instance Classes

	Total	UL Variables			LL Variables			UL Constraints		LL Constraints	
		Min	Max	Type	Min	Max	Type	Min	Max	Min	Max
interdiction											
assignment	24	25	25	B	25	25	B	1	1	45	45
clique	220	19	1593	B	8	1653	B	1	1	28	3363
generalized	90	40	50	B	40	50	MI	20	20	30	50
knapsack	599	10	500	B	10	500	I	1	1	11	501
multidimensional-knapsack	954	10	500	B	10	500	B	1	29	11	529
network	72	22	79	B	44	158	B	1	1	41	974
general-bilevel											
mixed-integer	489	10	714 549	MI	10	714 549	MI	0	480 585	4	961 170
pure-integer	146	1	78 734	I	1	78 733	I	0	2	3	4944

Data Formats

Input Data Format

- Every instance is a pair of files
- MPS file contains the high-point relaxation
- AUX file specifies the lower-level problem

Input Data Format: Example 2 in Moore and Bard (1990)

Upper Level

$$\begin{aligned} (-)\min_{x,y} \quad & F(x,y) = x + 2y \\ \text{s.t.} \quad & y \in S(x), \end{aligned}$$

Lower Level

$$\begin{aligned} (-)\min_{y} \quad & f(x,y) = -y \\ \text{s.t.} \quad & -x + 2.5y \leq 3.75, \\ & x + 2.5y \geq 3.75, \\ & 2.5x + y \leq 8.75, \\ & x, y \geq 0, \\ & x, y \in \mathbb{Z}. \end{aligned}$$

Input Format: MPS & AUX files

```
* ENCODING=ISO-8859-1
NAME          moore90_2
ROWS
 N  R0004
 L  R0001
 L  R0002
 L  R0003
COLUMNS
    MARK0000  'MARKER'                 'INTORG'
    C0001     R0004                          1
    C0001     R0001                         -1
    C0001     R0002                         -1
    C0001     R0003                        2.5
    C0002     R0004                          2
    C0002     R0001                        2.5
    C0002     R0002                       -2.5
    C0002     R0003                          1
    MARK0001  'MARKER'                 'INTEND'
RHS
    rhs       R0001                       3.75
    rhs       R0002                      -3.75
    rhs       R0003                       8.75
BOUNDS
 UP bnd       C0001                          3
 LO bnd       C0002                          1
 UP bnd       C0002                          2
ENDATA
```

Input Format: MPS & AUX files

```
* ENCODING=ISO-8859-1
NAME          moore90_2
ROWS
 N  R0004
 L  R0001
 L  R0002
 L  R0003
COLUMNS
    MARK0000  'MARKER'                 'INTORG'
    C0001     R0004                          1
    C0001     R0001                         -1
    C0001     R0002                         -1
    C0001     R0003                        2.5
    C0002     R0004                          2
    C0002     R0001                        2.5
    C0002     R0002                       -2.5
    C0002     R0003                          1
    MARK0001  'MARKER'                 'INTEND'
RHS
    rhs       R0001                       3.75
    rhs       R0002                      -3.75
    rhs       R0003                       8.75
BOUNDS
 UP bnd       C0001                          3
 LO bnd       C0002                          1
 UP bnd       C0002                          2
ENDATA
```

```
@NUMVARS
1
@NUMCONSTRS
3
@VARSBEGIN
C0002  -1.
@VARSEND
@CONSTRSBEGIN
R0001
R0002
R0003
@CONSTRSEND
@NAME
moore90_2
@MPS
moore90_2.mps
```

Solution Format (json)


```
{
    "name": "moore90_2",
    "bilevel_type": "optimistic",
    "status": "optimal",
    "difficulty": "easy",
    "objective_value": 5.0,
    "upper_level_decisions": {
        "C0001": 3.0
    },
    "lower_level_decisions": {
        "C0002": 1.0
    }
}
```

Numerical Results

Solvers

MibS 1.2.1

- Freely available
- Open-source
- DeNegre and Ralphs (2009), Tahernejad and Ralphs (2020)
- MILP sub-solver: CPLEX 22.1.1

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Virtual best solver

for each instance, the fastest

Hardware Setup

- Single node of a server with Intel XEON SP 6126 CPUs
- Time limit: 1 h
- Memory limit: 32 GB
- Number of threads: 4

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Just since April 2024

- 60 100 CPU hours
- Almost 7 CPU years

Number of Variables and Constraints in the Entire Collection

	Min	1st Quartile	Median	3rd Quartile	Max
UL Variables	1	64	250	500	714 549
Integer	0	0	0	0	77 626
Binary	0	45	100	400	636 923
Continuous	0	0	0	0	399 808
LL Variables	1	71	250	500	714 549
Integer	0	0	0	80	40 180
Binary	0	0	64	250	674 369
Continuous	0	0	0	0	399 608
Linking Variables	1	60	250	500	714 549
Integer	0	0	0	0	77 626
Binary	0	40	100	400	636 923
Continuous	0	0	0	0	394 447
UL Constraints	0	1	1	9	480 585
LL Constraints	3	84	201	501	961 170
Coupling Constraints	0	0	0	0	356 461

Statistics for the Entire Collection

Number of solved and open problems for the entire collection with time limit of 1 h

Total	Optimal	Infeasible	Open with feasible point	Open
2594	990	33	1141	430

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Runtimes (s) of the virtual best solver (only for instances solved to optimality)

Min	1st Quartile	Median	3rd Quartile	Max
0.01	0.42	2.68	32.18	3475.75

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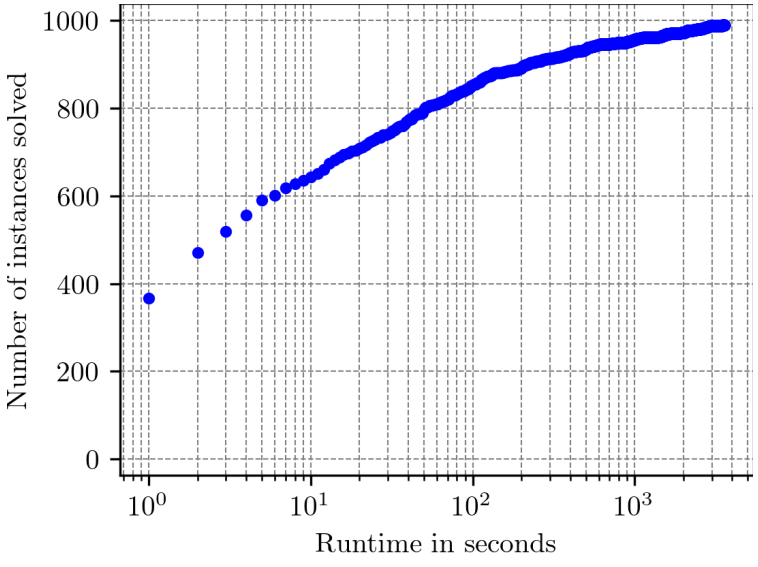
Min	1st Quartile	Median	3rd Quartile	Max
0.01	0.42	2.68	32.18	3475.75

Instances solved within specific time ranges (only for instances solved to optimality)

$[0, 10)$	$[10, 100)$	$[100, 1000)$	$[1000, 3600)$
636	211	109	34

Virtual Best Solver: Entire Collection



Take-Home Messages

- Large number of instances can be solved quickly (within 10 s)
- Instances whose solution time exceeds 10 s are much more difficult to solve to optimality
- Feasible point known but not solved to optimality for large number of instances
  - Status: open with feasible point
- Proving optimality seems to be the main challenge
- Library mainly contains instances that are either easy or difficult
- Need to increase the number of instances of moderate difficulty

Benchmark Instance Set

Defining Conditions

- The instance can be solved by both solvers within 1400 s
- It requires at least 10 s for each solver to solve the instance
- The instance is either infeasible or has a finite optimum
- The results of both solvers are consistent and pass the feasibility check

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- The instance can be solved by both solvers within 1400 s
- It requires at least 10 s for each solver to solve the instance
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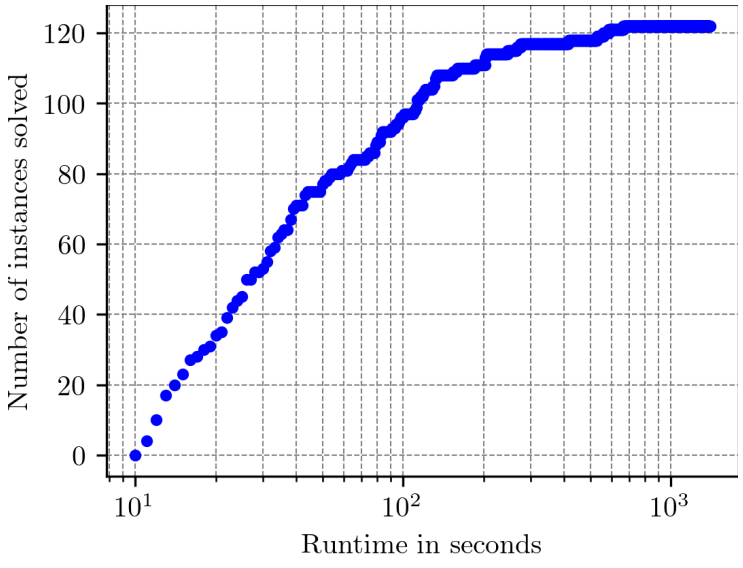
- The results of both solvers are consistent and pass the feasibility check

- 122 instances (all feasible)
- 60 instances are considered as easy, i.e., they can be solved by both solvers within 180 s
- Virtual best solver can solve 110 benchmark instances within 180 s

Virtual Best Solver: Benchmark Instance Set



Statistics for the Benchmark Instance Set

Runtimes (s) of the virtual best solver

Min	1st Quartile	Median	3rd Quartile	Max
10.51	19.03	33.85	83.84	664.73

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Runtimes (s) of the virtual best solver

Min	1st Quartile	Median	3rd Quartile	Max
10.51	19.03	33.85	83.84	664.73

Instances solved within specific time ranges

$[0, 10)$	$[10, 100)$	$[100, 1000)$	$[1000, 3600)$
0	96	26	0

Benchmark Instance Set

Sets	BOBILib	Benchmark Set
collection	2594	122
interdiction	1959	53
generalized	90	27
assignment	24	0
knapsack	599	9
multidimensional-knapsack	954	0
clique	220	0
network	72	17
general-bilevel	635	69
mixed-integer	489	63
pure-integer	146	6

Number of Variables and Constraints of the Benchmark Instances

	Min	1st Quartile	Median	3rd Quartile	Max
UL Variables	5	50	360	700	2258
Integer	0	0	10	600	1000
Binary	0	0	0	50	2258
Continuous	0	0	0	0	0
LL Variables	10	50	360	700	2258
Integer	0	10	170	315	512
Binary	0	0	0	20	2258
Continuous	0	0	20	308	527
Linking Variables	5	40	360	700	2258
Integer	0	0	10	600	1000
Binary	0	0	0	40	2258
Continuous	0	0	0	0	0
UL Constraints	0	1	20	240	400
LL Constraints	7	40	184	280	3664
Coupling Constraints	0	0	20	240	400

Future Plans

- Collect more instances of real-world bilevel problems
- More instances that are not of some kind of interdiction type
- More balanced set of instances
- More infeasible instances
- Extension to the pessimistic case

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`http://bobilib.org`

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- Please submit instances if you have some!
- Please report new solutions if you have some!
- Please report bugs if you find some!