vOptSolver: an open source software environment for multiobjective mathematical optimization

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vOpt Research Project

Exact Efficient Solution of Mixed Integer Programming Problems with Multiple Objective Functions (ANR/DFG-14-CE35-0034-01)

Parts (algorithms, instances) of the outputs are integrated in:

- **vOptSolver**: a solver of multiobjective linear optimization problems (MOCO, MOIP, MOMILP, MOLP)
- **vOptLib**: a numerical instances library of multiobjective linear optimization problems (MOCO, MOIP, MOMILP, MOLP)

  History: MCDMlib (opened in 1998) — MOCOlib, the MOCO section of the MCDMlib (opened in 2007) — GUEPARDlib (opened in 2010)

Introduction

Context

Computing Y_N for Multiobjective (linear) Optimization Problems (MOP):

$$\begin{aligned} \min z(x) &= Cx \\ \text{s/t } Tx &\leqq d \end{aligned}$$

$x \in \mathbb{R}^{n_1}$	$x \in \mathbb{R}^{n_1} \times \mathbb{Z}^{n_2}$	$x \in \mathbb{Z}^{n_2}$
Multi Objective Linear Problem (MOLP)	Multi Objective Mixed-Integer Linear Problem (MOMILP)	Multi Objective Integer Problem (MOIP)

MO(M)ILP + structure
MultiObjective Combinatorial Optimization (MOCO)

where:

$$\begin{aligned} T \in \mathbb{Z}^{m \times n} &\longrightarrow m \text{ constraints, } i = 1, \ldots, m \\ C \in \mathbb{Z}^{n \times p} &\longrightarrow \text{the objective matrix} \\ X = \{x \in \mathbb{R}^{n_1} \times \mathbb{Z}^{n_2} | Tx \leq d\} \subseteq \mathbb{R}^n &\longrightarrow \text{the set of feasible solutions} \\ Y = z(X) \subseteq \mathbb{R}^p &\longrightarrow \text{the set of images} \end{aligned}$$

Identified software for computing exact Y_N of MOP

- **ADBASE** (Ralph Steuer, 1975)
  - Problem class solved: MOLP
  - Algorithm(s): simplex algorithm
  - not available online
- **Bensolve** (Andreas Löhne, 2017); available online:
  - Problem class solved: vector linear programs (including MOLP)
  - Algorithm(s): Benson's algorithm (language C)
  - `http://bensolve.org`
- **Inner** (Laszlo Csirmaz, 2016); available online:
  - Problem class solved: MOLP
  - `https://github.com/lcsirmaz/inner`
- **PolySCIP** (Sebastian Schenker, 2016); available online:
  - Problem classes solved: p-LP, 2-IP, 3-IP (MOMILP experimentally)
  - `http://polyscip.zib.de`

Presentation of vOptSolver (1/2)

Solver of MOLP/MOMILP/MOIP/MOCO for **scientifics** and **practionners**

- Aims
  - **Easy** to formulate a problem, to provide data, to solve a problem, to collect the outputs, to analyze the solutions
  - **Natural and intuitive** use for mathematicians, informaticians, engineers

- Purposes
  - **Research needs:**
    support and primitives for the development of new algorithms
  - **Solving needs:**
    methods and algorithms for performing numerical experiments
  - **Pedagogic needs:**
    environment for practicing of theories and algorithms

Presentation of vOptSolver (2/2)

- **Characteristics**
  - Efficient, flexible, evolutive
  - Free, open source, multi-platform, reusing existing specifications
  - Easy to install (no need of being expert in computer science)

- **Background**
  - Julia programming language, and JuMP algebraic language
  - Free (GLPK) and commercial (CPLEX, GUROBI) MILP solvers
  - Homemade solvers implemented in C/C++ language

vOptSolver

$\sim$

a backbone,
based on Julia and JuMP,
embedding algorithms coded in C/C++/Julia

Why Julia and JuMP as cement of vOptSolver?

Julia programming language

- a high-level, high-performance programming language for scientific computing
- familiar for the practitioners of Matlab, Fortran, Python, C/C++, Pascal, etc.
- integrates natively a mechanism to call external libraries written in C or C++
- `http://julialang.org/`

JuMP algebraic language (Julia for mathematical optimization)

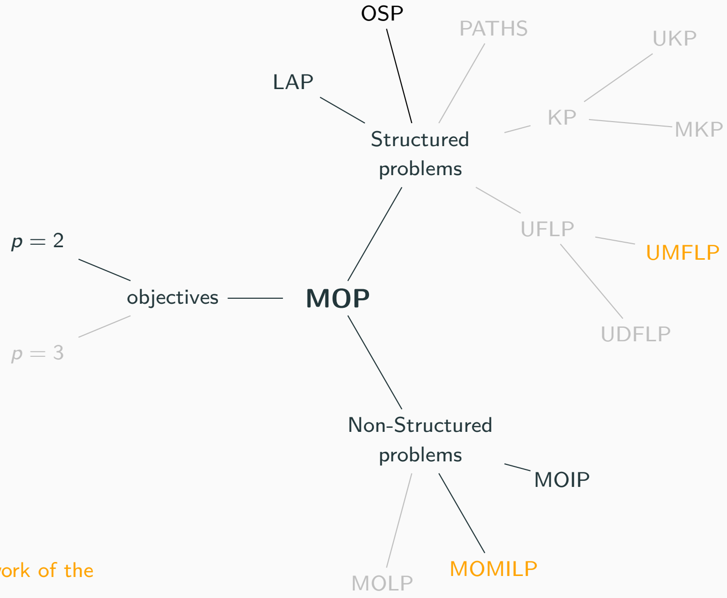
- a domain-specific modeling language for mathematical optimization in Julia
- familiar for the practitioners of GMP, AMPL, MPL, GAMS, OPL, and etc.
- wrapped with several open-source/commercial solvers (e.g. GLPK and CPLEX).
- `http://jump.readthedocs.io/en/latest/`

Miles Lubin and Iain Dunning: Computing in Operations Research Using Julia. *INFORMS Journal on Computing*, 27(2), 238–248, 2015.

Iain Dunning, Joey Huchette, and Miles Lubin: JuMP: A Modeling Language for Mathematical Optimization. *SIAM Review*, 59(2), 295–320. 2017.

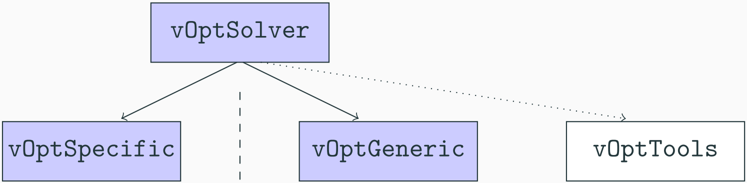
vOptSolver

Multi-objective linear optimization problems targeted



Framework of the
ANR/DFG research project

Design of vOptSolver



vOptSpecific	vOptGeneric	vOptTools
Multiobjective structured problems	Multiobjective non-structured problems	Multiobjective primitives
Application Programming Interface (API)	Algebraic Language (JuMP)	Application Programming Interface (API)
Collection of specific algorithms	Collection of generic algorithms	Collection of useful algorithms

Using vOptSolver

Two modes:

1. **a distant use**

   - in the cloud with JuliaBox

     `http://juliabox.com`

2. **a local use**

   - on macOS

     vOptGeneric and vOptSpecific tested on v10.12.5

   - on linux

     vOptGeneric and vOptSpecific tested on ubuntu 14.04 LTS

   - on windows

     not tested (vOptGeneric: ready; vOptSpecific: perhaps later...)

vOptSolver has been tested with:

- Julia v0.6
- GLPK v4.62

Example: 2-LAP

$$
\left[
\begin{array}{lcll}
\min z^k & = & \displaystyle\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}^k x_{ij} & k = 1, \ldots, 2 \\
s/c & & \displaystyle\sum_{i=1}^{n} x_{ij} = 1 & j = 1, \ldots, n \\
 & & \displaystyle\sum_{j=1}^{n} x_{ij} = 1 & i = 1, \ldots, n \\
 & & x_{ij} = (0, 1) & \begin{array}{l} i = 1, \ldots, n \\ j = 1, \ldots, n \end{array}
\end{array}
\right]
$$

$$
C^1 = \begin{pmatrix} 3 & 9 & 0 & 0 & 6 \\ 16 & 0 & 6 & 12 & 19 \\ 2 & 7 & 11 & 15 & 8 \\ 4 & 11 & 7 & 16 & 3 \\ 2 & 5 & 1 & 9 & 0 \end{pmatrix}
$$

$$
C^2 = \begin{pmatrix} 16 & 5 & 6 & 19 & 12 \\ 15 & 7 & 13 & 7 & 7 \\ 1 & 2 & 13 & 2 & 3 \\ 14 & 7 & 8 & 1 & 7 \\ 10 & 10 & 1 & 0 & 0 \end{pmatrix}
$$

Example: 2-LAP

$$\left[\begin{array}{lcll} \min z^k & = & \displaystyle\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}^k x_{ij} & k = 1, \ldots, 2 \\ s/c & & \displaystyle\sum_{i=1}^{n} x_{ij} = 1 & j = 1, \ldots, n \\ & & \displaystyle\sum_{j=1}^{n} x_{ij} = 1 & i = 1, \ldots, n \\ & & x_{ij} = (0,1) & \begin{array}{l} i = 1, \ldots, n \\ j = 1, \ldots, n \end{array} \end{array}\right]$$

```
n  =  5

C1 = [  3   9   0   0   6 ;
       16   0   6  12  19 ;
        2   7  11  15   8 ;
        4  11   7  16   3 ;
        2   5   1   9   0   ]

C2 = [ 16   5   6  19  12 ;
       15   7  13   7   7 ;
        1   2  13   2   3 ;
       14   7   8   1   7 ;
       10  10   1   0   0   ]
```

Example: 2-LAP and vOptSpecific

Algorithm: Two phases

A. Przybylski, X. Gandibleux, and M. Ehrgott. Two phase algorithms for the bi-objective assignment problem. *European Journal of Operational Research*, 185(2):509–533, 2008.

Routine: algorithm provided in language C

Output: $X_E \subseteq \mathbb{N}^n$, $Y_N \subseteq \mathbb{Z}^2$

Program:

```
using vOptSpecific
m = set2LAP( n , C1 , C2 )
solver = LAP_Przybylski2008( )
z1, z2, S = vSolve( m , solver )
```

or simply (using default options)

```
using vOptSpecific
m = set2LAP( n , C1 , C2 )
z1, z2, S = vSolve( m )
```

Example: 2-LAP and vOptGeneric

Algorithm: ϵ-constraint

Y.V. Haimes, L.S. Lasdon, D.A. Wismer: On a bicriterion formation of the problems of integrated system identification and system optimization. *IEEE Transactions on Systems, Man and Cybernetics*. Volume SMC-1, Issue 3, 296-297, 1971.

MILP: GLPK

Output: $X_E \subseteq \mathbb{N}^n$, $Y_N \subseteq \mathbb{Z}^2$

Program:

```
using vOptGeneric
using GLPK ; using GLPKMathProgInterface
m = vModel( solver = GLPKSolverMIP() )
@variable( m , x[1:n,1:n] , Bin )
@addobjective( m , Min, sum( C1[i,j]*x[i,j] for i=1:n,j=1:n )
@addobjective( m , Min, sum( C2[i,j]*x[i,j] for i=1:n,j=1:n )
@constraint( m , cols[i=1:n], sum(x[i,j] for j=1:n) == 1 )
@constraint( m , rows[j=1:n], sum(x[i,j] for i=1:n) == 1 )
solve( m , method = :epsilon , step = 0.5 )
```

Example: 2-LAP and vOptGeneric

Algorithm: ϵ-constraint

Y.V. Haimes, L.S. Lasdon, D.A. Wismer: On a bicriterion formation of the problems of integrated system identification and system optimization. *IEEE Transactions on Systems, Man and Cybernetics*. Volume SMC-1, Issue 3, 296-297, 1971.

MILP: GLPK

Output: $X_E \subseteq \mathbb{N}^n$, $Y_N \subseteq \mathbb{Z}^2$

Program:

```
using vOptGeneric
using GLPK ; using GLPKMathProgInterface
m = vModel( solver = GLPKSolverLP() )
@variable( m , x[1:n,1:n] >= 0 )
@addobjective( m , Min, sum( C1[i,j]*x[i,j] for i=1:n,j=1:n )
@addobjective( m , Min, sum( C2[i,j]*x[i,j] for i=1:n,j=1:n )
@constraint( m , cols[i=1:n], sum(x[i,j] for j=1:n) == 1 )
@constraint( m , rows[j=1:n], sum(x[i,j] for i=1:n) == 1 )
solve( m , method = :epsilon , step = 0.5 )
```

Performances

Measure of CPUt (s) for 2-LAP when the algorithm is embedded or not:

Computer characteristics: processor intel core i5 6300U 2.40GHz x 2 – RAM: 13Mb – OS: linux ubuntu 14.04 LTS 64 bits

instance id	$\mid Y_N \mid$	without vOptSolver	with vOptSpecific		with vOptGeneric		
					with GLPK		with CPLEX
		local	local	distant	local	distant	local
2AP50-1	163	0,548	0,72	0,76	18,74	18,17	19,51
2AP50-1A40	216	0,94	1,116	1,19	27,28	28,2	30,27
2AP50-1A60	304	0,9	1,05	15	39,86	37,85	35,89
2AP50-1A80	375	1,27	1,62	14,98	47,5	50,62	43,97
2AP50-1A100	301	0,84	1,08	14,57	44,91	45,27	39,72
sum		*4,79*	*6,02*	*46,95*	*192,74*	*204,25*	*185,37*
ratio			*1,25*	*7,79*		*1,05*	*0,96*
2AP100-1	223	10,68	10,14	11,07	N.A.	N.A.	89,72
2AP100-1A40	429	11,78	12,64	31,21	N.A.	N.A.	150,4
2AP100-1A60	585	18,96	19,07	39,12	N.A.	N.A.	N.A.
2AP100-1A80	845	28,39	29,26	69,92	N.A.	N.A.	N.A.
2AP100-1A100	947	26,23	32,37	72,36	N.A.	N.A.	N.A.
sum		*96,04*	*103,48*	*223,68*			
ratio			*1,07*	*2,16*			

N.A: not available (timeout of 180s)

- The overcost due to using vOptSpecific is negligible
- In distant mode, the displays on the console are penalizing (verbose to switch off)

Now and Tomorrow

On-going works

In the very short term:

- deliver the functionalities awaited for testing theories and algorithms developed in the framework of the vOpt research project
- integrate all the solving algorithms developed at Nantes by our research group
- collaborate with all colleagues who are willing to contribute to the development of the solver

In the mid term:

- introduce vOptSolver in OR/MCDM courses and seminars, as support for exercices and research projects
- integrate feedbacks of users to enhance the use of vOptSolver, release versions incorporating new/improved problems/algorithms
- consider to integrate approximation algorithms, such as multiobjective (meta)heuristics

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Homepage of vOptSolver:
http://voptsolver.github.io/vOptSolver/

Repository of vOptSolver:
http://github.com/vOptSolver

Repository of vOptSpecific:
http://github.com/vOptSolver/vOptSpecific.jl

Repository of vOptGeneric:
http://github.com/vOptSolver/vOptGeneric.jl

Repository of vOptLib (temporary url):
http://gitlab.univ-nantes.fr/vopt1/vOptLib

Contact concerning vOptSolver:
vopt@univ-nantes.fr

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@vOptSolver

Homepage of the ANR/DFG research project “vOpt”:
http://vopt-anr-dfg.univ-nantes.fr