

vOptSolver – Version 0.2

Software developed with the support of the
ANR/DFG-14-CE35-0034-01

Université de Nantes

<https://github.com/vOptSolver>
<https://voptsolver.github.io/vOptSpecific/>
<https://voptsolver.github.io/vOptGeneric/>

July 6, 2017

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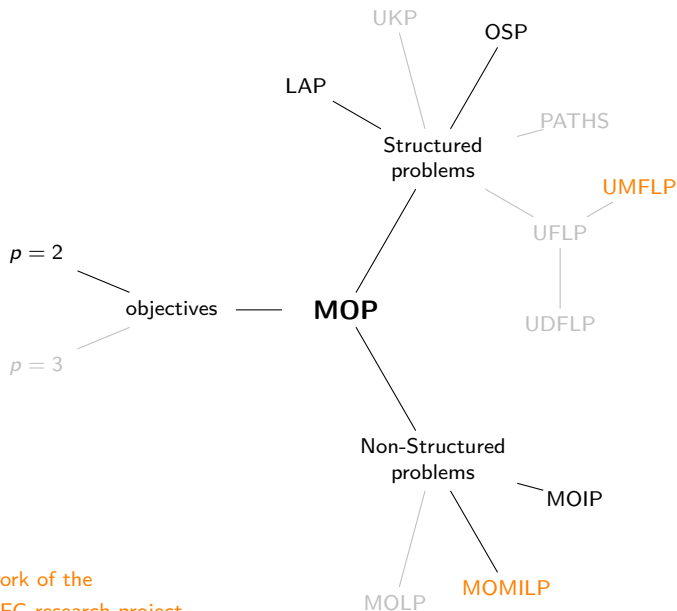
Convention: `text in grey` \Rightarrow functionality integrated in future releases

Introduction to vOptSolver

Multi-objective linear optimization problems targeted

- ▶ LP: Linear Program
- ▶ MILP: Mixed Integer Linear Program
- ▶ IP: Integer Linear program
- ▶ CO: Combinatorial Optimization
- ▶ LAP: Linear Assignment Problem
- ▶ OSP: One machine Scheduling Problem
- ▶ UKP: Unidimensional 01 Knapsack Problem
- ▶ MKP: Multidimensional 01 Knapsack Problem
- ▶ UFLP: Uncapacitated Facility Location Problem
- ▶ UDFLP: Discrete Uncapacitated Facility Location Problem
- ▶ UMFLP: Mixed Uncapacitated Facility Location Problem
- ▶ SSCFLP: Single Source Capacitated Facility Location Problem
- ▶ CFLP: Capacitated Facility Location Problem
- ▶ PATHS: shortest paths problem

Multi-objective linear optimization problems targeted



Framework of the
ANR/DFG research project

Solutions reached

For a given problem, the aim is to compute

Y_N , the set of nondominated “points”

corresponding to

X_E , a complete set of efficient solutions

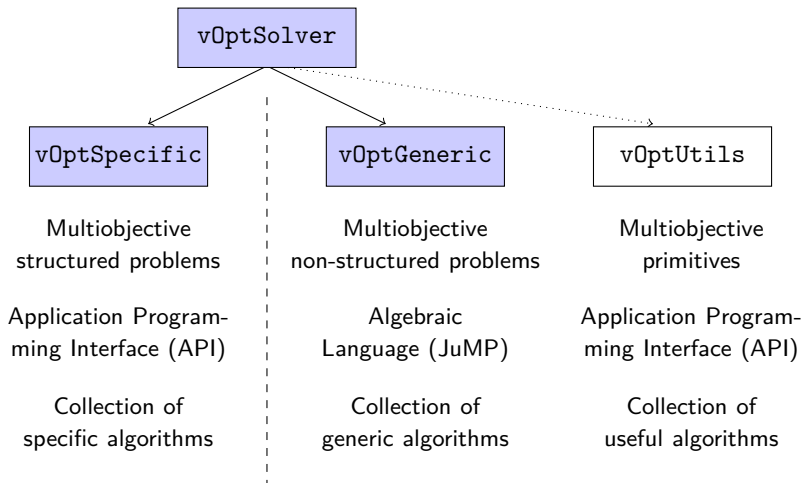
More on definitions and notations, refer to this book:

Matthias Ehrgott.

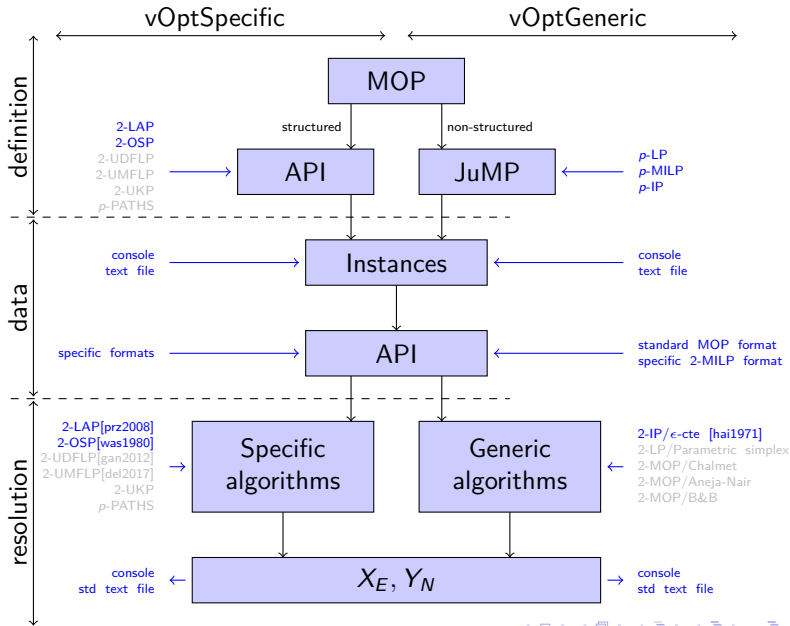
Multicriteria Optimization.

Springer-Verlag New York, 2005.

Design of vOptSolver



Design of vOptSolver in details



Design of vOptSolver in details

vOptUtils:

a collection of algorithms for managing and analyzing outcome set

- ▶ multidimensional datastructure for filtering and storing Y_N
- ▶ primitives for plotting Y_N
- ▶ primitives for analyzing Y_N

Integrated specific algorithms (1/2)

- ▶ 2-LAP [prz2008]; in C:

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.

output: $X_E \subseteq \mathbb{N}^n$, $Y_N \subseteq \mathbb{Z}^P$

- ▶ 2-OSP with here $1 \mid . \mid (\sum C_i, T_{max})$ [was1980]; in Julia:

L.N. Van Wassenhove and L.F. Gelders. Solving a bicriterion scheduling problem. *European Journal of Operational Research*, 4(1):42–48, 1980.

output: $X_E \subseteq \mathbb{N}^n$, $Y_N \subseteq \mathbb{Z}^P$

- ▶ 2-UKP [jor2010]; in Julia:

J. Jorge. *Nouvelles propositions pour la résolution exacte du sac à dos multi-objectif unidimensionnel en variables binaires*. Thèse de doctorat, Université de Nantes - France. 2010.

output: $X_E \subseteq \{0, 1\}^n$, $Y_N \subseteq \mathbb{Z}^P$

Integrated specific algorithms (2/2)

- ▶ 2-UDFLP [gan2012]; in C++:

X. Gandibleux, A. Przybylski, S. Bourougaa, A. Derrien, A. Grimaud. Computing the efficient frontier for the 0/1 biobjective uncapacitated facility location problem. *10th International Conference on Multiple Objective Programming and Goal Programming*. June 11-13 2012, Niagara Falls, Canada.

output: $X_E \subseteq \{0, 1\}^n$, $Y_N \subseteq \mathbb{Z}^p$

- ▶ 2-UMFLP [del2017]; in C++:

Q. Delmée, X. Gandibleux, A. Przybylski. Résolution exacte du problème de localisation de services bi-objectif sans contrainte de capacité en variables mixtes. *ROADEF2017 : 18ème congrès annuel de la Société Française de Recherche Opérationnelle et d'Aide à la Décision*, Feb 2017, Metz, France. 2017

output: $X_E \subseteq \{0, 1\}^{n_1} \times \mathbb{R}^{n_2}$, Y_N

- ▶ PATHS [gan2004]; in C:

X. Gandibleux, Fr. Beugnies and S. Randriamasy: Martins' algorithm revisited for multi-objective shortest path problems with a MaxMin cost function. *4OR: A Quarterly Journal of Operations Research*. Volume 4, Number 1, pp. 47-59, 2006.

output: X_E , Y_N

Integrated generic algorithms (1/2)

- ▶ 2-IP/ ϵ -constraint method [hai1971]; in Julia:

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, Pages 296-297, July 1971.

output: $X_E \subseteq \mathbb{Z}^n$, $Y_N \subseteq \mathbb{Z}^p$

- ▶ 2-IP/dichotomic method:

Aneja, Y. and K. Nair: Bicriteria transportation problem. *Management Science* 25 (1), 73?78. 1979.

output: $X_{SE} \subseteq \mathbb{Z}^n$, $Y_{SN} \subseteq \mathbb{Z}^p$

- ▶ 2-IP/Chalmet & al., 1986:

L.G. Chalmet, L. Lemonidis, and D.J. Elzinga. An algorithm for the bi-criterion integer programming problem. *European Journal of Operational Research*, 25:292-300, 1986.

output: $X_E \subseteq \mathbb{Z}^n$, $Y_N \subseteq \mathbb{Z}^p$

Integrated generic algorithms (2/2)

► 2-MILP/Vincent & al., 2014:

Th. Vincent, F. Seipp, S. Ruzika, A. Przybylski, X. Gandibleux. Multiple objective branch and bound for mixed 0-1 linear programming: Corrections and improvements for the biobjective case. *Computers & Operations Research*, Volume 40, Issue 1, pp. 498–509, 2013.

Fl. Lucas. *Multiobjective branch & cut*. Master Thesis, University of Nantes, France. June 2017.

output: $X_E \subseteq \mathbb{R}^{n_1} \times \mathbb{Z}^{n_2}$, Y_N

► 2-LP/parametric simplex:

Description available in: Matthias Ehrgott. *Multicriteria Optimization*. Springer-Verlag New York, 2005.

output: $X_{SE} \subseteq \mathbb{R}^n$, $Y_{SN} \subseteq \mathbb{R}^p$

Selectable (M)LP Engines

- ▶ open source:
 - GLPK (GNU Linear Programming Kit)
- ▶ commercial:
 - CPLEX
 - GUROBI

NB: CPLEX and GUROBI are currently not available on JuliaBox

Instructions for installing and running vOptSolver

Instructions for installing vOptSolver

vOptSolver has been tested with:

- ▶ Julia v0.6
- ▶ GLPK v4.62

Choose between:

1. a local use
 - on macOS (tested on v10.12.5)
 - on linux (tested on ubuntu 14.04 LTS)
 - on windows (perhaps later...)
2. a distant use
 - in the cloud with JuliaBox.

Instructions for a distant use in the cloud

- ▶ Local installation

1. nothing to do

- ▶ Run Julia

1. go to <https://juliabox.com> and sign in to open a session
2. click on the icon “console”
3. when the prompt is ready, type in the console

```
julia
```

- ▶ Before the first use of vOptSolver, add the following packages:

1. when the prompt *julia* is ready, type in the terminal

```
Pkg.add("GLPK"); Pkg.add("GLPKMathProgInterface")  
Pkg.clone("http://github.com/vOptSolver/vOptGeneric.jl")  
Pkg.clone("http://github.com/vOptSolver/vOptSpecific.jl")  
Pkg.build("vOptSpecific")
```

At this point, vOptSolver is properly installed

Instructions for a local use on your own computer

► Local installation

1. install Julia on your computer, instructions here:

<http://julialang.org/downloads/>

2. install (e.g.) GLPK on your computer, instructions here:

<http://jump.readthedocs.io/en/latest/installation.html>

NB: a standard C/C++ compiler must be installed (GCC is suggested)

At this point, Julia and GLPK are properly installed

► Run Julia

1. on linux: open a console on your computer; when the prompt is ready, type in the console `julia`
2. on macOS: locate the application julia and click on the icon; julia console comes on the screen

► Before the first use of vOptSolver, add both following packages:

1. when the prompt julia is ready, type in the console

```
Pkg.add("GLPK"); Pkg.add("GLPKMathProgInterface")  
Pkg.clone("http://github.com/vOptSolver/vOptGeneric.jl")  
Pkg.clone("http://github.com/vOptSolver/vOptSpecific.jl")  
Pkg.build("vOptSpecific")
```

At this point, vOptSolver is properly installed

Instructions for running vOptSolver

When vOptSolver is properly installed, vOptSpecific and vOptGeneric are ready locally or in the cloud.

- ▶ Run Julia

1. open a console on your computer or in the cloud
2. when the prompt is ready, type in the console
`julia`

- ▶ when the prompt *julia* is ready, type in the terminal

1. `using vOptSpecific`
2. `using vOptGeneric`
3. `using GLPK ; using GLPKMathProgInterface`

Remark 1: you may invoke only using vOptSpecific if you are only working with vOptSpecific. Same remark for vOptGeneric.

Remark 2: you may invoke CPLEX or GUROBI in the place of GLPK (ps: in local mode, the MILP solver selected must be properly installed)

- ▶ vOptSpecific and vOptGeneric are ready. See examples for further informations

vOptSpecific problem by problem

definition (problem, inputs)
data (console, text file)
resolution (API, outputs, text file)

LAP | Definition | The linear assignment problem

$$\left[\begin{array}{ll} \min z^k &= \sum_{i=1}^n \sum_{j=1}^n c_{ij}^k x_{ij} & k = 1, \dots, p \\ s/c & \sum_{i=1}^n x_{ij} = 1 & j = 1, \dots, n \\ & \sum_{j=1}^n x_{ij} = 1 & i = 1, \dots, n \\ & x_{ij} = (0, 1) & i = 1, \dots, n \\ & & j = 1, \dots, n \end{array} \right] \quad (\text{p-LAP})$$

LAP | Definition | Inputs

Valid for 2-LAP.

- ▶ n (integer):
number n of assignments task-resource
- ▶ C1 (matrix of $n \times n$ of integers):
coefficients c_{ij}^1 of the objective 1
- ▶ C2 (matrix of $n \times n$ of integers):
coefficients c_{ij}^2 of the objective 2

LAP | Data | Example (console)

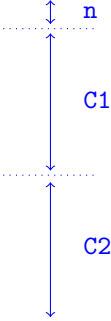
```
n = 5
```

```
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 ]
```

LAP | Data | Example (text file)

5					
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	
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	



► load2LAP

Load an instance of a 2-LAP from the file `fname`

```
MOCO = load2LAP( fname )
```


- ▶ **set2LAP**

Create a new instance of a 2-LAP and set up all required values

```
MOCO = set2LAP( n , C1, C2 )
```

- ▶ **LAP_Przybylski2008**

Set up the solver to use for the 2-LAP

```
solver = LAP_Przybylski2008( )
```

- ▶ **vSolve**

Solve the instance provided with the mentioned solver and return the results

```
z1, z2,  $\sigma$  = vSolve( MOCO , solver )
```

LAP | Resolution | Outputs (specification)

Valid for 2-LAP.

vSolve returns:

- ▶ $z1$: vector of $(1, \dots, |Y_N|)$ of integers
- ▶ $z2$: vector of $(1, \dots, |Y_N|)$ of integers
- ▶ σ : matrix of $(1, \dots, |Y_N| ; \sigma_1, \dots, \sigma_n)$ of integers
where
 - ▶ σ_i : a permutation coding ($x_{ij} = 1 \Leftrightarrow \sigma_i = j$)

OSP | Definition | One machine scheduling problem

The general one machine scheduling problem considered here is defined as:

$$1 \mid r_i \mid (f_1, f_2) \quad (2\text{-OSP})$$

and the specific OSP currently considered is:

$$1 \mid . \mid (\sum C_i, T_{max})$$

OSP | Definition | Inputs

Valid for 2-OSP.

- ▶ n (integer):
number n of jobs, $i = 1 \dots n$
- ▶ r (vector of n integers):
 r_i , the release date for job i
- ▶ p (vector of n integers):
 p_i , the processing time for job i
- ▶ d (vector of n integers):
 d_i , the due date for job i
- ▶ w (vector of n integers):
 w_i , the weight associated to job i

OSP | Data | Example (console)

```
n = 4  
p = [ 2 , 4 , 3 , 1 ]  
d = [ 1 , 2 , 4 , 6 ]  
r = [ 0 , 0 , 0 , 0 ]  
w = [ 1 , 1 , 1 , 1 ]
```

OSP | Data | Example (text file)

4				↕ n
2	4	3	1
				↕ p
1	2	4	6
				↕ d
0	0	0	0
				↕ r
1	1	1	1
				↕ w

► load2OSP

Load an instance of a 2-OSP from the file `fname`

```
id = load2OSP( fname )
```

- ▶ **set2OSP**

Create a new instance of a 2-OSP and set up all required values

```
id = set2OSP( n , p , d , r , w )
```

- ▶ **OSP_VanWassenhove1980**

Set up the solver to use for the 2-OSP

```
solver = OSP_VanWassenhove1980( )
```

- ▶ **vSolve**

Solve an instance of a 2OSP with the mentioned solver and return the results

```
z1, z2 ,  $\sigma$  = vSolve( id , solver )
```

OSP | Resolution | Outputs (specification)

Valid for 2-OSP.

vSolve returns:

- ▶ $z1$: vector of $(1, \dots, |Y_N|)$ of integers
- ▶ $z2$: vector of $(1, \dots, |Y_N|)$ of integers
- ▶ σ : matrix of $(1, \dots, |Y_N| ; \sigma_1, \dots, \sigma_n)$ of integers
where
 - ▶ σ_i : a permutation coding ($\sigma_i = j \Leftrightarrow$ job j in position i)

vOptGeneric problem by problem

definition (problem, inputs, JuMP)

data (console, text file)

resolution (solve, outputs, text file)

MOMILP-MOLP-MOIP | Definition

Three Multi Objective Linear Optimization Problems:

$$\begin{array}{lll} \min z(x) & = & Cx \\ \text{s/t } Tx & \leq & d \\ x & \in & \mathbb{R}^{n_1} \times \mathbb{Z}^{n_2} \end{array}$$

Multi Objective
Mixed-Integer Linear
Problem (MOMILP)

$$\begin{array}{lll} \min z(x) & = & Cx \\ \text{s/t } Tx & \leq & d \\ x & \in & \mathbb{R}^{n_1} \end{array}$$

Multi Objective
Linear
Problem (MOLP)

$$\begin{array}{lll} \min z(x) & = & Cx \\ \text{s/t } Tx & \leq & d \\ x & \in & \mathbb{Z}^{n_2} \end{array}$$

Multi Objective
Integer
Problem (MOIP)

where:

$$T \in \mathbb{Z}^{m \times n} \longrightarrow m \text{ constraints, } i = 1, \dots, m$$

$$C \in \mathbb{Z}^{n \times p} \longrightarrow \text{the objective matrix}$$

$$X = \{x \in \mathbb{R}^{n_1} \times \mathbb{Z}^{n_2} \mid Tx \leq d\} \subseteq \mathbb{R}^n \longrightarrow \text{the set of feasible solutions}$$

$$Y = z(X) \subseteq \mathbb{R}^p \longrightarrow \text{the set of images}$$

MOMILP-MOLP-MOIP | Formulation

Following specifications of JuMP for formulating a model, see:

- ▶ <http://jump.readthedocs.io/en/latest/quickstart.html#creating-a-model>

Plus:

- ▶ `@addobjective(<model>, <opt>, <function>)`

where

- ▶ model: id of the model concerned
- ▶ opt: function to Min imize or Max imize
- ▶ function: definition of the function

MOMILP-MOLP-MOIP | Example of formulation

$$\begin{array}{ll}\min & c_1^1 x_1 + c_2^1 x_2 \\ \min & c_1^2 x_1 + c_2^2 x_2 \\ \text{s/t} & t_{11}x_1 + t_{12}x_2 \leq d_1 \\ & t_{21}x_1 + t_{22}x_2 \leq d_2 \\ & x_1 \in \mathbb{R}, x_2 \in \mathbb{Z}\end{array}$$

```
# --- create a MOMILP and set the model ---
MOMILP = vModel(solver=<working on it>)
@variable(MOMILP, x1 >= 0)
@variable(MOMILP, x2 >= 0, Int)
@addobjective(MOMILP, Min, c11*x1 + c12*x2)
@addobjective(MOMILP, Min, c21*x1 + c22*x2)
@constraint(MOMILP, t11*x1 + t12*x2 <= d1)
@constraint(MOMILP, t21*x1 + t22*x2 <= d2)
```

$$\begin{array}{ll}\min & c_1^1 x_1 + c_2^1 x_2 \\ \min & c_1^2 x_1 + c_2^2 x_2 \\ \text{s/t} & t_{11}x_1 + t_{12}x_2 \leq d_1 \\ & t_{21}x_1 + t_{22}x_2 \leq d_2 \\ & x_1, x_2 \in \mathbb{R}\end{array}$$

```
# --- create a MOLP and set the model ---
MOLP = vModel(solver=<working on it>)
@variable(MOMILP, x1 >= 0)
@variable(MOMILP, x2 >= 0)
@addobjective(MOLP, Min, c11*x1 + c12*x2)
@addobjective(MOLP, Min, c21*x1 + c22*x2)
@constraint(MOLP, t11*x1 + t12*x2 <= d1)
@constraint(MOLP, t21*x1 + t22*x2 <= d2)
```

$$\begin{array}{ll}\min & c_1^1 x_1 + c_2^1 x_2 \\ \min & c_1^2 x_1 + c_2^2 x_2 \\ \text{s/t} & t_{11}x_1 + t_{12}x_2 \leq d_1 \\ & t_{21}x_1 + t_{22}x_2 \leq d_2 \\ & x_1, x_2 \in \mathbb{Z}\end{array}$$

```
# --- create a MOIP and set the model ---
MOIP = vModel(solver=GLPKSolverMIP())
@variable(MOIP, x1 >= 0, Int)
@variable(MOIP, x2 >= 0, Int)
@addobjective(MOIP, Min, c11*x1 + c12*x2)
@addobjective(MOIP, Min, c21*x1 + c22*x2)
@constraint(MOIP, t11*x1 + t12*x2 <= d1)
@constraint(MOIP, t21*x1 + t22*x2 <= d2)
```

MOMILP-MOLP-MOIP | Data | Example (console)

```
c11 = 3    ; c12 = 1  
c21 = -1   ; c22 = -2
```

```
t11 = 0    ; t12 = 1    ; d1 = 3  
t21 = 3    ; t22 = -1   ; d2 = 6
```

MOMILP-MOLP-MOIP | Data | Example (format MOP)

parseMOP

Load an instance (MOP format) from the file `fname`

```
jumpModel = parseMOP( fname , solver=<solver to invoke> )
```

writeMOP

Write a model according to the MOP format to a file `fname`

```
writeMOP( vModel , fname )
```

NB: the MOP format is an extension of

the MPS format

([https://en.wikipedia.org/wiki/MPS_\(format\)](https://en.wikipedia.org/wiki/MPS_(format)))

to multiple objectives

(http://mopl原因ib.zib.de/format_desc/mop_format.pdf)

MOMILP-MOLP-MOIP | Example of resolution

MOMILP

Algorithm: branch&bound

Solver: working on it

```
# --- solve the model ---  
status = solve( MOMILP )
```

```
# --- Print the results ---  
print_X_E( MOMILP )
```

MOLP

Algorithm: parametric simplex

Solver: working on it

```
# --- solve the model ---  
status = solve( MOLP )
```

```
# --- Print the results ---  
print_X_E( MOLP )
```

MOIP

Algorithm: ϵ -constraint

Solver: GLPK or CPLEX

```
# --- solve the model ---  
status = solve( MOIP , method =:epsilon , step = 0.5 )
```

```
# --- Print the results ---  
print_X_E( MOIP )
```

```
# --- Get the results ---  
getY_N( MOIP )
```

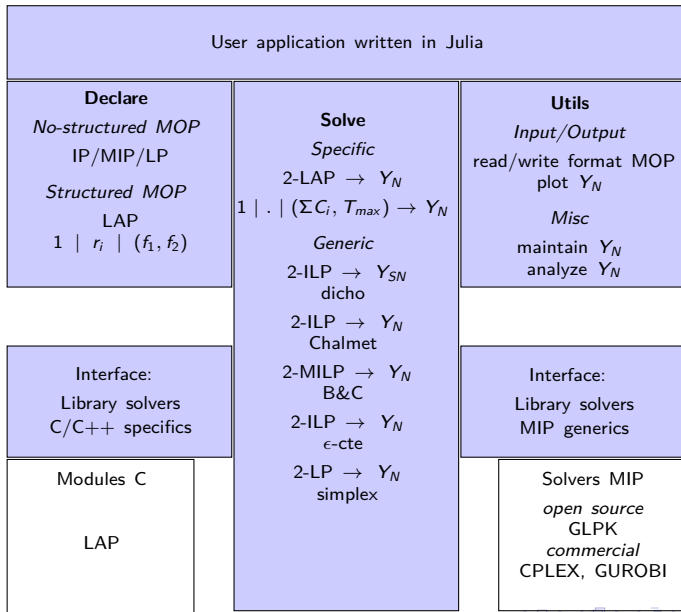
MOMILP-MOLP-MOIP | Resolution | Outputs (specification)

Y_N of the 2-MOP is defined by

- ▶ 2-MILP: a mixed nondominated set (composed of edges that are either closed, half-open, open or reduced to a point)
- ▶ 2-LP: a continuous nondominated set (composed of edges)
- ▶ 2-IP: a discrete nondominated set (composed of points)

Technical overview

Technical overview ...



History

History

- ▶ v1.0: July 2016; first prototype; not opened to the public
- ▶ v2.0: June 23, 2017; first stable version; released to the public with
 - ▶ a depot on github, webpages, and a tutorial
 - ▶ JuMP extended to multiple objectives (vOptGeneric)
 - ▶ primitives for loading/printing/writing a non-structured problem in std MOP format
 - ▶ ϵ -constraint algorithm for bi-objective integer programming
 - ▶ backbone in Julia (vOptSpecific)
 - ▶ API and solver for bi-objective linear assignment problem
 - ▶ API and solver for bi-objective one machine scheduling problem
 - ▶ primitives for I/O of a 2LAP and 2OSP on files

Taskforce

Taskforce

Involved in the development of vOptSolver:

Currently:

- ▶ GANDIBLEUX Xavier (coordinator)
- ▶ SOLEILHAC Gauthier
- ▶ PRZYBYLSKI Anthony

Previously:

- ▶ CHATELLIER Pauline
- ▶ DUMEZ Dorian
- ▶ LUCAS Flavien

Links and contact

Follow/join us here

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>

Contact concerning vOptSolver:

vopt@univ-nantes.fr

Homepage of the ANR/DFG research project “vOpt”:

<http://vopt-anr-dfg.univ-nantes.fr>