ÖGOR Summer-Workshop for PhD-candidates and Post-Docs

An introduction to Julia and JuMP for Operations Research

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Topic 5

Optimisation

JuMP (part 1)

version 1.0.0 and later

Overview of JuMP

A modeling language for Mathematical Optimization (linear, mixed-integer, conic, semidefinite, nonlinear):

- **User friendliness**: syntax that mimics natural mathematical expressions.
- **Speed**: similar speeds to special-purpose modeling languages such as AMPL.
- **Solver independence**: JuMP uses *MathOptInterface (MOI)*, an abstraction layer designed to provide a unified interface to mathematical optimization solvers.

  Currently supported solvers: Artelys Knitro, Baron, Bonmin, Cbc, Clp, Couenne, CPLEX, FICO Xpress, GLPK, Gurobi, SCIP, etc.
- **Ease of embedding**: JuMP itself is written purely in Julia. Solvers are the only binary dependencies.

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Getting started

Install:

```
using Pkg
Pkg.add("JuMP")
```

```
Pkg.add("GLPK")
```

Setup:

```
using JuMP
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Writing a model (1/5)

Example:

$$\left[\begin{array}{lrcrcrr} \max z(x) = & x_1 & + & 3x_2 & & & (0) \\ s.t & x_1 & + & x_2 & \leqslant & 14 & (1) \\ & -2x_1 & + & 3x_2 & \leqslant & 12 & (2) \\ & 2x_1 & - & x_2 & \leqslant & 12 & (3) \\ & x_1 & , & x_2 & \geqslant & 0 & (4) \end{array}\right]$$

Writing a model (2/5)

Creating a Model:

```
modName = Model(solver)
```

```
julia> model = Model(GLPK.Optimizer)
```

Result:

$$\left[\begin{array}{c} \\ \\ \end{array}\right]$$

Writing a model (3/5)

Defining Variables:

```
@variable(modName, varName definition)
```

```
julia> @variable(model, x1 >= 0)
julia> @variable(model, x2 >= 0)
```

Result:

$$\left[x_1 \quad , \quad x_2 \geqslant 0 \qquad (4) \right]$$

Writing a model (4/5)

Defining Objective:

```
@objective(modName, min/max, objectiveFunction)
```

```
julia> @objective(model, Max, x1 + 3x2)
```

Result:

$$\left[\begin{array}{lcccccr} \max z(x) = & x_1 & + & 3x_2 & & & (0) \\ \\ & x_1 & , & x_2 & \geqslant & 0 & (4) \end{array}\right]$$

Writing a model (5/5)

Defining Constraints:

```
@constraint(modName, cstName, cstDefinition)
```

```
julia> @constraint(model, cst1, x1 + x2 <= 14)
julia> @constraint(model, cst2, -2x1 + 3x2 <= 12)
julia> @constraint(model, cst3, 2x1 - x2 <= 12)
```

Result:

$$\left[\begin{array}{lrcrcrr} \max z(x) = & x_1 & + & 3x_2 & & & (0) \\ s.t & x_1 & + & x_2 & \leqslant & 14 & (1) \\ & -2x_1 & + & 3x_2 & \leqslant & 12 & (2) \\ & 2x_1 & - & x_2 & \leqslant & 12 & (3) \\ & x_1 & , & x_2 & \geqslant & 0 & (4) \end{array}\right]$$

Details on

The model:

- print a summary of the problem:

```
julia> @show(model)
```

- print the formulation of the model:

```
julia> print(model)
```

Solve a model

```
optimize!(modName)
```

```
julia> optimize!(model)
```

Querying the solution

```
julia> @show termination_status(model)
julia> @show primal_status(model)
julia> @show dual_status(model)
```

```
julia> @show objective_value(model)
julia> @show value(x1)
julia> @show value(x2)
```

```
julia> @show dual(cst1)
julia> @show dual(cst2)
julia> @show dual(cst3)
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julia> solution_summary(model)
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Details on

`termination_status`:

```
termination_status(modName)
```

Common return values

- OPTIMAL:
  The algorithm found a globally optimal solution
- INFEASIBLE:
  The algorithm concluded that no feasible solution exists.
- TIME_LIMIT:
  The algorithm stopped after a user-specified computation time.
- NUMERICAL_ERROR:
  The algorithm stopped because a numerical error.
- etc.

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Recommended workflow

For solving a model and querying the solution:

```
julia> if termination_status(model) == MOI.OPTIMAL
           zOpt = objective_value(model)
           @printf(" z=%5.2f x1=%5.2f x2=%5.2f \n",
                    zOpt,
                    value(x1),
                    value(x2))
           @printf(" u1=%5.2f u2=%5.2f u3=%5.2f \n",
                    dual(cst1),
                    dual(cst2),
                    dual(cst3))
       elseif termination_status(model) == DUAL_INFEASIBLE
           println("problem unbounded")
       elseif termination_status(model) == MOI.INFEASIBLE
           println("problem infeasible")
       end
```

Details on

Variables:

- by default, the variables are continous and unbounded:

```
julia> @variable(model, x)              # x is free
```

- possible to setup lower and/or upper bounds on a variable:

```
julia> @variable(model, x≥lb))     # x is bounded
julia> @variable(model, x≤ub)
julia> @variable(model, lb≤x≤ub)
julia> @variable(model, x==2)          # x is fixed
```

- possible to specify the type of a variable:

```
julia> @variable(model, x≥0, Int)          # x ∈ ℕ
julia> @variable(model, x, Bin)         # x ∈ {0,1}
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