# StochDynamicProgramming.jl : a Julia package for multistage stochastic optimization.

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# Contents

# Programming Language for Numerical Mathematics

We often tends to believe that making numerical code should be done in a two step process:

1. writing the algorithm in a high-level script like language (matlab, scilab, python...) to test the idea and variations on small to medium sized problem.
2. re-writing the algorithm in a low level language (C, C++, Fortran...) for numerical efficiency applicable on large scale problem.

Which means writing the algorithm twice.

Could we do it only once ?

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# What is Julia ?

- A beautiful woman name
- A "high-level, high-performance language for technical computing, with syntax that is familiar to users of other technical computing environments"
- Summary of best features:
  - Supports Windows, OSX, and Linux
  - Just in Time compiler
  - Automatic generation of efficient, specialized code for different argument types
  - Designed for parallelism and distributed computation
  - Powerful shell-like capabilities for managing other processes
  - Call python and C function
  - Built-in Package manager
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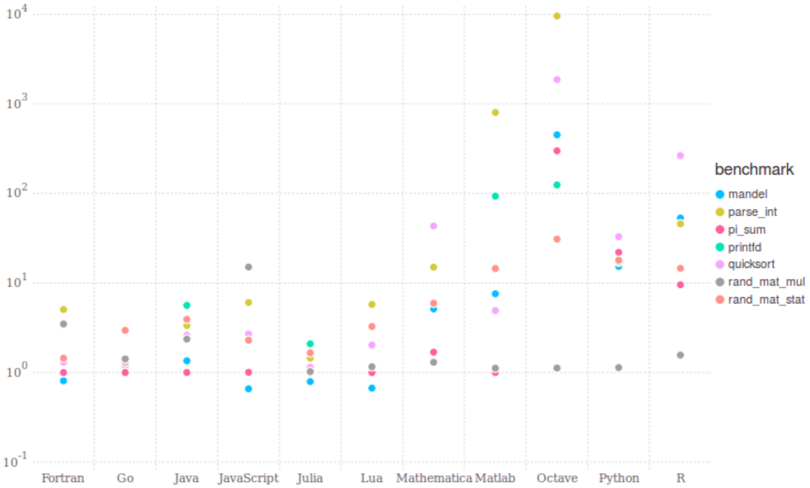
# Is Julia really faster than alternatives ?



# What is JuliaOpt ?

- JuliaOpt is an organization that brings together packages written in Julia that are related to optimization.
- Two modeller:
  - JuMP
  - Convex
- Interfaced with a number of solver (CPLEX, Gurobi, Mosek, Clp, GLPK, Knitro, Cbc, ECOS, Ipopt, NLopt, SCS).
- Optim contains the basic non-linear algorithms.

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# Problem statement

We consider the optimization problem

$$\begin{aligned} \min_{\pi} \quad & \mathbb{E}\left(\sum_{t=0}^{T-1} L_t(\boldsymbol{X}_t, \boldsymbol{U}_t, \boldsymbol{W}_t) + K(\boldsymbol{X}_T)\right) \\ s.t. \quad & \boldsymbol{X}_{t+1} = f_t(\boldsymbol{X}_t, \boldsymbol{U}_t, \boldsymbol{W}_t) \\ & \boldsymbol{U}_t = \pi_t(\boldsymbol{X}_t, \boldsymbol{W}_t) \end{aligned}$$

under the crucial assumption that $(\boldsymbol{W}_t)_{t\in\{1,\cdots,T\}}$ is a white noise

# Stochastic Dynamic Programming

By the white noise assumption, this problem can be solved by dynamic programming, where the Bellman functions satisfy

$$\begin{cases} V_T(x) & = & K(x) \\ \hat{V}_t(x,w) & = & \min_{u_t \in \mathbb{U}} L_t(x,u_t,w) + V_{t+1} \circ f_t(x,u_t,w) \\ V_t(x) & = & \mathbb{E}\Big(\hat{V}_t(x,\boldsymbol{W}_t)\Big) \end{cases}$$

Indeed, an optimal policy for this problem is given by

$$\pi_t(x,w) \in \arg\min_{u_t \in \mathbb{U}} \Big\{ L_t(x,u_t,w) + V_{t+1} \circ f_t(x,u_t,w) \Big\}$$

# SDDP : At the beginning of step $k$

At the beginning of step $k$, we suppose that we have, for each time step $t$, an approximation $V_t^k$ of $V_t$ satisfying

- $V_t^k \leq V_t$
- $V_T^k = K$
- $V_t^k$ is convex

# SDDP: Forward path: define a trajectory

- Randomly select a scenario $(\xi_0, \dots, \xi_{T-1}) \in \mathbb{W}^T$
- Define a trajectory $(x_t^{(k)})_{t=0,\dots,T}$ by

$$x_{t+1}^{(k)} = f_t(x_t^{(k)}, u_t^{(k)}, \xi_t)$$

where $u_t^{(k)}$ is an optimal solution of

$$\min_{u \in \mathbb{U}} L_t\left(x_t^{(k)}, u, \xi_t\right) + V_{t+1}^{(k)} \circ f_t\left(x_t^{(k)}, u, \xi_t\right)$$

- This trajectory is given by the optimal policy where $V_t$ is replaced by $V_t^{(k)}$

# SDDP: Backward path: add cuts

- For any $t$ we want to add a cut to the approximation $V_t^{(k)}$ of $V_t$
- At time $t$ solve, for any possible $w$,

$$\hat{\beta}_t^{(k+1)}(w) = \min_{x,u} \quad L_t(x,u,w) + V_{t+1}^{(k+1)} \circ f_t(x,u,w),$$
$$s.t \quad x = x_t^{(k)} \qquad [\hat{\lambda}_t^{(k+1)}(w)]$$

- Compute $\lambda_t^{(k+1)} = \mathbb{E}\left(\lambda_t^{(k+1)}(\boldsymbol{W}_t)\right)$ and $\beta_t^{(k+1)} = \mathbb{E}\left(\beta_t^{(k+1)}(\boldsymbol{W}_t)\right)$
- Add a cut

$$V_t^{(k+1)}(x) = \max\left\{V_t^{(k)}(x), \beta_t^{(k+1)} + \left\langle \lambda_t^{(k+1)}, x - x_t^{(k)} \right\rangle\right\}$$

- Go one step back in time: $t \leftarrow t-1$. Upon reaching $t=0$, we have completed step $k$ of the algorithm

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# What is StochDynamicProgramming.jl ?

- A package written in Julia, part of JuliaOpt, aimed at solving multistage stochastic optimization.
- The focus is on Dynamic Programming like approaches.
- The idea is to define the SP model:
  - define the dynamic of the system $f_t$
  - define the costs of the problem $L_t$
  - define the constraints
  - define noise laws (assumed discrete and time-independent)
- Then it can be solved in three ways:
  - with an extensive formulation approach and calling a solver
  - with a DP approach (defining the discretization of state and controls)
  - with a SDDP approach

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# What is our philosophy ?

- Enable user to easily define the SP model.
- Allow to compare different approaches to tackle a given problem.
- Allow to benchmark variants of SDDP on a given problem.
- Invite academic contributions...

# Current capabilities

- Linear and quadratic cost, linear dynamic support
- Cut selection heuristics
- Regularization heuristics
- Hazard-Decision and Decision-Hazard framework
- Integer integration in forward phases (heuristic)
- Benchmarking framework to compare multiple setup of SDDP

# Wait, but is it difficult to install and use ?

Short answer: no.

Long answer:

1. Install Julia (see: http://julialang.org/downloads/).
2. launch julia.
   - Pkg.update()
   - Pkg.add("StochDynamicProgramming")
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   - If you have CPLEX (resp. Gurobi) Pkg.add("CPLEX") (resp Pkg.add("Gurobi")). Else Pkg.add("Clp").
3. You are all set to go. I suggest looking at stock-example.jl (in the example directory) as a tutorial. (notebooks are on the way).

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# Conclusion and warning

- This is a free and open-source package for simple implementation of multistage stochastic optimization problem (with an MDP approach).
- It implements three ways of solving the problem, with a focus on SDDP.
- It is easy to install and test.
- It is still an early version with lots of evolution to come in the next months...
- But what the package lacks in documentation is compensated by a dedicated support team for our first users ;-)
- Don't hesitate to contact us for help, feedback or contributions !

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# Going further

Next week we organize a working day around SDDP in Julia.

- Wednesday 7th June, Ecole des Ponts, Coriolis, F202
- morning : 4 presentations around SDDP
- afternoon : working session