Abstract glue for optimization in Julia

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Why did we choose Julia?


- “I want to model and solve a large LP/MIP within a programming language, but Python is too slow and C++ is too low level”
- “I want to implement optimization algorithms in a fast, high-level language designed for numerical computing”
- “I want to create an end-user-friendly interface for optimization without writing MEX files”
And so...

We (and many other contributors) developed a new set of tools to help us do our work in Julia.
JuliaOpt

- JuMP
- Convex.jl

MathProgBase.jl

- Cbc.jl
- Clp.jl
- CPLEX.jl
- ECOS.jl
- GLPK.jl
- Gurobi.jl
- Ipopt.jl
- KNITRO.jl
- Mosek.jl
- NLopt.jl
- SCS.jl

- CoinOptServices.jl
- AmplNLWriter.jl
- AmplNLReader.jl

- Optim.jl
- LsqFit.jl
Modeling languages in Julia

● JuMP
  ○ Linear, mixed-integer, conic, and nonlinear optimization
  ○ Like AMPL, GAMS, Pyomo
● Convex.jl (Udell, Thursday at 10:20am)
  ○ Disciplined convex programming
  ○ Like CVX, cvxpy
● Both use the same solver infrastructure
MathProgBase

- A standard interface which solver wrappers implement
  - Like COIN-OR/OSI
MathProgBase philosophy

• In a small package which wraps the solver’s C API, implement a few additional methods to provide a standardized interface to the solver.
  ○ Clp.jl, Cbc.jl, Gurobi.jl, ECOS.jl, etc...
MathProgBase philosophy

- Make it easy to access low-level features.
  - Don’t get in the user’s way
MathProgBase philosophy

- If the solver’s interface doesn’t quite match the abstraction, either:
  - perform some transformations within the solver wrapper, or
  - if the above is too hard, update the abstraction
Diverse classes of solvers

- LP++
- Conic
- Nonlinear
LP++

\[
\min_{x} c^T x \\
\text{s.t.} \quad a_i^T x \text{ sense}_i b_i \forall i \\
\quad l \leq x \leq u
\]

- Plus integer variables, quadratic objective, quadratic constraints, SOCP
- LP hotstarts, branch & bound callbacks
- CPLEX, Gurobi, Cbc/Clp, GLPK, Mosek
Conic

\[
\begin{align*}
\min_{x} c^T x & \quad \max_{y} -b^T y \\
\text{s.t. } b - Ax & \in K_1 \\
x & \in K_2
\end{align*}
\]

\[
\begin{align*}
\text{s.t. } c + A^T y & \in K_2^* \\
y & \in K_1^*
\end{align*}
\]

- Linear, SOC, SDP, exponential, power cones
- Mosek, ECOS, SCS
Nonlinear

\[ \min_{x} f(x) \]

\[ s.t. \ lb \leq g(x) \leq ub \]

\[ l \leq x \leq u \]

- Gradient, Jacobian, Hessian oracles, expression graphs
- Ipopt, Mosek, KNITRO, NLopt
How it looks for users:

```plaintext
using JuMP, Clp
m = Model(solver=ClpSolver())
@defVar(m, x[1:2] >= 0)
@setObjective(m, Max, sum(x))
@addConstraint(m, x[1]+2*x[2] <= 1)
status = solve(m)

using Convex, Clp
x = Variable(2)
problem = maximize(sum(x),
                  [x >= 0, x[1]+2*x[2] <= 1])
solve!(problem, ClpSolver())

using MathProgBase, Clp
sol = linprog([-1.0, -1.0], [1.0 2.0], ‘<’, 1.0, ClpSolver())
```
Wait, how do I set solver options?

ClpSolver(PrimalTolerance=1e-5)
GurobiSolver(Method=2,Crossover=0)
CplexSolver(CPX_PARAM_TILIM=100)
MosekSolver(LOG=0)

- We don’t abstract over parameters
Wait, how do I do this thing which I can only do from the solver API?

# With JuMP model object m
grb = MathProgBase.getrawsolver(getInternalModel(m))
Gurobi.computeIIS(grb)
iisconstr = Gurobi.get_intarray(grb, "IISConstr", 1, n_constr)

Example to compute IIS (Irreducible Inconsistent Subsystem) with Gurobi
Branch & bound callbacks!

```python
m = Model(solver=GurobiSolver())
def function lazyCallback(cb)
    ...
    # e.g., TSP subtour elimination
end
addLazyCallback(m, lazyCallback)
solve(m)
```
Branch & bound callbacks!

- Lazy constraints, user cuts, user heuristics
- Currently supported by Gurobi, CPLEX, and GLPK
Conic interface

\[
\begin{align*}
\min_{x} & \quad c^T x \\
\text{s.t.} & \quad b - Ax \in K_1 \\
& \quad x \in K_2
\end{align*}
\]

\[
\begin{align*}
\max_{y} & \quad -b^T y \\
\text{s.t.} & \quad c + A^T y \in K_2^* \\
& \quad y \in K_1^*
\end{align*}
\]

- Input format is sparse matrix A and list of cones (inspired by CBLIB format)
- We have an LP++ $\leftrightarrow$ Conic translation layer
Nonlinear

- JuMP implements automatic sparse Hessian computations ([preprint](https://example.com/preprint))
Nonlinear

- If you write a solver in Julia accepting MathProgBase input, you can call it from both AMPL and JuMP!
Nonlinear

Solvers
- IPOPT
- MOSEK
- KNITRO

MathProgBase

Modeling
- JuMP
- AMPL
- User

Demo
Expression graphs

- Nonlinear interface also allows access to expression graphs

\[ \sin(x^2 + y) \]
Expression graphs

• Nonlinear interface also allows access to *expression graphs*

• Allows us to write “solvers” which write instances to OSiL and NL file formats
  ○ CoinOptServices.jl, AmplNLWriter.jl
  ■ Tony Kelman, Thursday at 10:20 am

• **DReal.jl** – interface to a nonlinear satisfiability solver
Julia is not an island

- Embeddable C API
- Pyjulia
I am in somewhat disbelief that I can't do this:
[xopt,fmin] = linprog(c, Acon, rhsvec) ;

to solve min c' * x given Acon * x <= rhsvec.

The above is the one line matlab interface to linprog. **There should be something similar in Python in support of CLP using it's primary matrix array interface, numpy/ndarrays.**
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We can do that: pylinprog
In conclusion

MathProgBase makes it easier than ever before to:

● Write fast, solver-independent code.
  ○ There is no loss of performance
● Write solvers and hook them into open-source and commercial modeling languages.
What’s next

- SCIP
- Constraint programming?
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