AMPL Solver Interfaces With Callbacks

Featuring: Python callbacks for Gurobi and CPLEX!

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Virtual 2020 INFORMS Annual Meeting – November 11, 2020

What is AMPL?

- AMPL: **A** **M**athematical **P**rogramming **L**anguage
- Algebraic modeling language built specially for optimization
- Designed to support many solvers
- Natural, easy-to-learn modeling principles
- Efficient processing that scales well with problem size

Model: diet.mod

```
# Choose prepared foods to meet certain nutritional requirements:
set NUTR;
set FOOD;

param cost {FOOD} > 0;
param f_min {FOOD} >= 0;
param f_max {j in FOOD} >= f_min[j];

param n_min {NUTR} >= 0;
param n_max {i in NUTR} >= n_min[i];

param amt {NUTR,FOOD} >= 0;

var Buy {j in FOOD} >= f_min[j], <= f_max[j];

minimize Total_Cost:  sum {j in FOOD} cost[j] * Buy[j];

subject to Diet {i in NUTR}:
   n_min[i] <= sum {j in FOOD} amt[i,j] * Buy[j] <= n_max[i];
```

How to interact with the model and the data?

Using the Python API (amplpy):

```
>>> from amplpy import AMPL
>>> ampl = AMPL()                            # > ampl
>>> ampl.read('diet.mod')                    # ampl: model diet.mod;
>>> ampl.read('diet.dat')                    # ampl: data diet.dat;
>>> ampl.option['solver'] = 'gurobi' # ampl: option solver gurobi;
>>> ampl.solve()                             # ampl: solve;
Gurobi 7.5.0: optimal solution; objective 88.2
1 simplex iterations
>>> ampl.getVariable('Buy').getValues().toPandas()
        Buy.val
BEEF   0.000000
CHK    0.000000
FISH   0.000000
HAM    0.000000
MCH   46.666667
MTL    0.000000
SPG    0.000000
TUR    0.000000
```

Setting data from Python

In Python:

```
>>> ampl.set['FOOD'] = [
    'BEEF', 'CHK', 'FISH', 'HAM', 'MCH', 'MTL', 'SPG', 'TUR']
>>> ampl.param['cost'] = [
    3.59, 2.59, 2.29, 2.89, 1.89, 1.99, 1.99, 2.49]
>>> ampl.param['f_min'] = [2, 2, 2, 2, 2, 2, 2, 2]
>>> ampl.param['f_max'] = [10, 10, 10, 10, 10, 10, 10, 10]
>>> ampl.eval('display cost, f_min, f_max;')
:      cost f_min f_max    :=
BEEF   3.59    2     10
CHK    2.59    2     10
FISH   2.29    2     10
HAM    2.89    2     10
MCH    1.89    2     10
MTL    1.99    2     10
SPG    1.99    2     10
TUR    2.49    2     10
;
```

Travelling Salesman Problem (TSP)

```
from amplpy import AMPL
ampl = AMPL()
ampl.eval('''
param n;
set V := 1..n;
set A := {(i,j) in V cross V : i != j};
param c{A} >= 0 default Infinity;
var x{A}, binary;
minimize total: sum{(i,j) in A} c[i,j] * x[i,j];
s.t. enter{j in V}: sum{i in V: i != j} x[i, j] == 1;
s.t. leave{i in V}: sum{j in V: j != i} x[i, j] == 1;

# subtour elimination Miller, Tucker and Zemlin (MTZ) (1960)
var u{V} >= 0;
subject to MTZ{(i,j) in A: i != 1}: u[i]-u[j] + (n-1)*x[i,j] <= n-2;
''')
n, dist = load_tsp_instance('tsp_51_1.txt')
ampl.param['n'] = n
ampl.param['c'] = dist
```

Defining a generic callback in Python

```python
import amplpy_gurobi as ampls
# Define my generic callback function
class MyCallback(ampls.GenericCallback):
    def __init__(self):
        self.nMIPnodes = 0
    def run(self):
        t = self.getAMPLWhere()
        if t == ampls.Where.MSG:
            print('>' + self.getMessage())
        elif t == ampls.Where.MIPNODE:
            self.nMIPnodes += 1
            print("New MIP node, count {}".format(self.nMIPnodes))
        elif t == ampls.Where.MIPSOL:
            print("MIP Solution = {}".format(self.getObj()))
        return 0
```

Using the callback with Gurobi

Export model object, optimize, and import solution:

```
m = ampl.exportGurobiModel() # export model object
cb = MyCallback()            # instantiate callback
m.setCallback(cb)            # set the callback to use
m.optimize()                 # run the optimization process
if m.getStatus() == ampls.Status.OPTIMAL:
    ampl.importSolution(m)   # load the solution into ampl
    ampl.display('total')    # display objective value form ampl
```

Output of m.optimize():

```
...
MIP Solution = 460.07905777356814
>*  206   208          44     460.0790578  419.71967  8.77%  19.5    1s
MIP Solution = 440.442642507044
>H  230   206                 440.4426425  419.75510  4.70%  18.6    1s
MIP Solution = 439.9556742664898
>*  354   250          42     439.9556743  419.75510  4.59%  18.3    1s
MIP Solution = 439.1123891294378
>*  490   284          55     439.1123891  420.06206  4.34%  18.1    1s
MIP Solution = 436.18563128541143
>H 1046   627                 436.1856313  423.97345  2.80%  18.0    3s
>  1074   648  426.46288   12  128  436.18563  426.46288  2.23%  19.9    5s
MIP Solution = 435.47746822093836
>H 1082   619                 435.4774682  426.47191  2.07%  19.7    5s
MIP Solution = 432.502179738009
>H 1089   593                 432.5021797  426.47191  1.39%  22.3    6s
MIP Solution = 431.10323765840644
>H 1191   621                 431.1032377  426.75789  1.01%  24.6    8s
MIP Solution = 428.871756392034
>* 1567   655         120     428.8717564  426.75789  0.49%  23.4    8s
...
```

Generate subtour elimination cuts with a callback

```
import amplpy_cplex as ampls # use cplex instead of gurobi
class TSPCuts(ampls.GenericCallback):
    def run(self):
        if self.getAMPLWhere() == ampls.Where.MIPSOL:
            self.mipsol()
        return 0
    def mipsol(self):
        sol = self.getSolutionVector()
        uf = UnionFind()
        for i, (u, v) in xvars.items():
            if sol[i] > 1e-5:
                uf.link(u, v)
        groups = uf.groups()
        if len(groups) == 1:
            print('Valid solution!')
            return
        for g in groups:
            print('> sub-tour: ', g)
            vnames = [ampl_var('x', i, j) for i in g for j in g if i != j]
            coeffs = [1 for i in range(len(vnames))]
            self.addLazy(vnames, coeffs, ampls.CutDirection.LE, len(grp)-1)
```

Using the callback with CPLEX

Export model object, optimize, and import solution:

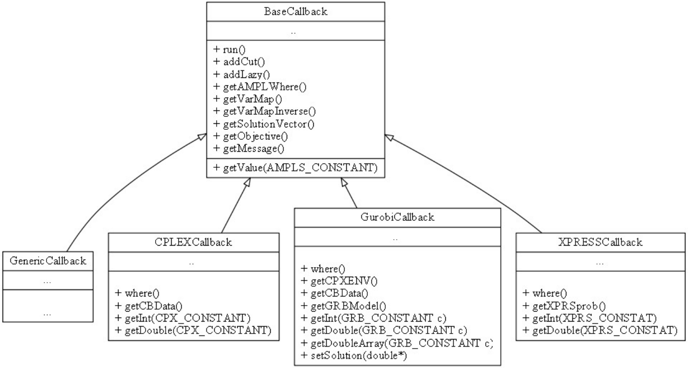
```python
m = ampl.exportCplexModel()  # export model object
cb = TSPCuts()               # instantiate callback
m.setCallback(cb)            # set the callback to use
m.optimize()                 # run the optimization process
if m.getStatus() == ampls.Status.OPTIMAL:
    ampl.importSolution(m)   # load the solution into ampl
    ampl.display('total')    # display objective value form ampl
```

Output of m.optimize():

```
...
MIPSOL #16
Valid solution!
MIPSOL #17
> sub-tour:  ['1', '6', '3', '29', '4', '47', '5', '35', '7', '37', '8', '20', '9', '10', '46', '11', '12', '19', '13', '3
> sub-tour:  ['2', '32']
> sub-tour:  ['21', '26', '38']
> sub-tour:  ['22', '44']
> sub-tour:  ['30', '43']
MIPSOL #18
> sub-tour:  ['1', '34', '2', '32', '3', '6', '4', '28', '5', '9', '7', '37', '8', '14', '47', '10', '11', '29', '12', '43
> sub-tour:  ['25', '42']
MIPSOL #19
> sub-tour:  ['1', '34', '3', '29', '4', '47', '5', '35', '6', '7', '37', '8', '20', '9', '10', '46', '11', '13', '31', '1
> sub-tour:  ['2', '26', '21']
> sub-tour:  ['12', '43', '22', '38', '30', '44']
> sub-tour:  ['23', '32']
MIPSOL #20
Valid solution!
Solved for 2550 variables, objective 428.87175639203394
CPLEX 12.10.0.0: optimal integer solution; objective 428.87175639203394
1245 MIP simplex iterations
```

Conclusions

- Even though this presentation was focused on callbacks in Python, we provide solver extensions with callbacks for other languages and solvers.
- We provide a generic interface that allows implementing callbacks that work seamlessly with multiple solvers, and solver specific interfaces so that users can take full advantage of everything a specific solver provides.



- Last but not least, all this interfaces are **open-source** so that users can contribute to them and extend them to support additional languages and solver features.