Introduction to CPLEX

1.0 Overview

There are a number of commercial grade LP solvers available. Wikipedia gives a decent summary at https://en.wikipedia.org/wiki/List_of_optimization_software.

Some very convenient solvers for many students include those with Excel and Matlab.

The standard one that comes with Excel uses a basic implementation of the primal Simplex method; however, it is limited to 200 decision variables. To use it, the Solver add-in must be included (not installed by default). To add this facility you need to carry out the following steps:

1. Select the menu option File → Options
2. Click "Add-ins" and then in the Manage box, select "Solver add-in" and then click "OK"

On clicking OK, you will then be able to access the Solver option from the Analysis group of the Data tab. If you want to see how to use it, using the LP example we have been working on, click on http://www.economicsnetwork.ac.uk/cheer/ch9_3/ch9_3p07.htm. You can also buy commercial add-ons that significantly improve the power of Excel as an LP solver. For example, see http://www.solver.com/.

Matlab also has a very easy to use solver. And there is an add-on for Matlab, called Tomlab, which significantly increases the solver's capabilities, and we have it at ISU if you want to use it. See http://tomopt.com/tomlab/about/ for more details about Tomlab.

There are various commercial solvers today, including, for example, CPLEX, Gurobi, XPRESS, MOSEK, and LINDO. There are some lesser-known solvers that provide particularly effective means of decomposition, including ADMM and DSP. Although many of these implementations use similar algorithms, they perform quite differently on different types of problems.

You should also be aware that there are various commercial modeling systems that interface with the solvers, including, for example, GAMS, AMPL, AIMMS, and MPL. These systems, referred to as algebraic modeling languages (AMLs), link the domain-expert's conceptualization of their problem to the various algorithms instantiated in the solvers, via problem expressions that are similar to the mathematical description one uses when writing the problem objective function and constraints. Generally, the choice of modeling system does not affect the solution speed of the solver, but different modeling systems may enable easier development of certain algorithm designs.

Many of the market/EMS software vendors in the power engineering industry use CPLEX (commercialized by ILOG later purchased by IBM). These organizations, together with the ISO's that they serve, are very interested in hiring people knowledgeable in mathematical programming (MP), and the tools available to implement MPs.

Once you are in industry, you may find yourself working for or interfacing with one of the market/EMS software vendors serving the power engineering industry (GE, Siemens, Hitachi, Toshiba, Open Systems International), and if you do, you may benefit from familiarity with CPLEX. And even if you don't find yourself working for or interfacing with one of these organizations, you may still find knowledge of CPLEX to be very useful as it is an excellent LP/MIP-solver platform. In these notes, I will show you how to access and use it.

General information about CPLEX can be found at

www.ibm.com/support/knowledgecenter/SSSA5P_12.6.2/ilog.odms.studio.help/Optimization_Studio/topics/COS_home.html.

Another attractive facility from ILOG is the capability to integrate solvers into existing code. This is available if you also acquire ILOG's Optimization Programming Language (ILOG OPL).

So I need to tell you how to access CPLEX at ISU.

2.0 Accessing CPLEX

CPLEX version 12.8 resides on an ISU server. To access it, you will need to logon to it remotely. To do that, you will need a ftp and telnet facility. I suggest using the facilities WinSCP and PuTTY. WinSCP is an ftp facility. PuTTY is a free implementation of Telnet and SSH for Win32 and Unix platforms, along with an xterm terminal emulator. Links to download both of these programs are found at https://wikis.ece.iastate.edu/it/index.php/Useful_Software.

Once you download and install WinSCP and then bring up the program, you can type into the "Hostname" the server name of the servers which has CPLEX installed. These servers are listed at http://it.engineering.iastate.edu/remote/. For example, you can type linux-6.ece.iastate.edu, enter you username and password, and then click "Login." (If you are off-campus, you will first have to log on to the ISU VPN using the Cisco AnyConnect tool). Once logged-in, a navigation screen for your local machine will appear on your left, and a navigation screen for the remote machine will appear on your right. You can click on the "up" directory towards the top of each screen to move upwards, and of course just click on a directory to move down into it.

To transfer a file from your local machine to the remote machine, use the left screen to navigate to the directory on your local machine where the file resides. Then click once on the file you want to transfer. (If you want to transfer multiple files, you can click once on each file while holding down the "control" key.)

Now navigate to the directory on your remote machine where you want to put the file. Once there, right-click on the file you want from the left-hand-screen, and select "upload" to move the file to the server on the right-hand screen.

To download PuTTY,

1. The PuTTY download page is at www.chiark.greenend.org.uk/~sgtatham/putty/download.html. At this page, you will find some alternatives; I used (successfully) the putty-0.73-installer.msi.

2. Run PuTTY and get the window shown in Fig. 1. Input "linux-6.ece.iastate.edu" in the Host Name. (If you are off-campus, you will first have to log on to the ISU VPN using the Cisco AnyConnect tool).

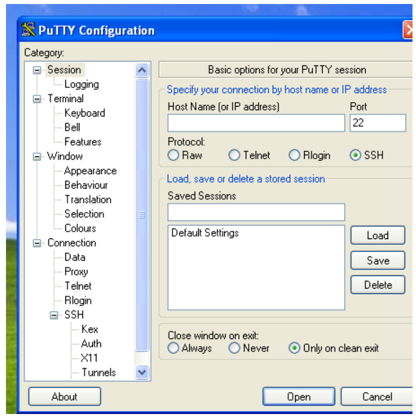

Fig. 1 Run PuTTY

3. Use your ISU username and password to log in. You will find yourself on a unix terminal emulator.
4. You might like to create a working directory. To do this, use mkdir DirectoryName, where DirectoryName is the name of the directory you want to use. To enter that directory, use cd DirectoryName. You can see what files reside in that directory using the command ls .
5. To run CPLEX, type cplex

Although you can use CPLEX from a command line, I find it is almost always better to prepare a file. It is probably better to prepare a file on your own computer, and then port it over to the server.

3.0 A CPLEX Example

To illustrate this process, I will solve the following problem using CPLEX.

$$\max F = 5x_1 + 4x_2 + 3x_3$$

Subject to

$$2x_1 + 3x_2 + x_3 \le 5$$

$$4x_1 + x_2 + 2x_3 \le 11$$

$$3x_1 + 4x_2 + 2x_3 \le 8$$

$$x_1 \ge 0, x_2 \ge 0, x_3 \ge 0$$

The first thing to do is to construct a file containing the problem. To construct this file, you can use the program called “notepad” under the “accessories” selection of the start button in Windows.

Once you open notepad, you can immediately save to your local directory under the filename “filename.lp.” You can choose “filename” to be whatever you want, but you will need the extension “lp.”

To obtain the extension “lp” when you save, you should do “save as” and then choose “all files.” Otherwise, it will assign the suffix “.txt” to your file.

Here is what I typed into the file I called “ex2.lp”…

```
maximize
  5 x1 + 4 x2 + 3 x3
subject to
 2 x1 + 3 x2 + x3 <= 5
 4 x1 + x2 + 2x3 <= 11
 3 x1 + 4 x2 + 2 x3 <= 8
 x1 >= 0
 x2 >= 0
 x3 >= 0
end
```

The format of the above file is quite forgiving. Nonetheless, your first time through, perhaps you should do it exactly as I have done.

Once I saved the file “ex2.lp” on my local hard drive, I then used WinSCP to port it over to the server, where I saved it in a special directory called EE458 that I had set up for this.

Then I used PuTTY to telnet to the server, where I then used the “cd” command to go into the directory where the “ex2.lp” file was located. Once in that directory, I typed “cplex” at the command prompt. The following is the log of my CPLEX session from this point on:

```
[jdm@linux-6 ~/EE458]$ cplex
Welcome to IBM(R) ILOG(R) CPLEX(R) Interactive Optimizer 12.9.0.0
  with Simplex, Mixed Integer & Barrier Optimizers
5725-A06 5725-A29 5724-Y48 5724-Y49 5724-Y54 5724-Y55 5655-Y21
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Type 'help' for a list of available commands.
Type 'help' followed by a command name for more
information on commands.

CPLEX> read ex2.lp
Problem 'ex2.lp' read.
Read time = 0.08 sec. (0.00 ticks)

CPLEX> primopt
Tried aggregator 1 time.
LP Presolve eliminated 3 rows and 0 columns.
Reduced LP has 3 rows, 3 columns, and 9 nonzeros.
Presolve time = 0.00 sec. (0.00 ticks)

Iteration log . . .
Iteration:     1    Objective     =            12.500000

Primal simplex - Optimal:  Objective =  1.3000000000e+01
Solution time =    0.04 sec.  Iterations = 2 (0)
Deterministic time = 0.01 ticks  (0.16 ticks/sec)
```

```
CPLEX> display solution variables -
Variable Name          Solution Value
x1                         2.000000
x3                         1.000000
All other variables in the range 1-3 are 0.

CPLEX> display solution slacks -
Constraint Name           Slack Value
slack c2                    1.000000
slack c4                   -2.000000
slack c6                   -1.000000
All other slacks in the range 1-6 are 0.
CPLEX> display solution dual -
Constraint Name            Dual Price
c1                         1.000000
c3                         1.000000
All other dual prices in the range 1-6 are 0.
CPLEX> quit
[jdm@linux-6 ~/EE458]$
```

A few comments about the above might be useful:

1. The command "read ex2.lp" was required to read the problem. Note that this command reinitializes CPLEX. Once you solve a problem, it will not resolve until you reinitialize.
2. Once we had read in the problem, we solved it by issuing the command "primopt" which calls the

primal simplex algorithm. This is the simplex algorithm studied in EE/Econ 458 (there are other algorithms that you can call with CPLEX as well).

3. The objective function improved to 12.5 after the first iteration (from 0).
4. The problem solved in the second iteration.
5. The command display solution variables - was used to display the values of the decision variables at the solution.
6. The values of the decision variables at the solution were $x_1=2$, $x_2=0$, $x_3=1$, and at this solution, the value of the objective function was $F=13$.
7. Note that CPLEX does not print the values of decision variables that are zero.
8. The command display solution slacks – was used to display the values of the slacks at the solution.
9. CPLEX will name the slack variables

$$c_1, c_2, \ldots, c_m, c_{m+1}, \ldots, c_{m+n}$$

where there are m constraints and n decision variables. Therefore the first m slack variables (c_1, c_2, …, c_m) correspond to the explicit inequality constraints, and the last n slack variables (c_{m+1},…, c_{m+n}) correspond to the nonnegativity constraints on the decision variables.

10. The values of the slack variables at the solution were $c_1=0$, $c_2=1$, $c_3=0$, $c_4=-2$, $c_5=0$, $c_6=-1$.
11. Note that CPLEX does not print the values of slack variables that are zero.

12. The fact that $c_1=0$ and $c_3=0$ indicates that the first and third constraints are binding. That $c_2=1$ indicates the left-hand side of the second constraint is less than the right-hand-side by 1. Checking these constraints, we find

Constraint 1:

$$2x_1 + 3x_2 + x_3 \le 5$$

$$2(2) + 3(0) + 1 = 5 \qquad \surd$$

Constraint 2:

$$4x_1 + x_2 + 2x_3 \le 11$$

$$4(2) + 0 + 2(1) = 10 \qquad \surd$$

Constraint 3:

$$3x_1 + 4x_2 + 2x_3 \le 8$$

$$3(2) + 4(0) + 2(1) = 8 \qquad \surd$$

13. The fact that $c_5=0$ indicates that the second inequality constraint is binding, i.e.,

$$x_2 \ge 0$$

which is consistent with the fact that $x_2=0$.

14. The facts that $c_4=-2$, $c_6=-1$ is interesting because these slacks are negative. This is a result of the fact that the corresponding constraints are actually "greater than or less to" constraints instead of "less

than or equal to constraints." The way they are treated in CPLEX is as follows:

$$x_1 \geq 0 \Rightarrow x_1 + c_4 = 0$$

so that when $x_1=2$, as it is in the solution, $c_4=-2$. Likewise,

$$x_3 \geq 0 \Rightarrow x_3 + c_6 = 0$$

so that when $x_3=1$, as it is in the solution, $c_6=-1$.

So the above is a very brief and concise introduction to CPLEX. I have also provided IBM's more detailed tutorial and IBM's user manual on the course website to give you good references to use for CPLEX. Although these two references are slightly dated (2017 and 2015, respectively), I am pretty sure 99% (or more) of the information in them is accurate. For the most recent information, go to
www.ibm.com/support/knowledgecenter/SSSA5P_12.6.2/ilog.odms.studio.help/Optimization_Studio/topics/COS_home.html
However, I find the posted tutorial and user manual easier to use than the materials posted on the above website.