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Mathematical Sciences
Optimization
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MVE165
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Linear and Integer Optimization
with Applications
Exercise information
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Computer exercise: Linear programming and software solvers

Introduction

The purpose of this computer exercise is to make you familiar with the use of software for computing solutions to linear programs. While performing the exercises, you will learn about the different solvers with their strengths and drawbacks. This will be helpful for the assignments and hopefully also in your future work. The following softwares are included:

- AMPL[1], an algebraic modelling language for mathematical programming;
- MATLAB's optimization toolbox[2] handles linear, nonlinear unconstrained and constrained, and binary (linear) programs. It also contains special purpose solvers for quadratic programs and nonlinear least squares problems.
- CPLEX[3], a linear, integer linear, and quadratic programming solver with interfaces to AMPL and MATLAB;
- Gurobi[4] a linear, integer linear, and quadratic programming solver with interfaces to AMPL, MATLAB, and Python;
- Coin-Or project[5], an open-source project containing CLP linear and quadratic programming solver, CBC a integer linear programming solver, and PuLP a python interface to these and other solvers.

Before you do the exercise you shoud read Chapters 1, 2.1, 2.6, and 4 in the course book[6].

[1] `http://www.ampl.com/`
[2] `http://www.mathworks.com/products/optimization/`
[3] `http://www-01.ibm.com/software/integration/optimization/cplex/`
[4] `http://www.gurobi.com`
[5] `https://projects.coin-or.org`
[6] Optimization (2010)/Optimeringslära (2008), by J. Lundgren, M. Rönnqvist, P. Värbrand. Studentlitteratur

Exercise 1.1 – AMPL

A nonferrous metals corporation manufactures four different alloys from four basic metals. The objective is to determine the optimal product mix to maximize gross revenue without exceeding the supply limits. The requirements are given in the table below. Formulate a linear optimization model for this problem, implement the model in AMPL and solve it using CPLEX.

Metal	Proportions of metal in alloy				Total supply of
	1	2	3	4	metal/day
1	0.25	0.6	0.2	0.1	5 tons
2	0.25	0.2	0.6	0.7	5 tons
3	0.25	0	0.1	0.1	1 ton
4	0.25	0.2	0.1	0.1	2 tons
Selling price of alloy/ton:	\$30	\$15	\$25	\$23	

`AMPL` works with three files; a script file (`name.run`), a model file (`name.mod`), and a data file (`name.dat`). The variable names, the parameter names, the objective function, and the constraints are formulated in the model file. All the data (e.g., the entries of the cost vector c) are specified in the data file. The solution course is indicated in the script file.

The files `lp1.run`, `lp1.mod`, and `lp1.dat` (for solving the model (LP1)) can be downloaded from the course homepage `http://www.math.chalmers.se/Math/Grundutb/CTH/mve165/1718/`. To solve the above model, modify these files and solve the problem by typing[7] at the prompt (presuming that your script file is named `alloy.run`):

```
> ampl alloy.run
```

Transforming the linear program into an integer linear program is made by adding '`integer`' to the variable declaration in `lp1.mod`, according to '`var xJ integer >= 0;`'.

Common issues

Licence error If you run on the Chalmers Linux system and you get a licence error make sure to have run the terminal command reported on the course homepage: `vcs-select...` .

Solver not found If run the above code on the ampl version received from PingPong, you'll need to modify the `.run`-file and let

```
options solver cplex; # choose cplex as optimization solver
```

replace the old `options solver`-row. Note that the ping pong ampl version contains additional solvers, e.g. `gurobi`.

[7] Limited-time academic licences for `AMPL` and a few solvers—for use on your own computer—will be distributed to the students registered for the course.

Exercise 1.2 – MATLAB

Solve the simple linear programming problem

$$\begin{aligned} \text{(LP1)} \qquad \text{minimize} \quad & z = -x_1 - 2x_2, \\ \text{subject to} \quad & -2x_1 + x_2 \leq 2, \\ & -x_1 + x_2 \leq 3, \\ & x_1 \leq 3, \\ & x_1, \; x_2 \geq 0, \end{aligned}$$

graphically. Then, start MATLAB by typing '`matlab &`' in a Linux command window. Implement and solve (LP1) using `linprog` in MATLAB. The problem does not need to be in standard form, however it must be in matrix form. Try `'help linprog'`; it can handle equality constraints (`Aeq` and `beq`), inequality constraints (`A` and `b`), and lower (`lb`) and upper bounds (`ub`) on variables. Bounds on variables can be modlled using general linear inequalities, but it is often more efficient to model these explicitly. This is extra important for large problems.

With the structure `options`, the user can influence the algorithm. Try `'help optimoptions'` to see a list of options. To set any of them, e.g., `Display` and `MaxIter`, generate the structure '`options`' by

```
>> options = optimset('Display', 'on', 'MaxIter', 100);
```

and solve using (see also `'help linprog'`)

```
>> [x,f] = linprog(c, A, b, [], [], lb, [], x0, options)
```

where `x0` refers to a starting point (which may be omitted, using `[]`) and `options` is either set or omitted; to choose between different linear programming solvers (simplex and interior-point), type e.g.:

```
>> options = optimoptions('linprog','Algorithm','dual-simplex');
```

For this simple example, no difference between the methods is seen, but for larger problems the difference is huge. The simplex method implemented in `linprog` seems to be more robust than the interior-point method (see Ch. 7.5 of the book by Lundgren et al.). The simplex implementation in `linprog` cannot, however, handle sparse matrices efficiently, which makes it very slow for large problem instances.

For solving other problem types, as e.g., quadratic programs, try `'help optim'` to see a list of the solver routines in the toolbox.

Using Gurobi with MATLAB

Most commercial optimization solvers has an interface to MATLAB, Gurobi is one of these. If you intend to use Matlab for optimization (in this course or in the future) you should consider

using an external solver, here is a short introduction for the Gurobi interface (works best on your own computer).

1. Create an account at `http://www.gurobi.com/registration/general-reg`.
2. Download Gurobi at `http://www.gurobi.com/downloads/gurobi-optimizer`, if you're on the Chalmers linux system choose `gurobi7.5.2_linux64.tar.gz`.
3. Request a licence at `https://user.gurobi.com/download/licenses/free-academic`.
4. Goto `https://user.gurobi.com/download/licenses/current`
   (a) select the license
   (b) copy the terminal command `grbgetkey ` .....
5. Extract the Gurobi-file from step 2 to, e.g., your home folder.
6. Open a terminal and navigate to `/gurobi752/linux64/bin`
7. Execute the terminal command, e.g., `./grbgetkey ` .....
   (You need internet connection via Chalmers Domain, e.g., at campus or by vpn.)

You have now installed Gurobi on your system, note that the Licence is connected to your computer, hence if you're on the Chalmers system you might need to repeat steps 4–7, upon switching computer.

To use Gurobi with MATLAB do these steps.

1. In the MATLAB console navigate to your Gurobi directory (/gurobi752/linux64/matlab) or add it to the path.
2. run `gurobi_setup`
3. Use the `gurobi_example.m` from the course homepage (uses parts of next exercise) or consult the documentation[8].

[8] `http://www.gurobi.com/documentation/7.5/refman/matlab_gurobi.html`

Exercise 1.3 – NETLIB

In this exercise the MATLAB optimization toolbox and optionally Gurobi will be used to solve test problems from NETLIB[9] repository, which contains a large collection of numerical software. The repository also contains a linear programming test set, which has been used extensively for benchmarking linear programming solvers. The problems are small scale according to the standard of today, but many of them are nonetheless quite difficult to solve. The test problems have been submitted by several researchers; many of them are based on real applications. Other software solvers exist, e.g., SCIP[10].

From the course web page, download the recommended NETLIB examples `lpcoll.zip` (or the whole NETLIB repository `netlibfiles.zip`) and unzip it using the command '`unzip lpcoll.zip`' (or '`unzip netlibfiles.zip`'); all these examples are stored in MATLAB's `.mat`-format. To load a test example into MATLAB, type e.g., '`load agg3.mat`' in a MATLAB command window. Also, download the text file `lp_data_readme` containing information on the sizes and optimal values for the problems. Each `.mat`-file contains the matrices `A`, `b`, `c`, `lo`, and `hi`, and `z0` for a linear program on the form

$$\min z := c^{\mathrm{T}}x + z_0, \qquad \text{subject to} \quad Ax = b,\ \mathrm{lo} \le x \le \mathrm{hi}.$$

Compare the performance of the solvers on the NETLIB linear programming test set. Measure the computation time and whether the correct optimum is found. You don't have to try all problems; pick a few of varying size. Try to draw conclusions about the efficiency of the solvers applied to the different test problems.

MATLAB optimization toolbox Contains several algorithms for solving LP-problems. Try solving some instances with different algorithms, e.g.,

```
>> options = optimoptions('linprog','Algorithm','dual-simplex');
>> options = optimoptions('linprog','Algorithm','interior-point');
```

Matlab Gurobi Interface If you did install Gurobi according to the previous section, also try solving some instances with Gurobi; see the example `gurobi_example.m` on the course homepage.

[9] `http://www.netlib.org/`
[10] `http://scip.zib.de/`

Coin-Or Project

All above approaches involve commercial software that might not be accessible to you after this course, thus we here present one open-source alternative, which is still quite competitive. The two solvers are

CLP [11] a linear programming optimization solver with interface to `C` and support for the fileformat `.MPS`.

CBC [12] a integer linear programming optimization solver with interface to `C` and support for the fileformat `.MPS`.

Using these can be quite cumbersome to use, requiring low-level programming. However if you know (or are willing to learn) the scripting language `Python`, you can instead use the interface PuLP[13], that is an interface to several solvers both open-source (e.g., GLPK[14]) and commercial (e.g., Gurobi).

[11] `https://projects.coin-or.org/Clp`
[12] `https://projects.coin-or.org/Cbc`
[13] `https://github.com/coin-or/pulp`
[14] `https://www.gnu.org/software/glpk/`