Introduction to Gurobi

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Overview

Introduction to

- The Gurobi Optimizer is a state-of-the-art solver for mathematical programming.
- It has been developed by Zonghao **Gu**, Edward **Ro**thberg (they led the CPLEX development team for a decade) and Robert **Bi**xby, which is instead the founder of CPLEX.
- It includes solvers for the following types of problems:
  - Linear Programming problems (LP);
  - Mixed-Integer Linear Programming (MILP);
  - Mixed-Integer Quadratic Programming (MIQP);
  - Quadratic Programming (QP);
  - Quadratically Constrained Programming (QCP);
  - Mixed-Integer Quadratically Constrained Programming (MIQCP)

Features

- Advanced implementation of the **latest algorithms**:
  - LP Solver: primal and dual simplex algorithms, parallel barrier algorithm with crossover, concurrent optimization, and sifting algorithm
  - QP Solver: simplex and parallel barrier algorithms
  - QCP Solver: parallel SOCP barrier algorithm
  - MIP Solver: deterministic, parallel branch-and-cut, non-traditional tree-of-trees search, multiple default heuristics, solution improvement, cutting planes, and symmetry detection
- Standard MIP **cutting plane routines** and also new routines developed on purpose and not known to the public.
- **Interfaces** for object oriented languages (e.g., C++, Java, Python) and matrix-oriented languages (e.g., C, MATLAB, R).
- Links to standard modeling languages (e.g., **AMPL**, MPL).
- Extremely robust code and parallelism
- **Presolve**: before solving a problem, it performs some reductions working on the constraints (e.g., aggregation, bound strenghtening), in order to make the resolution faster.

Gurobi versions

According to the user type, Gurobi can be obtained through different licenses:

- Commercial users can have a free evaluation license to try the software for a certain period and then buy it;
- Independent Software Vendor users can make an agreement with Gurobi to exploit it in theirs products;
- Academic users instead can obtain a **free academic license** for a year at the following link, after registration:
  https://user.gurobi.com/download/licenses/free-academic
  The license will appear immediately on your account.
  Note: register with your academic e-mail address!

Installation

- Download the latest version of Gurobi for your operative system at this link: http://www.gurobi.com/downloads/gurobi-optimizer

Get the software

Gurobi Optimizer is the Gurobi optimization libraries. In addition to the software, the corresponding README file contains installation instructions. Here is the list of bug fixes for each release.

Current version		64-bit Windows	32-bit Windows	64-bit Linux	64-bit macOS	64-bit AIX
8.1.0	README	Gurobi-8.1.0-win64.msi		gurobi8.1.0_linux64.tar.gz	gurobi8.1.0_mac64.pkg	gurobi8.1.0_power64.tar.gz
Old versions						
8.0.1	README	Gurobi-8.0.1-win64.msi		gurobi8.0.1_linux64.tar.gz	gurobi8.0.1_mac64.pkg	gurobi8.0.1_power64.tar.gz
7.5.2	README	Gurobi-7.5.2-win64.msi	Gurobi-7.5.2-win32.msi	gurobi7.5.2_linux64.tar.gz	gurobi7.5.2_mac64.pkg	gurobi7.5.2_power64.tar.gz
7.0.2	README	Gurobi-7.0.2-win64.msi	Gurobi-7.0.2-win32.msi	gurobi7.0.2_linux64.tar.gz	gurobi7.0.2_mac64.pkg	gurobi7.0.2_power64.tar.gz

Gurobi for Mac OS X

1. Extract the package in your Downloads folder.
2. Double-click on the appropriate installer (e.g., gurobi8.1.0_mac64.pkg for Gurobi 8.1.0) and follow the prompts. By default, the installer will place the Gurobi 8.1.0 files in your system /Library/gurobi810/mac64.
3. **Check** to be connected to an academic network, because it will be needed to verify your license: Gurobi will check if the domain name is in its list of known academic domains.
4. Go to your license page on your Gurobi account at this link: https://user.gurobi.com/download/licenses/current

Current Gurobi Licenses

Your installed and available licenses

Click a line to view license details.

License ID	Purpose	Type	Version	Host Name	Date Issued
282200	Trial	Free Academic	8	MacBook-Pro-di-Alice-2.local	2018-11-16

5. Click on the license to see details and copy the code below starting with *grbgetkey*:

License Detail

License ID 282200

Information and installation instructions

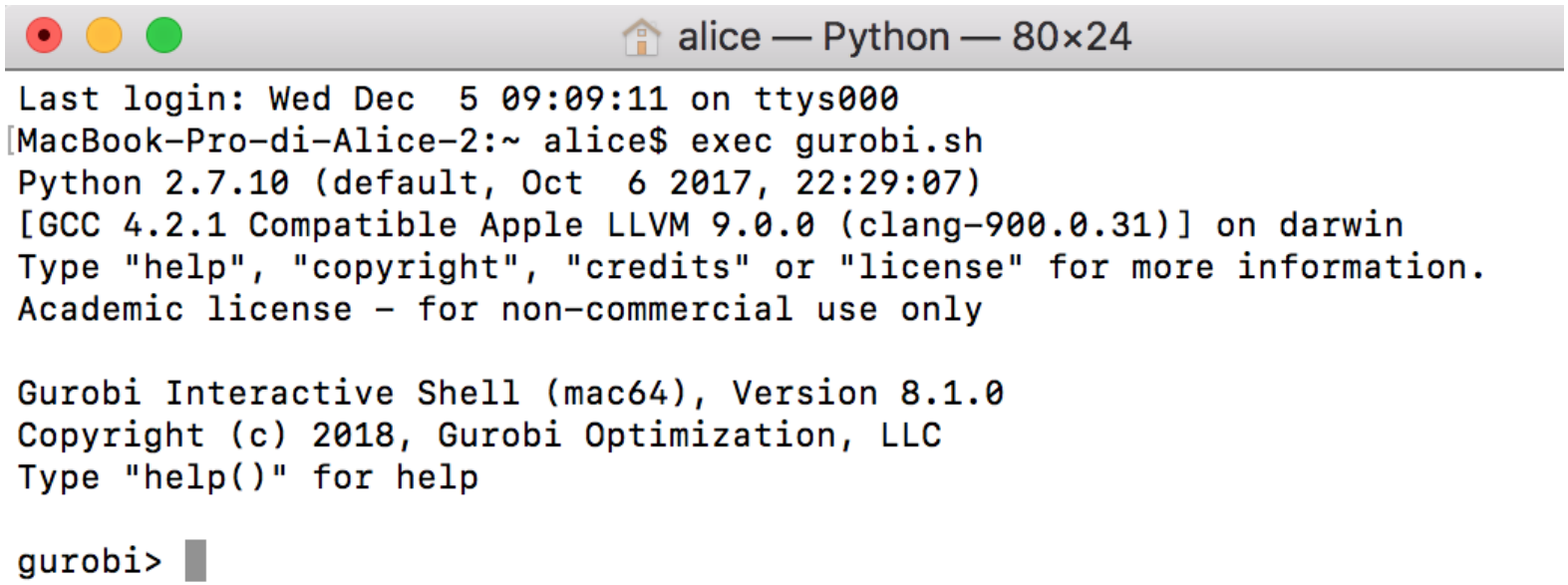
License ID	282200
Date Issued	2018-11-16T01:17:11-08:00
Purpose	Trial
License Type	Free Academic
Key Type	ACADEMIC
Version	8
Distributed Limit	0
Expiration Date	2019-11-16
Host Name	MacBook-Pro-di-Alice-2.local
Host ID	9b0bbce7
User Name	alice

To install this license on a computer where Gurobi Optimizer is installed, copy and paste the following command to the Start/Run menu (Windows only) or a command/terminal prompt (any system):

```
grbgetkey 665aaeaa-e980-11e8-a7cf-02e454ff9c50
```

6. Launch Gurobi and paste the code in the terminal that will be opened.
   Note: you must be connected to the University wireless network, in order to activate the license.

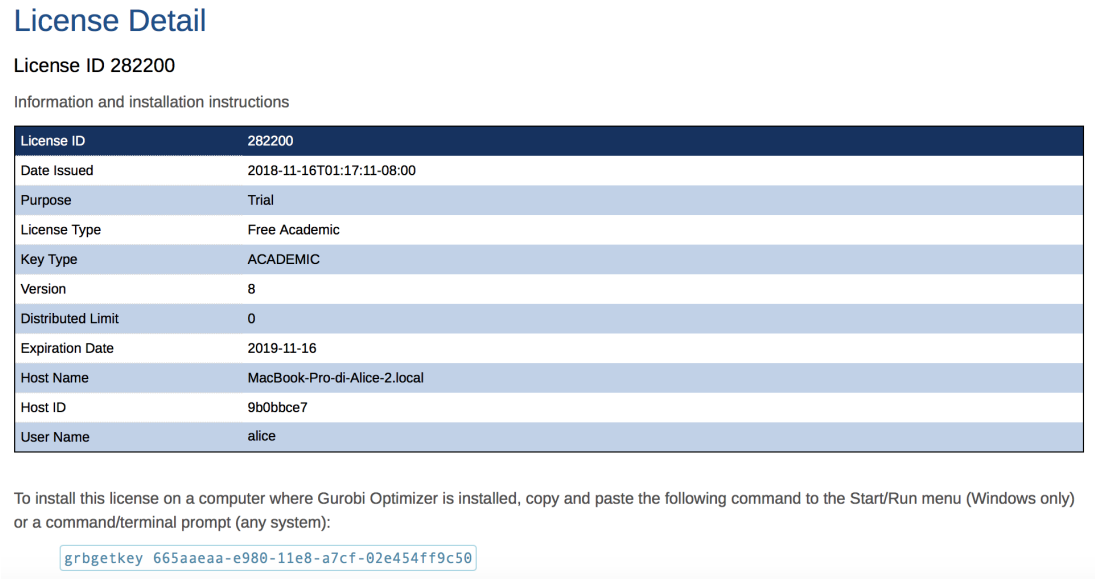
7. When the license activation is completed, launching Gurobi you will get the following terminal window:



Gurobi for Windows

1. Gurobi supports Windows 7, Windows 8 and Windows 10.
2. Download the 32-bit or 64-bit version according to your operative system.
3. Double-click on the package named **Gurobi-8.1.0-winXX** to launch installation.
4. By default, the installer will place the Gurobi 8.1.0 files in directory **C:\gurobi810\win64** (or **C:\gurobi810\win32** for 32-bit Windows installs).

5. Click on the license to see details and copy the code below starting with *grbgetkey*:



License Detail

License ID 282200

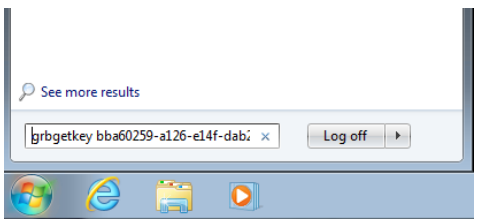
Information and installation instructions

License ID	282200
Date Issued	2018-11-16T01:17:11-08:00
Purpose	Trial
License Type	Free Academic
Key Type	ACADEMIC
Version	8
Distributed Limit	0
Expiration Date	2019-11-16
Host Name	MacBook-Pro-di-Alice-2.local
Host ID	9b0bbce7
User Name	alice

To install this license on a computer where Gurobi Optimizer is installed, copy and paste the following command to the Start/Run menu (Windows only) or a command/terminal prompt (any system):

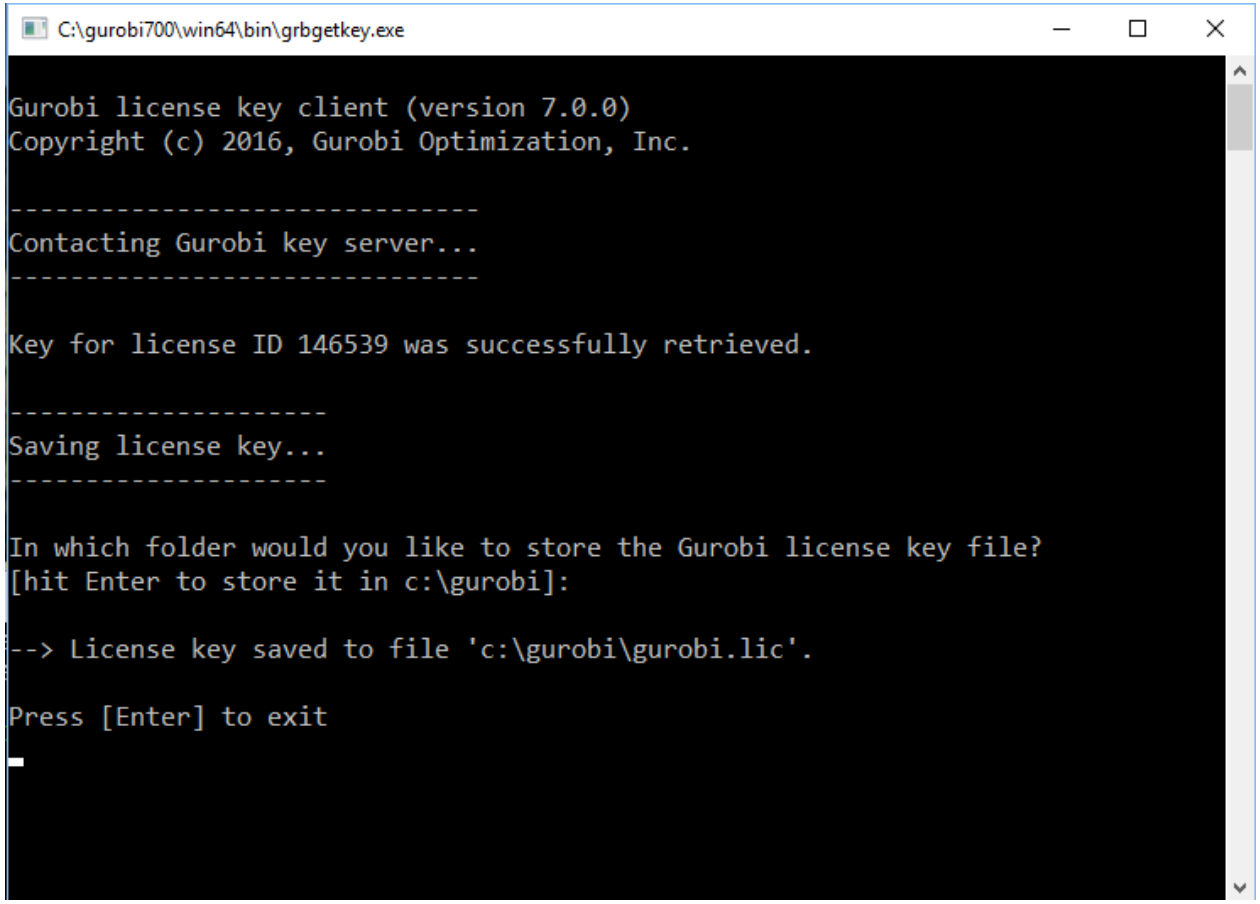
```
grbgetkey 665aaeaa-e980-11e8-a7cf-02e454ff9c50
```

6. Paste it directly into the Windows Search box and then hit Enter:



Note: you must be connected to the University wireless network, in order to activate the license.

7. You should get a command prompt window like the following:



8. Press Enter to complete the activation.

Gurobi lightweight command-line

- Firstable we can try to solve our first problem without writing code but just exploiting features of Gurobi.
- We are going to use a LP format to describe our model. Let's take back the formulation of the Diet problem:
  - A variable for every portion of each food: x_1, x_2, x_3, x_4, x_5
  - The objective function corresponds to the sum of the costs of every food: $min\ 3x_1 + 2x_2 + 3x_3 + 19x_4 + 15x_5$
  - Daily minimum necessities:
    - Calories: $150x_1 + 120x_2 + 160x_3 + 230x_4 + 450x_5 \geq 2000$
    - Proteins: $4x_1 + 8x_2 + 15x_3 + 14x_4 + 4x_5 \geq 50$
    - Calcium: $2x_1 + 285x_2 + 54x_3 + 80x_4 + 22x_5 \geq 700$
  - Maximum number of portions:
    - Bread: $0 \leq x_1 \leq 4$
    - Milk: $0 \leq x_2 \leq 7$
    - Eggs: $0 \leq x_3 \leq 2$
    - Meat: $0 \leq x_4 \leq 3$
    - Sweets: $0 \leq x_5 \leq 2$

The LP-format

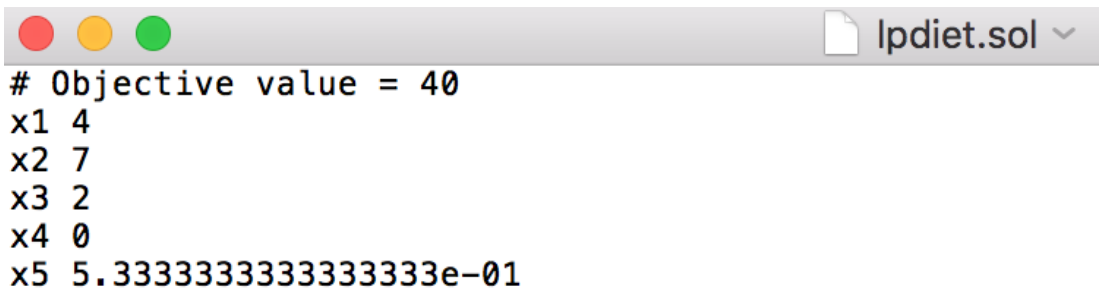
- The input syntax is a set of algebraic expressions and int declarations in the following order:
  - Objective function
  - Constraints
  - Declarations
- Here follows the **gurobi-lpformat-diet.lp** file:

gurobi-lpformat-diet

```
Minimize
        3 x1 + 2 x2 + 3 x3 + 19 x4 + 15 x5
Subject To
Calories: 150 x1 + 120 x2 + 160 x3 + 230 x4 + 450 x5 >= 2000
Proteins: 4 x1 + 8 x2 + 15 x3 + 14 x4 + 4 x5 >= 50
Calcium: 2 x1 + 285 x2 + 54 x3 + 80 x4 + 22 x5 >= 700
Bounds
x1 <= 4
x2 <= 7
x3 <= 2
x4 <= 3
x5 <= 2
Semi-continuous
x1 x2 x3 x4 x5
End
```

Solving the problem

1. Open a new terminal or a command prompt, go to the directory where you have saved the lp file and type **gurobi_cl ResultFile=gurobilpdiet.sol gurobi-lpformat-diet.lp**
2. Gurobi will show you its log and the value of the solution found, saving results in the .sol file:



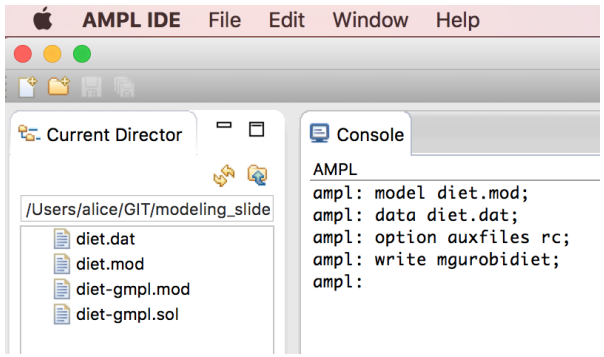
3. Gurobi logs:

Diet — -bash — 97×42

```
2016-23176:~ alice$ cd GIT/modeling_slides/modeling_exercises/Diet/
2016-23176:Diet alice$ gurobi_cl ResultFile=gurobilpdiet.sol gurobi-lpformat-diet.lp
Academic license - for non-commercial use only

Gurobi Optimizer version 7.5.2 build v7.5.2rc1 (mac64)
Copyright (c) 2017, Gurobi Optimization, Inc.

Read LP format model from file gurobi-lpformat-diet.lp
Reading time = 0.00 seconds
: 3 rows, 5 columns, 15 nonzeros
Optimize a model with 3 rows, 5 columns and 15 nonzeros
Variable types: 0 continuous, 0 integer (0 binary)
Semi-Variable types: 5 continuous, 0 integer
Coefficient statistics:
  Matrix range     [2e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 7e+00]
  RHS range        [5e+01, 2e+03]
Found heuristic solution: objective 97.0000000
Presolve removed 1 rows and 0 columns
Presolve time: 0.00s
Presolved: 2 rows, 5 columns, 10 nonzeros
Variable types: 5 continuous, 0 integer (0 binary)

Root relaxation: objective 4.000000e+01, 1 iterations, 0.00 seconds

    Nodes    |    Current Node    |     Objective Bounds      |     Work
 Expl Unexpl |  Obj  Depth IntInf | Incumbent    BestBd   Gap | It/Node Time

*    0     0               0      40.0000000   40.00000  0.00%     -    0s

Explored 0 nodes (1 simplex iterations) in 0.01 seconds
Thread count was 4 (of 4 available processors)

Solution count 2: 40 97

Optimal solution found (tolerance 1.00e-04)
Best objective 4.000000000000e+01, best bound 4.000000000000e+01, gap 0.0000%

Wrote result file 'gurobilpdiet.sol'
```

Another way exploiting AMPL

1. Launch AMPL and go to the folder where you have the .mod and .dat files of our Diet problem; in the console, write the following commands:



AMPL allows you to generate a **.mps model** with the command **write m***modelname*, saving it in the same directory. The command **option auxfiles rc** is useful to keep the original names of variables and constraints: by default AMPL changes them because the MPS format cannot handle long variables and constraints names.
Together with gurobidiet.mps, two additional files will be generated: *gurobidiet.row* and *gurobidiet.col*.

2. The *gurobidiet.mps* file will look like this:

gurobidiet.mps

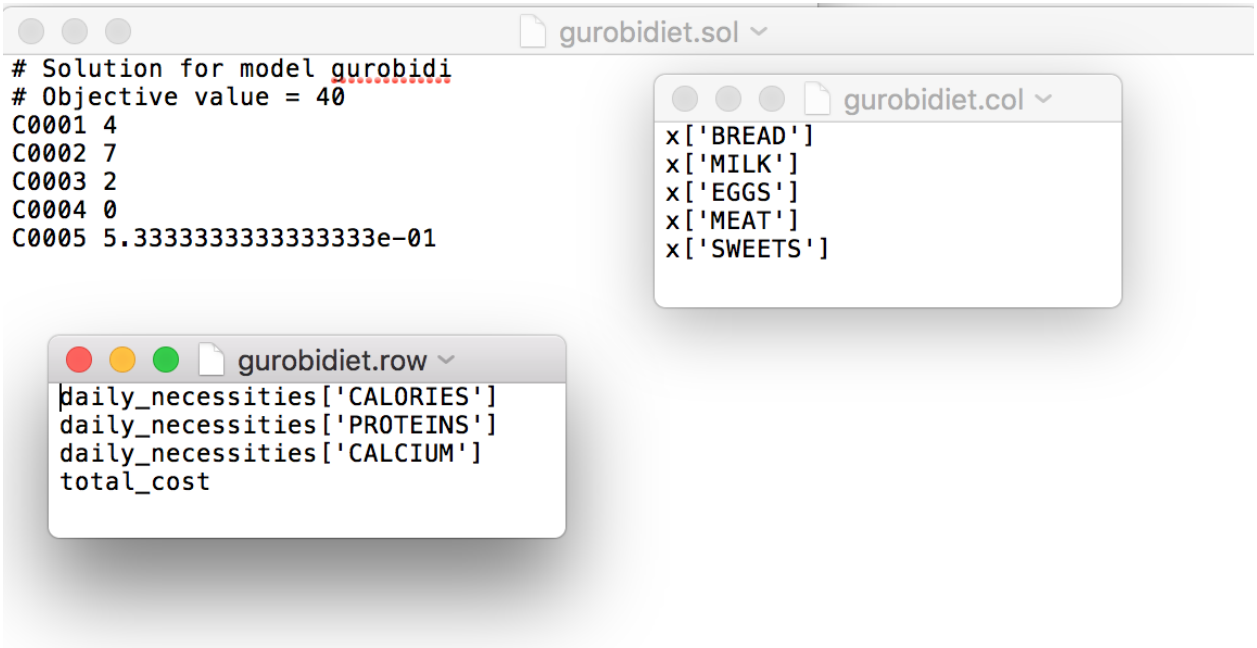
```
NAME          gurobidi
ROWS
 G  R0001
 G  R0002
 G  R0003
 N  R0004
COLUMNS
    C0001     R0001     150
    C0001     R0002     4
    C0001     R0003     2
    C0001     R0004     3
    C0002     R0001     120
    C0002     R0002     8
    C0002     R0003     285
    C0002     R0004     2
    C0003     R0001     160
    C0003     R0002     15
    C0003     R0003     54
    C0003     R0004     3
    C0004     R0001     230
    C0004     R0002     14
    C0004     R0003     80
    C0004     R0004     19
    C0005     R0001     450
    C0005     R0002     4
    C0005     R0003     22
    C0005     R0004     15
RHS
    B         R0001     2000
    B         R0002     50
    B         R0003     700
BOUNDS
 UP BOUND     C0001     4
 UP BOUND     C0002     7
 UP BOUND     C0003     2
 UP BOUND     C0004     3
 UP BOUND     C0005     2
ENDATA
```

3. To solve the problem with Gurobi command-line, open a new terminal and go to the folder where you have your diet files.
4. Type **gurobi_cl gurobidiet.mps** to launch the software and display the log in the terminal.
5. If you want to save results in an appropriate file to review the solution, instead type **gurobi_cl ResultFile=gurobidiet.sol gurobidiet.mps**

Diet — -bash — 86×29

```
Last login: Sat Nov 18 10:59:48 on ttys000
MacBook-Pro-di-Alice:~ alice$ cd GIT/modeling_slides/modeling_exercises/Diet/
MacBook-Pro-di-Alice:Diet alice$ gurobi_cl ResultFile=gurobidiet.sol gurobidiet.mps
Academic license - for non-commercial use only

Gurobi Optimizer version 7.5.1 build v7.5.1rc0 (mac64)
Copyright (c) 2017, Gurobi Optimization, Inc.

Read MPS format model from file gurobidiet.mps
Reading time = 0.00 seconds
gurobidi: 3 rows, 5 columns, 15 nonzeros
Optimize a model with 3 rows, 5 columns and 15 nonzeros
Coefficient statistics:
  Matrix range     [2e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 7e+00]
  RHS range        [5e+01, 2e+03]
Presolve time: 0.00s
Presolved: 3 rows, 5 columns, 15 nonzeros

Iteration    Objective       Primal Inf.    Dual Inf.      Time
       0    0.0000000e+00   1.968750e+02   0.000000e+00      0s
       1    4.0000000e+01   0.000000e+00   0.000000e+00      0s

Solved in 1 iterations and 0.01 seconds
Optimal objective  4.000000000e+01

Wrote result file 'gurobidiet.sol'
```

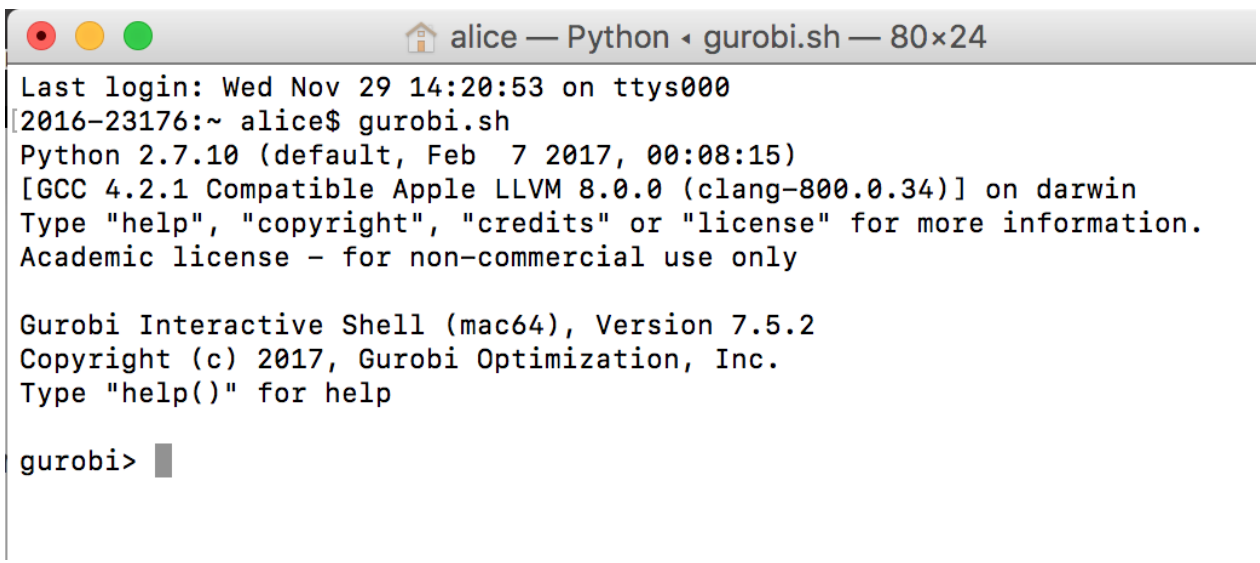
6. The *gurobidiet.sol*, *gurobidiet.row* and *gurobidiet.col* files:



7. As you can see, we obtained the same optimal result (the total cost is 40) and the advices about which foods and how many portions to eat.

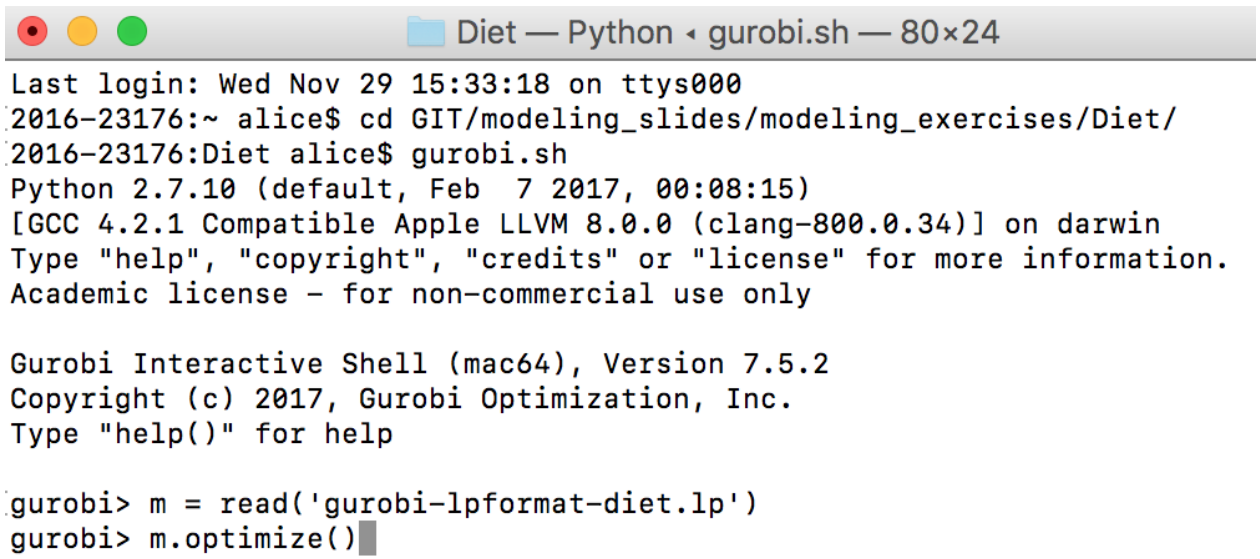
Using Gurobi Interactive Shell

- The Gurobi package includes a shell based on Python's one.
- It allows us to perform hands-on interaction and experimentation with optimization models.
- In fact it is possible to read models from files, perform complete or partial optimization runs on them, change parameters, modify the models, re-optimize, and so on.
- You can type in a terminal **gurobi.sh** to open it:



The Diet Problem with the Interactive Shell

1. Open a terminal and go to the directory where you have saved your diet lp file that we used before.
2. Type gurobi.sh and then you can use the command **m = read('filename')** to load a model from a file and save it into the variable **m**.
3. Once read and loaded the model, run the command **m.optimize()** to solve the instance.



4. Here follow Gurobi resolution logs:

Diet — Python ◂ gurobi.sh — 80×35

```
Gurobi Interactive Shell (mac64), Version 7.5.2
Copyright (c) 2017, Gurobi Optimization, Inc.
Type "help()" for help

gurobi> m = read('gurobi-lpformat-diet.lp')
gurobi> m.optimize()
Optimize a model with 3 rows, 5 columns and 15 nonzeros
Variable types: 0 continuous, 0 integer (0 binary)
Semi-Variable types: 5 continuous, 0 integer
Coefficient statistics:
  Matrix range     [2e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 7e+00]
  RHS range        [5e+01, 2e+03]
Found heuristic solution: objective 97.0000000
Presolve removed 1 rows and 0 columns
Presolve time: 0.00s
Presolved: 2 rows, 5 columns, 10 nonzeros
Variable types: 5 continuous, 0 integer (0 binary)

Root relaxation: objective 4.000000e+01, 1 iterations, 0.00 seconds

    Nodes    |    Current Node    |     Objective Bounds      |     Work
 Expl Unexpl |  Obj  Depth IntInf | Incumbent    BestBd   Gap | It/Node Time

*    0     0               0      40.0000000   40.00000  0.00%     -    0s

Explored 0 nodes (1 simplex iterations) in 0.00 seconds
Thread count was 4 (of 4 available processors)

Solution count 2: 40 97

Optimal solution found (tolerance 1.00e-04)
Best objective 4.000000000000e+01, best bound 4.000000000000e+01, gap 0.0000%
```

Changing the model

- Print values of variables:
  - **m.printAttr('X')** will display all nonzero variables and their values in a formatted way;
  - **m.getVars()** instead will print all variables as an array.
- You can do some modifications to the model, for example changing lower and upper bounds:
  gurobi> v = m.getVars()
  gurobi> v[1].ub = 2
  m.optimize()
  You will obtain a different solution, with value 50.
- A list of all methods on Model objects can be obtained typing **help(Model)** or **help(m)**.

Changing Gurobi parameters

- Gurobi solving operations are controlled by parameters like:
  - **MIPGap** (only for MIP models):
    - the MIP solver will terminate (with an optimal result) when the gap between the lower and upper objective bound is less than MIPGap times the absolute value of the upper bound;
    - default value: 1e-4.
  - **CutOff**:
    - its value indicates that you aren't interested in solutions whose objective values are worse than the specified value;
    - a solution with value better than the specified cutoff will be considered optimal.
  - **MIPFocus**:
    - it allows you to modify your high-level solution strategy, depending on your goals;
    - by default, its value is 0 (no strategy);
    - if its value is 1, the goal is to obtain a feasible solution; else if you want a feasible and optimal solution, its value is 2; finally, if its value is 3, Gurobi will focus on the objective bound.

- Let's try to change the CutOff in our diet problem, saying that we are satisfied with a total cost of 50;
- Type **m.setParam('CutOff', 50)** and then again **m.optimize()**, to obtain a different solution, with value exactly 50.
- To reset any changes we introduced, we can always type **m.resetParams()**.
- To reset the model to an unsolved state, discarding any previously computed solution information, type **m.reset()**.
- There is a simple automated tool to try different set of parameters: **m.tune()**.
- You can find the **complete list** of parameters at the link: http://www.gurobi.com/documentation/8.1/refman/parameters.html .

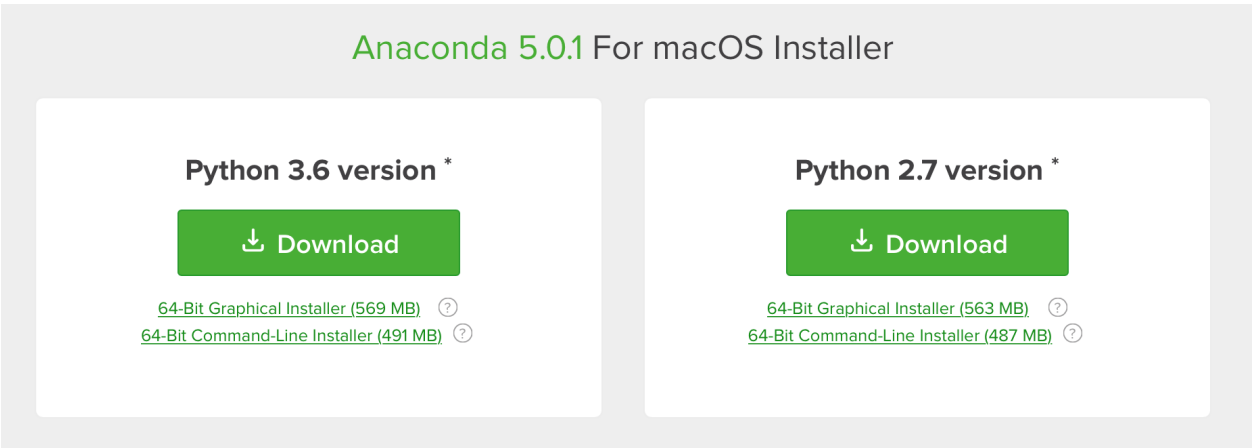
Gurobi and the Python interface

- We are going to use Python as our programming language. If you need help with Python syntax and rules, look in the References for some useful links.
- There is already a Python interpreter and a basic set of Python modules in Gurobi but, in order to increase interactivity and productivity of Python experience on model building, it is better to install a widely-used Python platform.

- We can install the Anaconda Python distribution, which includes:
  - Spyder, a graphical development environment;
  - Jupyter, a notebook-style interface.

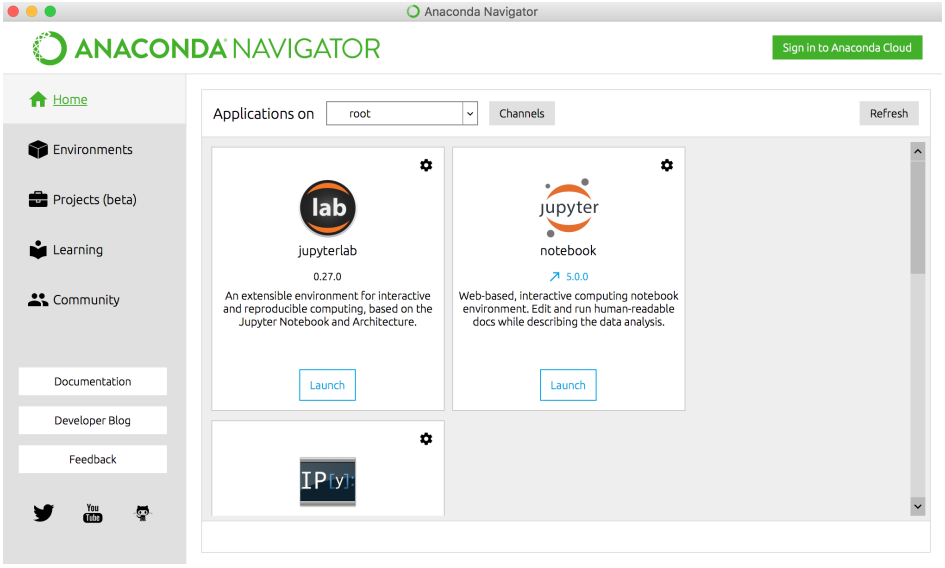
Anaconda for Mac OS X

1. Download Anaconda 5.0.1 for macOS Installer at the following link: **https://www.anaconda.com/download/#macos**
   You can choose between two versions:

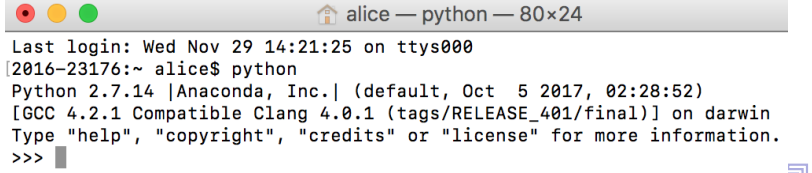


(If you want, you can check before which Python version you already have in your system, opening a terminal and typing **python**).

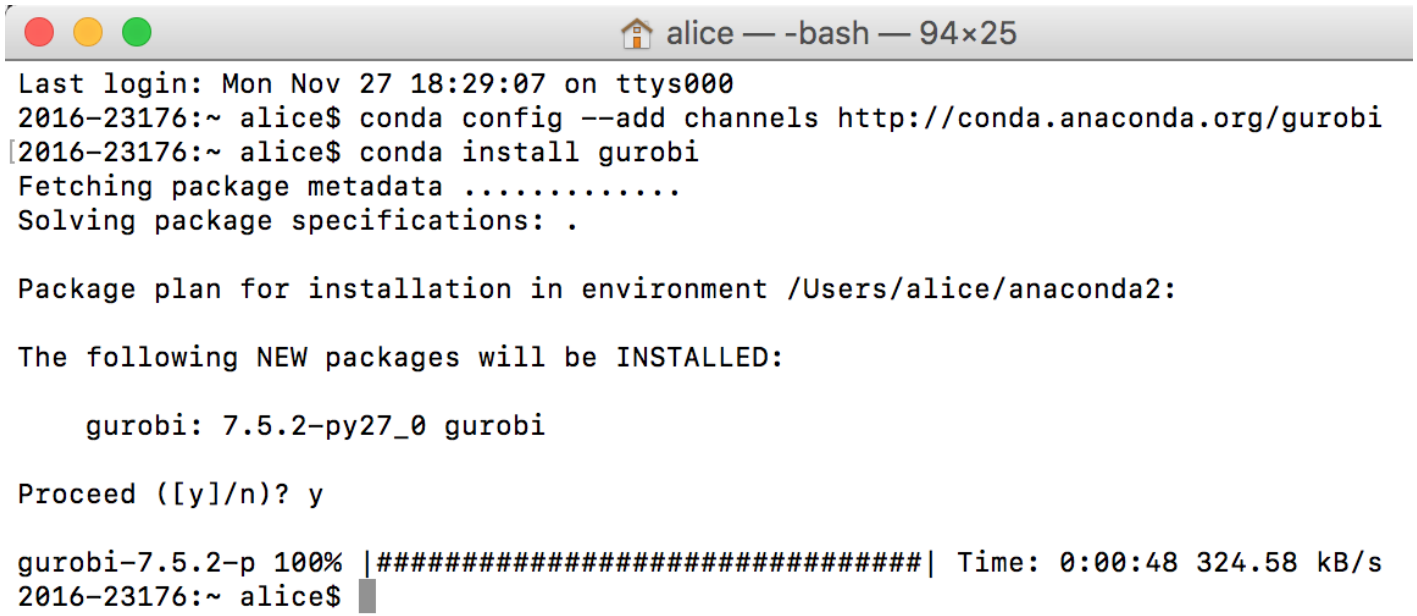
2. Extract the package and launch the installation
3. Answer the prompts on the Introduction, Read Me and License screens, then choose "Install for me only" and go ahead.
4. After your install is complete, verify it by opening Anaconda Navigator, a program that is included with Anaconda: from Launchpad, select Anaconda Navigator.



5. You can also open a terminal and type **python**, getting this:

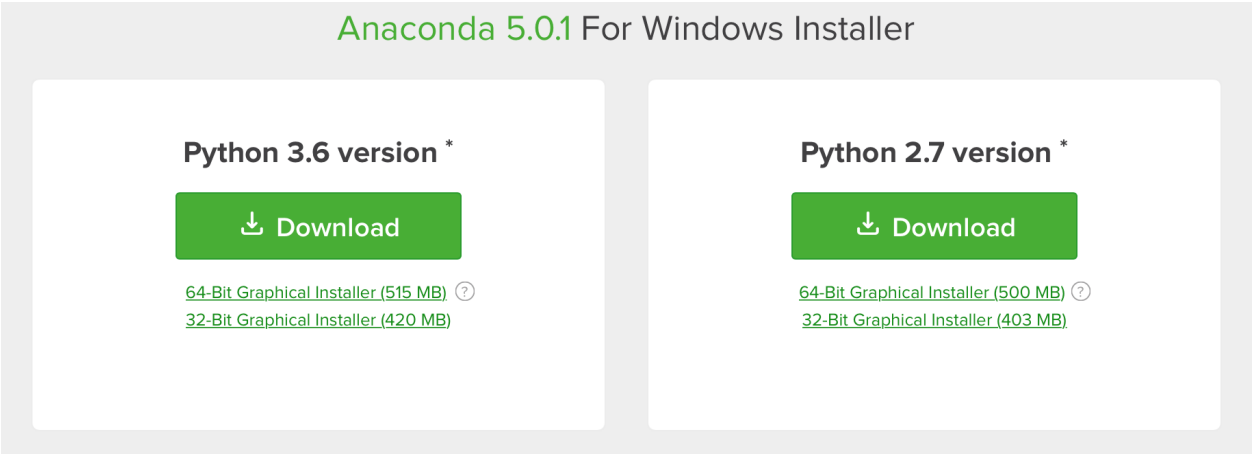


6. To install the Gurobi package into Anaconda, open a terminal and follow these steps:
   - 6.1 Add the Gurobi channel to your Anaconda channels: **conda config –add channels http://conda.anaconda.org/gurobi**
   - 6.2 Install the package: **conda install gurobi** and type **y** to confirm.
   - 6.3 If you want to remove it: **conda remove gurobi**.



Anaconda for Windows

1. Download Anaconda 5.0.1 for Windows Installer at the following link:
   https://www.anaconda.com/download/#windows
   You can choose between two versions:



(If you want, you can check before which Python version you already have in your system, opening a command prompt and typing **python**).

2. Extract the package and launch the installation.
3. Click Next, read the licensing terms and click "I agree", then choose "Just me" and click Next.
4. Select a destination folder and click Next.
5. Choose whether to add Anaconda to your PATH environment variable. On the website they recommend not adding Anaconda to the PATH environment variable, since this can interfere with other software.
6. Click on the Install button and, after it finishes, verify the install by opening Anaconda Navigator, a program that is included with Anaconda: from your Windows Start menu, select the shortcut Anaconda Navigator.

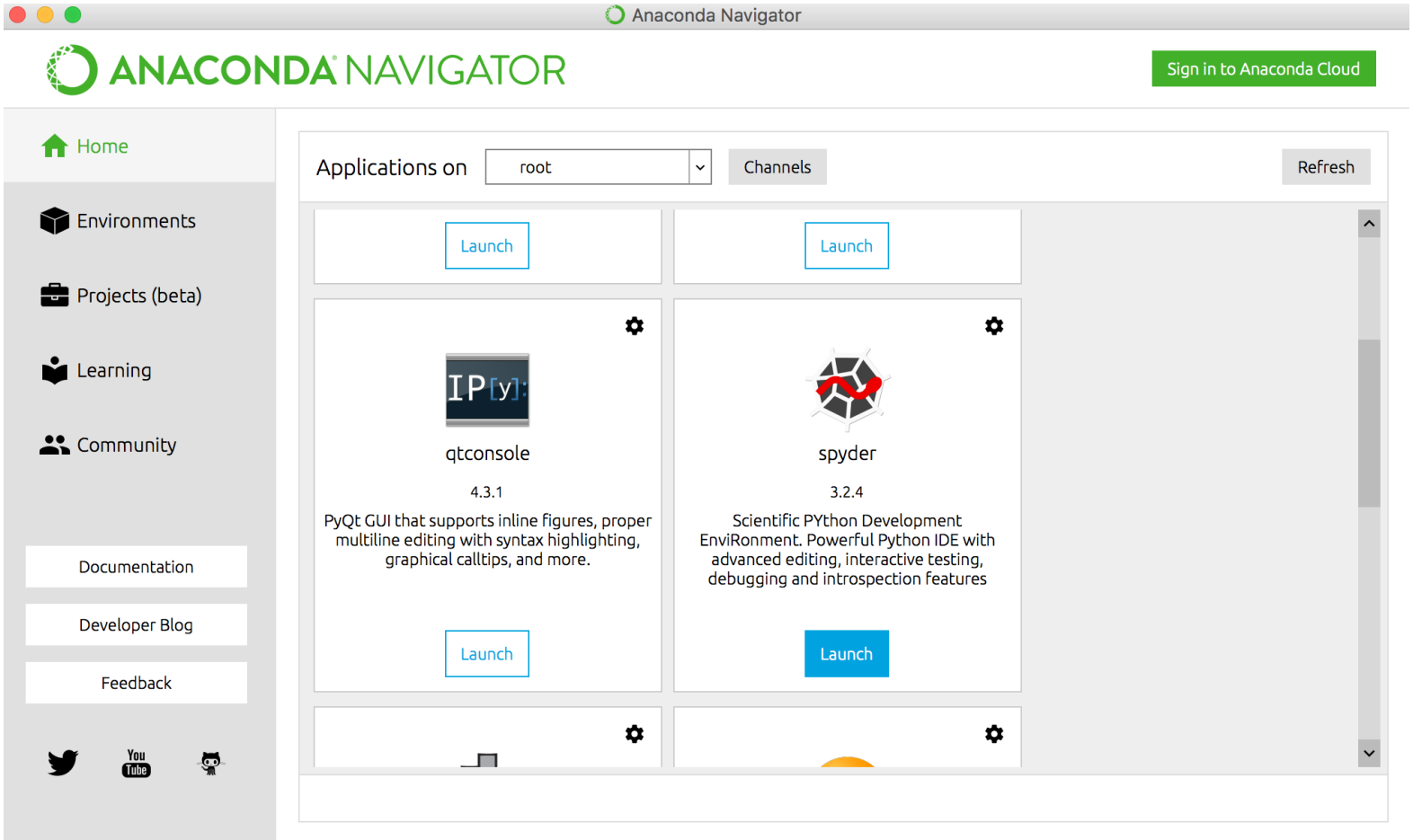
7. To install the Gurobi package into Anaconda, from your Windows Start menu open the Anaconda command prompt and follow these steps:
   - 7.1 Add the Gurobi channel to your Anaconda channels: **conda config –add channels http://conda.anaconda.org/gurobi**
   - 7.2 Install the package: **conda install gurobi** and type **y** to confirm.
   - 7.3 If you want to remove it: **conda remove gurobi**.

Note about Python environment

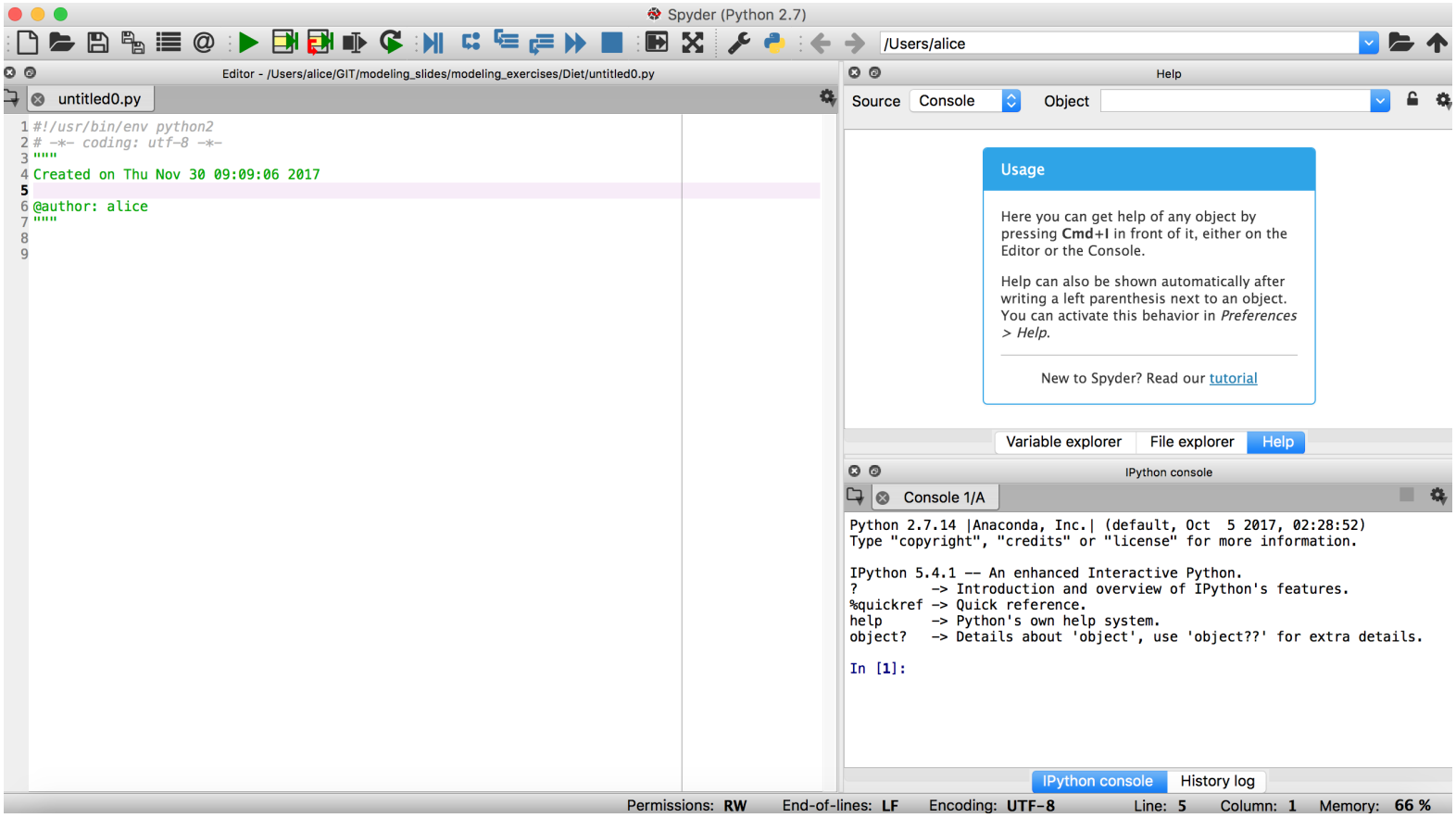
- **Only** if you prefer to use another environment different from Anaconda, that you had already installed before, you must add the package **gurobipy** to be able to use Gurobi.
- In Linux and Mac OS X systems, open a terminal, go to **Library/gurobi810/mac64/** and type **python setup.py install** to link Gurobi to your environment.
- In Windows systems, open command prompt, go to C:\gurobi810\winXX and type **python setup.py install**.
- After the installation of gurobipy package, you can type **import gurobipy** or **from gurobipy import *** from your Python shell and access all of the Gurobi classes and methods.

The Diet Problem with Anaconda

1. Launch Anaconda Navigator and open Spyder:



2. Spyder will look like this:



Gurobi Interactive Shell commands can be typed directly in the Spyder console, but the purpose now is to write instructions in Python in order to build the model.

3. In the File menu, click "New file..."
4. **Note:** the first thing to do, in every Gurobi project developed in a Python IDE like Spyder, is to import Gurobi module with libraries: **from gurobipy import *** or **import gurobipy** (not required launching gurobi.sh).
5. To define a model, it is enough to declare a new object m and instantiate it with the appropriate method imported with Gurobi module: **m = Model("modelname")**.

```
# Solve the diet problem

from gurobipy import *

# Model
m = Model("diet")
```

6. Then we need to define sets and parameters of our instances: we can exploit Python data structures, such as lists, tuples and dictionaries, which allow to map arbitrary key values to pieces of data; the function to use is **multidict**:

```
# Sets and parameters
categories, minNutrition, maxNutrition = multidict({
  'calories': [2000, GRB.INFINITY],
  'protein':  [50, GRB.INFINITY],
  'calcium':  [700, GRB.INFINITY]})

foods, cost, maxPortions = multidict({
  'bread':  [3, 4],
  'milk':   [2, 7],
  'eggs':   [3, 2],
  'meat':   [19, 3],
  'sweets': [15, 2]})

# Nutrition values for the foods
nutritionValues = {
  ('bread', 'calories'): 150,
  ('bread', 'protein'): 4,
  ('bread', 'calcium'): 2,
  ('milk', 'calories'): 120,
  ('milk', 'protein'): 8,
  ('milk', 'calcium'): 285,
  ('eggs', 'calories'): 160,
  ('eggs', 'protein'): 15,
  ('eggs', 'calcium'): 54,
  ('meat', 'calories'): 230,
  ('meat', 'protein'): 14,
  ('meat', 'calcium'): 4,
  ('sweets', 'calories'): 450,
  ('sweets', 'protein'): 4,
  ('sweets', 'calcium'): 22}
```

7. Now we can introduce our variables:

```
# Using Python looping constructs and m.addVar() to create decision variables:
buy = {}
for f in foods:
    buy[f] = m.addVar(0.0, maxPortions[f], name=f)
```

The buy object is initially defined as an empty dictionary; then for every food, a variable is added using **m.addVar(...)**.
The first argument is the lower bound of the variable, followed by the upper bound and finally by the name given to the variable (always recommended, especially when you have a huge number of variables).

8. We define the objective function of the model, using **m.setObjective(...)**:

```
# The objective is to minimize the costs, using looping constructs:
m.setObjective(sum(buy[f]*cost[f] for f in foods), GRB.MINIMIZE)
```

The first argument is the expression, whereas the second is the purpose, that could be GRB.MINIMIZE or GRB.MAXIMIZE.

9. To add constraints about the minimum daily necessities of calories, proteins and calcium, we can use the method **m.addConstr(...)** or, if we know that there is a range to respect, with a minimum and maximum value, we can use **m.addRange(...)**, like here:

```
# Nutrition constraints to respect minimum daily necessities:
for c in categories:
    m.addRange(
            sum(nutritionValues[f,c] * buy[f] for f in foods), minNutrition[c], maxNutrition[c], c)
```

The first argument is the expression, the second and the third one are respectively the lower and the upper bound, the last one is the name given to the constraint.

10. Now we add everything we need to solve the model; before doing it, we can define a method to display results nicely:

```
def printSolution():
    if m.status == GRB.Status.OPTIMAL:
        print('\nCost: %g' % m.objVal)
        print('\nBuy:')
        buyx = m.getAttr('x', buy)
        for f in foods:
            if buy[f].x > 0.0001:
                print('%s %g' % (f, buyx[f]))
    else:
        print('No solution')
```

This method is based on the model status and prints the solution only if it is optimal.
The objective function value can be obtained with **m.objVal**, while variables with **m.getAttr('x', objectName)**.

11. To solve the problem, the instruction is again **m.optimize()**, as in the command-line or in the Interactive Shell, and then **printSolution()**:

```
# Solve
m.optimize()
printSolution()
```

12. To run the code, press the green arrow in the top menu or press F5; then look at the console:

```
In [3]: runfile('/Users/alice/GIT/modeling_slides/modeling_exercises/Diet/python-
diet.py', wdir='/Users/alice/GIT/modeling_slides/modeling_exercises/Diet')
Optimize a model with 3 rows, 5 columns and 15 nonzeros
Coefficient statistics:
  Matrix range     [2e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 7e+00]
  RHS range        [5e+01, 2e+03]
Presolve time: 0.02s
Presolved: 3 rows, 5 columns, 15 nonzeros

Iteration    Objective       Primal Inf.    Dual Inf.      Time
       0    0.0000000e+00   1.968750e+02   0.000000e+00      0s
       1    4.0000000e+01   0.000000e+00   0.000000e+00      0s

Solved in 1 iterations and 0.03 seconds
Optimal objective  4.000000000e+01

Cost: 40

Buy:
sweets 0.533333
eggs 2
bread 4
milk 7
```

13. If we want to add another constraint, for example that the sum of portions of milk and eggs cannot be more than 6, we can type another instruction at the end of our code (or directly in the console) and solve the problem again:

```
print('\nAdding constraint: at most 6 servings of milk and eggs')
m.addConstr(buy['milk'] + buy['eggs'] <= 6, "limit_milk_eggs")

# Solve
m.optimize()
printSolution()
```

14. Run the file again to obtain the new solution:

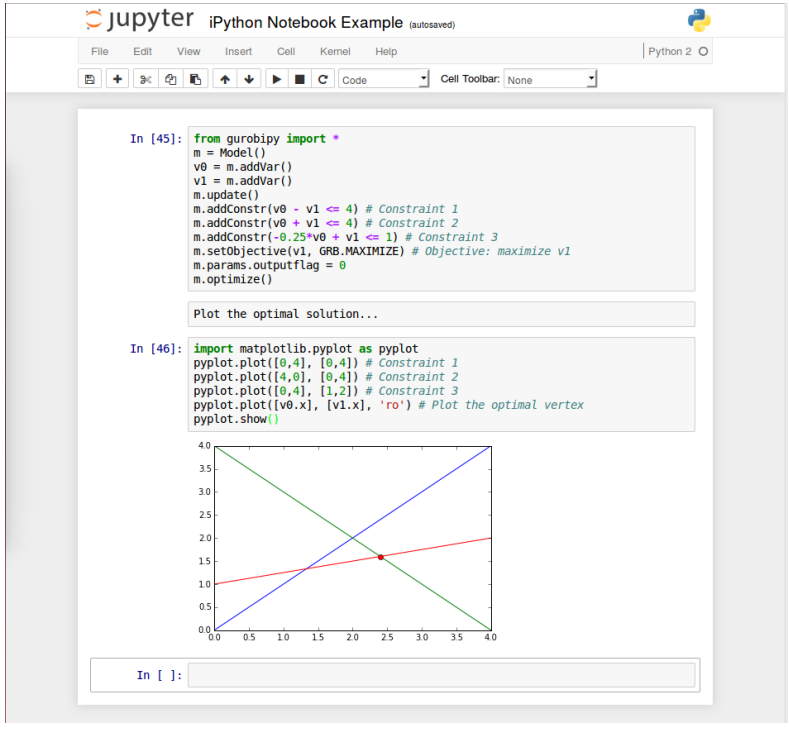
```
Adding constraint: at most 6 servings of milk and eggs
Optimize a model with 4 rows, 5 columns and 17 nonzeros
Coefficient statistics:
  Matrix range     [1e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 7e+00]
  RHS range        [6e+00, 2e+03]
Iteration    Objective       Primal Inf.    Dual Inf.      Time
       0    4.0000000e+01   4.800000e+01   0.000000e+00      0s
       1    4.6000000e+01   0.000000e+00   0.000000e+00      0s

Solved in 1 iterations and 0.04 seconds
Optimal objective  4.600000000e+01

Cost: 46

Buy:
sweets 1.33333
eggs 2
bread 4
milk 4
```

15. You can also write your Python code in any text editor you like and solve the model using the Gurobi Interactive Shell:

```
Diet — -bash — 84×27
Last login: Thu Nov 30 11:55:21 on ttys000
2016-23176:~ alice$ cd GIT/modeling_slides/modeling_exercises/Diet/
2016-23176:Diet alice$ gurobi.sh python-diet.py
Academic license - for non-commercial use only
Optimize a model with 3 rows, 5 columns and 15 nonzeros
Coefficient statistics:
  Matrix range     [2e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 7e+00]
  RHS range        [5e+01, 2e+03]
Presolve time: 0.00s
Presolved: 3 rows, 5 columns, 15 nonzeros

Iteration    Objective       Primal Inf.    Dual Inf.      Time
       0    0.0000000e+00   1.968750e+02   0.000000e+00      0s
       1    4.0000000e+01   0.000000e+00   0.000000e+00      0s

Solved in 1 iterations and 0.00 seconds
Optimal objective  4.000000000e+01

Cost: 40

Buy:
sweets 0.533333
eggs 2
bread 4
milk 7
```

16. As before, in the code you can set Gurobi params as you like.

Just a note about Jupyter



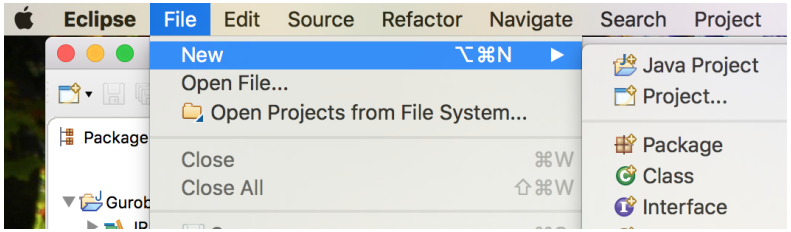
- Notebook-style interface to mix executable code, text and graphics, to create a self-documenting stream of results;
- We are not going to use it in the course (but it could be part of your project...)

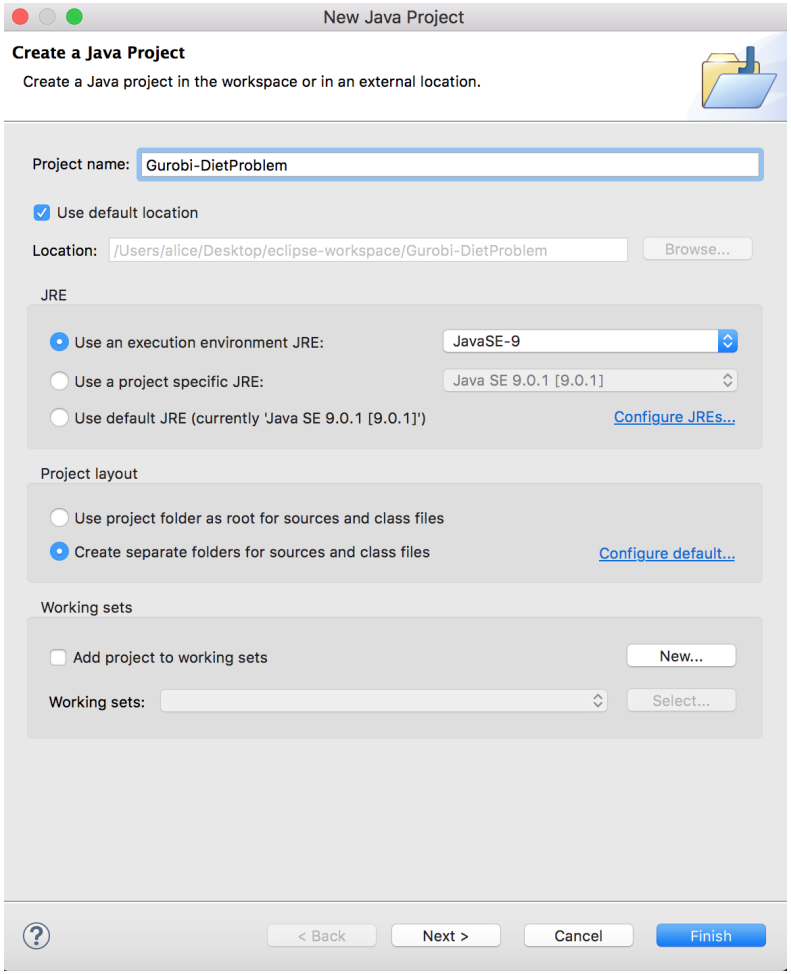
Gurobi and the Java interface

- In this optional part, we are going to use **Eclipse**, one of the most common integrated development environment for Java, after importing the Gurobi library into the Java project.
- You can download and then install Eclipse at the following link: **http://www.eclipse.org/downloads/**.

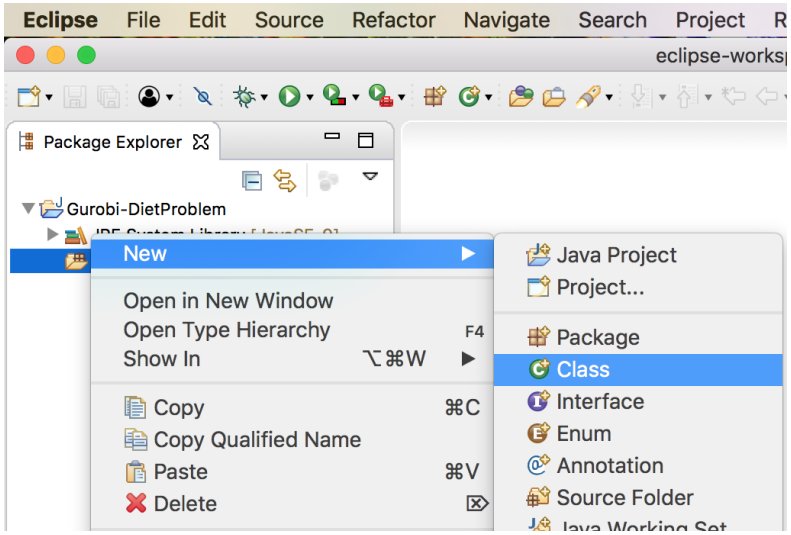
The Diet Problem with Eclipse

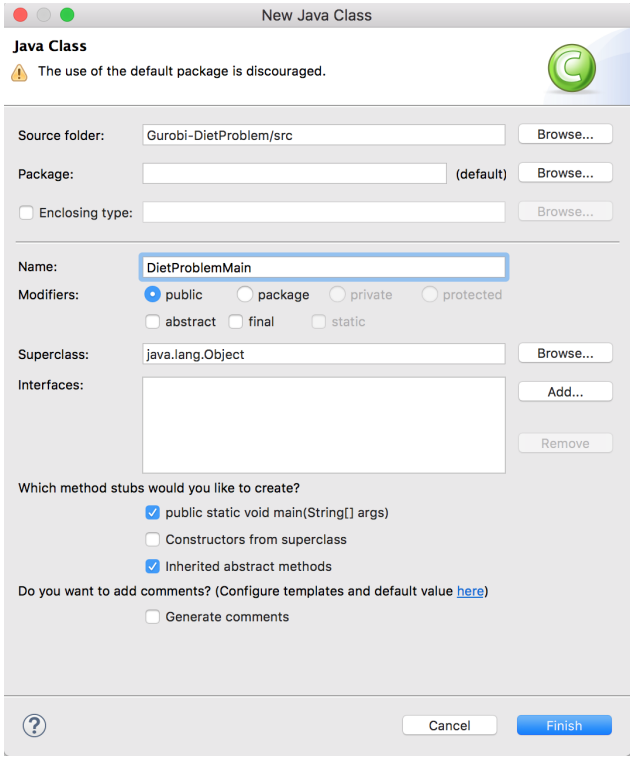
1. Launch Eclipse and create a new Java project named **Gurobi-DietProblem**:



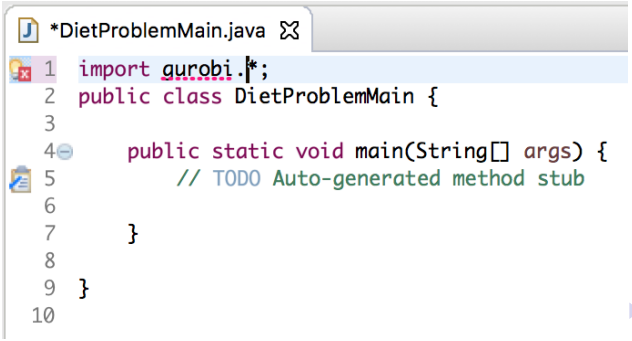


2. Add a new class named **DietProblemMain**:

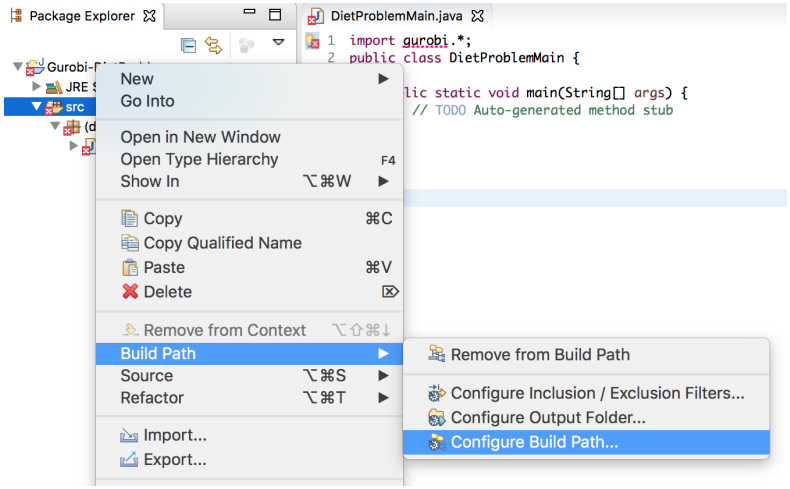




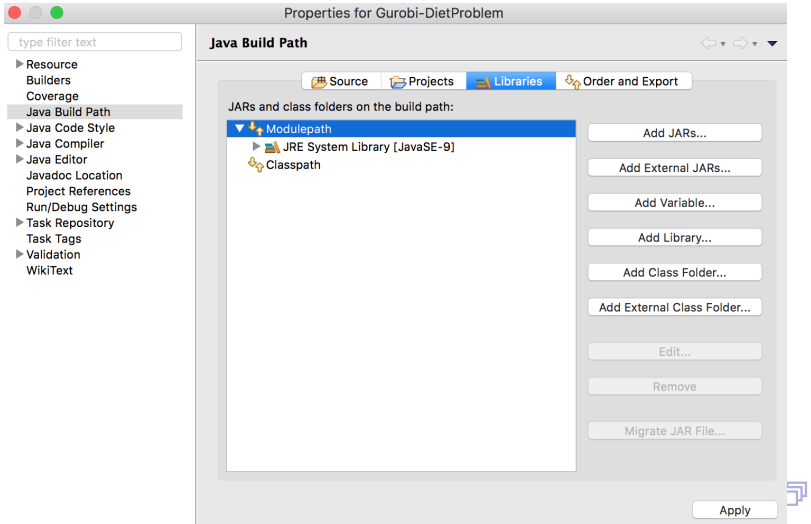
3. At the beginning add the instruction **import gurobi.*** that will show an error because the library which refers is missing:



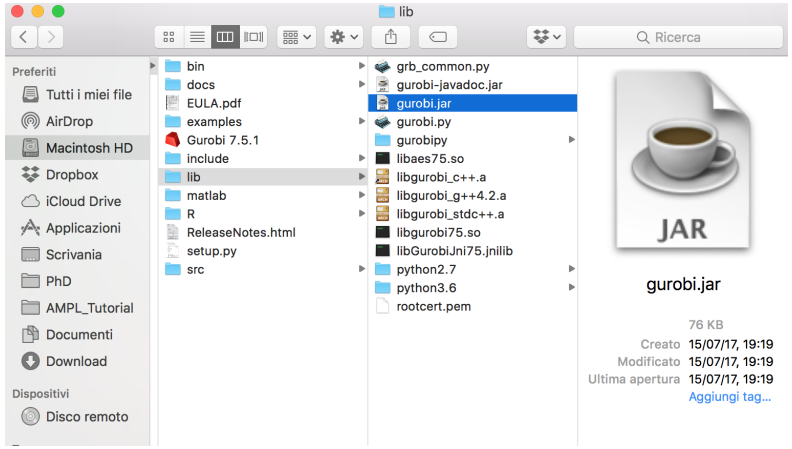
4. To import Gurobi library in Eclipse, double-click on the project and select **Build Path** and then **Configure Build Path...** :



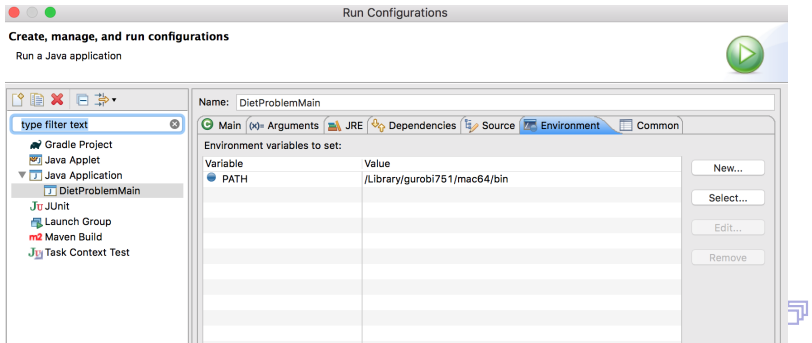
5. In the Libraries tab, click con Modulepath and then click on **Add External JARs...** :



6. Go to the Gurobi folder (e.g., on Mac OS X, /Library/gurobi751/mac64/lib) and select **gurobi.jar** to be added.



7. Once added, go to **Run** $\rightarrow$ **Run Configurations...**; on the left menu, select Java Application and then DietProblemMain; go to the Environment tab and add the variable PATH with the directory of Gurobi bin folder as value.



8. The error on the instruction should disappear, because now the project is linked to the Gurobi library.
9. Now we can write our code for the Diet Problem, starting with the section including sets and parameters, using arrays and matrixes as main data structures:

```
public static void main(String[] args) {
    try {

      // Set of substances
      String Substances[] = new String[] { "CALORIES", "PROTEINS", "CALCIUM"};
      int nSubstances = Substances.length;
      double minNutrition[] = new double[] { 2000, 50, 700};

      // Set of foods
      String Foods[] = new String[] { "BREAD", "MILK", "EGGS", "MEAT", "SWEETS"};
      int nFoods = Foods.length;
      double cost[] = new double[] {3, 2, 3, 19, 15};

      // Maximum number of portions for each food
      int maxNbPortions[] = new int [] {4, 7, 2, 3, 2};

      // Nutrition values for one portion of each food
      double amountPortion[][] = new double[][] {
          { 150, 120, 160, 230, 450 },   // CALORIES
          { 4, 8, 15, 14, 4 },           // PROTEINS
          { 2, 285, 54, 80, 22 },        // CALCIUM
          };
```

10. We need to define the **environment** and create an instance of the class **GRBModel**, in order to build one:

```
// Model
GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.set(GRB.StringAttr.ModelName, "diet");
```

11. Optimization models live within an environment: as a good practice, every programme should create (and in the end destroy/dispose) just one environment.
12. The model instance is created passing as parameter the environment, therefore is strictly linked to it. Set the model String attribute **ModelName** with an appropriate name.

13. Create appropriate decision variables and add constraints to the model through methods **addVar** and **addConstr**:

```
// Model
GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.set(GRB.StringAttr.ModelName, "diet");

// Create decision variables for the nutrition information,
// which we limit via bounds
GRBVar[] nutrition = new GRBVar[nSubstances];
for (int i = 0; i < nSubstances; ++i) {
  nutrition[i] =
      model.addVar(minNutrition[i], GRB.INFINITY, 0, GRB.CONTINUOUS,
                   Substances[i]);
}

// Create decision variables for the foods to buy
GRBVar[] buy = new GRBVar[nFoods];
for (int j = 0; j < nFoods; ++j) {
  buy[j] =
      model.addVar(0, maxNbPortions[j], cost[j], GRB.CONTINUOUS, Foods[j]);
}

// Nutrition constraints
for (int i = 0; i < nSubstances; ++i) {
  GRBLinExpr ntot = new GRBLinExpr();
  for (int j = 0; j < nFoods; ++j) {
    ntot.addTerm(amountPortion[i][j], buy[j]);
  }
  model.addConstr(ntot, GRB.EQUAL, nutrition[i], Substances[i]);
}

// The objective is to minimize the total costs
model.set(GRB.IntAttr.ModelSense, GRB.MINIMIZE);
```

14. Set the objective of the problem.

15. Solve the problem and dispose *env* and *model*:

```
// Solve
model.optimize();
printSolution(model, buy, nutrition);

// Dispose of model and environment
model.dispose();
env.dispose();
```

16. The procedure **printSolution** was developed on purpose and it prints as output what you need to know about the resolution.

```
private static void printSolution(GRBModel model, GRBVar[] buy,
                                  GRBVar[] nutrition) throws GRBException {
  if (model.get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL) {
    System.out.println("\nCost: " + model.get(GRB.DoubleAttr.ObjVal));
    System.out.println("\nBuy:");
    for (int j = 0; j < buy.length; ++j) {
      if (buy[j].get(GRB.DoubleAttr.X) > 0.0001) {
        System.out.println(buy[j].get(GRB.StringAttr.VarName) + " " +
            buy[j].get(GRB.DoubleAttr.X));
      }
    }
    System.out.println("\nNutrition:");
    for (int i = 0; i < nutrition.length; ++i) {
      System.out.println(nutrition[i].get(GRB.StringAttr.VarName) + " " +
          nutrition[i].get(GRB.DoubleAttr.X));
    }
  } else {
    System.out.println("No solution");
  }
}
```

17. And this is the output:

Problems @ Javadoc Declaration Console

<terminated> DietProblemMain [Java Application] /Library/Java/JavaVirtualMachines/jdk-9.0.1.jdk/Contents/Home/bin/java (11 nov 2017, 17:48:41)

```
Academic license - for non-commercial use only
Optimize a model with 3 rows, 8 columns and 18 nonzeros
Coefficient statistics:
  Matrix range     [1e+00, 4e+02]
  Objective range  [2e+00, 2e+01]
  Bounds range     [2e+00, 2e+03]
  RHS range        [0e+00, 0e+00]
Presolve removed 0 rows and 3 columns
Presolve time: 0.00s
Presolved: 3 rows, 5 columns, 15 nonzeros

Iteration    Objective       Primal Inf.    Dual Inf.      Time
       0    3.3333333e+01   1.546667e+02   0.000000e+00      0s
       1    4.0000000e+01   0.000000e+00   0.000000e+00      0s

Solved in 1 iterations and 0.01 seconds
Optimal objective  4.000000000e+01

Cost: 40.0

Buy:
BREAD 4.0
MILK 7.0
EGGS 2.0
SWEETS 0.5333333333333333

Nutrition:
CALORIES 2000.0
PROTEINS 104.13333333333334
CALCIUM 2122.733333333333
```

Conclusion

- We showed how it is possible to solve ILP problems using Gurobi Optimizer , both exploiting its command-line options (lightweight version and Interactive Shell) and its libraries.
- Gurobi can interface not only with Python and Java, but also with C, C++, MATLAB and R: why not trying to do this diet exercise with other languages?
- We will deepen Gurobi to take advantage of its features: our journey towards a more complex problem has just started.

References

Gurobi Optimization and Official Documentation
http://www.gurobi.com
http://www.gurobi.com/documentation/

Anaconda
https://www.anaconda.com

Python Official Documentation (English):
https://docs.python.org/release/2.7/tutorial/

Python Tutorial (English):
https://www.tutorialspoint.com/python/

Learn Python (English, Italian, Spanish):
https://www.learnpython.org/en/

Eclipse
http://www.eclipse.org/home/index.php

AMPL Faqs about Files and Preprocessing:
http://ampl.com/faqs/category/filespreprocessing/