

# GUROBI OPTIMIZER EXAMPLE TOUR



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The Gurobi<sup>TM</sup> distribution includes an extensive set of examples that illustrate commonly used features of the Gurobi libraries. Most examples have versions for C, C++, C#, Java, Visual Basic, and Python. A few, however, illustrate features that are specific to the Python interface.

This document provides a brief tour of these examples. We won't go through each example in detail. Instead, we'll start with an [Overview](#) of the set of tasks that you are likely to want to perform with the Gurobi Optimizer. Later sections will then describe how specific examples accomplish each of these tasks. We suggest that you browse the example source code (in a text editor, or in another browser window) while reading this document. This document includes [Source Code](#) for all of the examples, in all available languages. Source files are also available in the `examples` directory of the Gurobi distribution.

A brief note for users of the Gurobi MATLAB<sup>®</sup> and R interfaces: our interfaces to these languages are built around the assumption that you will use the rich matrix-oriented capabilities of the underlying languages to build your optimization models. Thus, our examples for these languages don't attempt to show you how to build models. We have instead chosen to provide a few simple examples that demonstrate how to pass matrices into our interface.

If you would like further details on any of the Gurobi routines used in these examples, please consult the [Gurobi Reference Manual](#).

This document provides a quick guided tour of the Gurobi examples; we will try to highlight some of the most important features of these examples. Full source code is provided in this document, so you are free to explore the examples in full detail.

Wherever possible, we try to discuss the examples in a manner that is independent of programming languages. We will refer to each example using a brief, language independent name. You will need to map this name to the specific source file name for your language. For example, the `facility` example corresponds to six different implementations, one in C ([facility\\_c.c](#)), one in C++ ([facility\\_c++.cpp](#)), one in Java ([Facility.java](#)), one in C# ([facility\\_cs.cs](#)), one in Visual Basic ([facility\\_vb.vb](#)), and one in Python ([facility.py](#)). If you would like to look at the language implementation for a particular example, please refer to the appropriate example source file.

## The Gurobi examples

The following is a list of all of the examples included in the Gurobi distribution. The source code for these examples can be found in the `examples` directory of the distribution, or in the [Source Code](#) section of this document.

- **callback** - Demonstrates the use of Gurobi callbacks.
- **dense** - Solves a model stored using dense matrices. We don't recommend that you use dense matrices for your models, but this example may be helpful if your data is already in this format.
- **diet** - Builds and solves the classic diet problem. Demonstrates model construction and simple model modification - after the initial model is solved, a constraint is added to limit the number of dairy servings.
- **diet2, diet3, diet4, dietmodel** - Python-only variants of the diet example that illustrate model-data separation.
- **facility** - Simple facility location model: given a set of plants and a set of warehouses, with transportation costs between them, this example finds the least expensive set of plants to open in order to satisfy product demand. This example demonstrates the use of MIP starts — the example computes an initial, heuristic solution and passes that solution to the MIP solver.
- **feasopt** - Reads a MIP model from a file, adds artificial slack variables to relax each constraint, and then minimizes the sum of the artificial variables. It then computes the same relaxation using the *feasibility relaxation* feature. The example demonstrates simple model modification by adding slack variables. It also demonstrates the feasibility relaxation feature.
- **fixanddive** - Implements a simple MIP heuristic. It reads a MIP model from a file, relaxes the integrality conditions, and then solves the relaxation. It then chooses a set of integer variables that take integer or nearly integer values in the relaxation, fixes them to the nearest integer,

and solves the relaxation again. This process is repeated until the relaxation is either integer feasible or linearly infeasible. The example demonstrates different types of model modification (relaxing integrality conditions, changing variable bounds, etc.).

- **lp** - A very simple example that reads a continuous model from a file, optimizes it, and writes the solution to a file. If the model is infeasible, it writes an Irreducible Inconsistent Subsystem (IIS) instead.
- **lpmethod** - Demonstrates the use of different LP algorithms. Reads a continuous model from a file and solves it using multiple algorithms, reporting which is the quickest for that model.
- **lpmod** - Demonstrates the use of advanced starts in LP. Reads a continuous model from a file, solves it, and then modifies one variable bound. The resulting model is then solved in two different ways: starting from the solution of the original model, or restarting from scratch.
- **mip1** - Builds a trivial MIP model, solves it, and prints the solution.
- **mip2** - Reads a MIP model from a file, optimizes it, and then solves the fixed version of the MIP model.
- **netflow** - A Python-only example that solves a multi-commodity network flow model. It demonstrates the use of several Python modeling constructs, including dictionaries, tuples, and tuplelist objects.
- **params** - Demonstrates the use of Gurobi parameters. Reads a MIP model from a file, and then spends 5 seconds solving the model with each of four different values of the `MIPFocus` parameter. It compares the optimality gaps for the four different runs, and continues with the `MIPFocus` value that produced the smallest gap.
- **qp** - Builds a trivial QP model, solves it, converts it to an MIQP model, and solves it again.
- **qcp** - Builds and solves a trivial QCP model.
- **sensitivity** - MIP sensitivity analysis. Reads a MIP model, solves it, and then computes the objective impact of fixing each binary variable in the model to 0 or 1. Demonstrates simple MIP model modification by changing variable bounds.
- **sos** - Builds and solves a trivial SOS models.
- **sudoku** - Reads a Sudoku puzzle dataset from a file, builds a MIP model to solve that model, solves it, and prints the solution.
- **tsp** - Solves a traveling salesman problem using lazy constraints.
- **tune** - Uses the parameter tuning tool to search for improved parameter settings for a model.
- **workforce1** - Formulates and solves a workforce scheduling model. If the model is infeasible, the example computes and prints an Irreducible Inconsistent Subsystem (IIS).

- **workforce2** - An enhancement of **workforce1**. This example solves the same workforce scheduling model, but if the model is infeasible, it computes an IIS, removes one of the associated constraints from the model, and re-solves. This process is repeated until the model becomes feasible. Demonstrates constraint removal.
- **workforce3** - A different enhancement of **workforce1**. This example solves the same workforce scheduling model, but if the model is infeasible, it adds artificial variables to each constraint and minimizes the sum of the artificial variables. This corresponds to finding the minimum total change in the right-hand side vector required in order to make the model feasible. Demonstrates variable addition.
- **workforce4** - An enhancement of **workforce3**. This example solves the same workforce scheduling model, but it starts with artificial variables in each constraint. It first minimizes the sum of the artificial variables. Then, it introduces a new quadratic objective to balance the workload among the workers. Demonstrates optimization with multiple objective functions.

## The example tour

The easiest place to start your introduction to the Gurobi examples is probably with the examples that [load and solve a model from a file](#). These demonstrate the most basic capabilities of the Gurobi libraries. They also demonstrate the use of model attributes, which are an important concept in the Gurobi optimizer.

Once you are comfortable with these examples, you should move on to the examples that [build a model](#) from scratch. These show you how to create variables and constraints, and add them to an optimization model. They also illustrate the use of *lazy updates*, which you will need to understand in order to use the Gurobi libraries.

The next topic covered in this document is [model modification](#). The Gurobi distribution includes examples that add and remove constraints, add variables, and change variable types, bounds and objective coefficients. You modify a model in much the same way that you build a model from scratch, but there are some important differences involving the use of the solution information.

Next, this document covers [parameter changes](#). The `params` example shows you how to change parameters, and in particular how to use different parameter settings for different models.

On a related note, the [tuning](#) section demonstrates the use of our automated tuning tool. This tool searches for parameter settings that improve performance on a particular model.

The [infeasibility](#) section considers a few examples that cope with model infeasibility. Some use an Irreducible Inconsistent Subsystem (IIS) to handle the infeasibility, while others relax constraints.

One useful MIP feature that is worth understanding is [MIP starts](#). A MIP start allows you to specify a known feasible solution to the MIP solver. The solution provides a bound on the objective of the best possible solution, which can help to limit the MIP search. The solution also provides a potential start point for the local search heuristics that are utilized by the Gurobi MIP solver.

It is possible to achieve model-data separation when using our Python interface, as is often done in modeling languages, but you need to make use of Python modules to do so. The [model-data separation](#) section provides an example of how this is done. It considers two versions of the diet example, which obtain model data from very different places. Both use the same file to formulate and solve the actual optimization model on that data.

The final topic we cover in this document is [Gurobi callbacks](#). Callbacks allow the user to obtain periodic progress information related to the optimization.

## 2.1 Load and solve a model from a file

**Examples:** `callback`, `feasopt`, `fixanddive`, `lp`, `lpmethod`, `lpmod`, `mip2`, `params`, `sensitivity`

One of the most basic tasks you can perform with the Gurobi libraries is to read a model from a file, optimize it, and report the result. The `lp` ([lp\\_c.c](#), [lp\\_c++.cpp](#), [lp\\_cs.cs](#), [Lp.java](#), [lp.py](#), [lp\\_vb.vb](#)) and `mip2` ([mip2\\_c.c](#), [mip2\\_c++.cpp](#), [mip2\\_cs.cs](#), [Mip2.java](#), [mip2.py](#), [mip2\\_vb.vb](#)) examples are simple illustrations of how this is done in the various supported Gurobi languages. While the specifics vary from one language to another, the basic structure remains the same for all languages.

After initializing the Gurobi environment, the examples begin by reading the model from the specified file. In C, you call the `GRBreadmodel()` function:

```
error = GRBreadmodel(masterenv, argv[1], &model);
```

In C++, this is done by constructing a `GRBModel` object:

```
GRBModel model = GRBModel(env, argv[1]);
```

In C# and Java, this is also done by constructing a `GRBModel` object:

```
GRBModel model = new GRBModel(env, args[0]);
```

In Python, this is done via the `read` global function:

```
model = read(sys.argv[1])
```

The next step is to invoke the Gurobi optimizer on the model. In C, you call `GRBoptimize()` on the `model` variable:

```
error = GRBoptimize(model);
```

In C++, Java, and Python, this is accomplished by calling the `optimize` method on the `model` object:

```
model.optimize();
```

In C#, the first letter of the method name is capitalized:

```
model.Optimize();
```

A successful `optimize` call populates a set of solution attributes in the model. For example, once the call completes, the `X` variable attribute contains the solution value for each variable. Similarly, for continuous models, the `Pi` constraint attribute contains the dual value for each constraint.

The examples then retrieve the value of the model `Status` attribute to determine the result of the optimization. In the `lp` example, an optimal solution is written to a solution file (`model.sol`).

There are many other things you can do once you have read and solved the model. For example, `lp` checks the solution status — which is highly recommended. If the model is found to be infeasible, this example computes an Irreducible Inconsistent Subsystem (IIS) to isolate the source of the infeasibility.

## 2.2 Build a model

**Examples:** diet, facility, mip1, qcp, qp, sos, sudoku, workforce1, workforce2, workforce3, workforce4

Several of the Gurobi examples build models from scratch. We start by focusing on two, `mip1` and `sos`, which build very simple models to illustrate the basic process.

Typically, the first step in building a model is to create an empty model. This is done using the `GRBnewmodel` function in C:

```
error = GRBnewmodel(env, &model, "mip1", 0, NULL, NULL, NULL, NULL);
```

You can optionally create a set of variables when you create the model, as well as specifying bounds, objective coefficients, and names for these variables. These examples add new variables separately.

In C++, C#, and Java, you create a new model using the `GRBModel` constructor. In Java, this looks like:

```
GRBModel model = new GRBModel(env);
```

In Python, the class is called `Model`, and its constructor is similar to the `GRBModel` constructor for C++ and Java.

Once the model has been created, the typical next step is to add variables. In C, you use the `GRBaddvars` function to add one or more variables:

```
error = GRBaddvars(model, 3, 0, NULL, NULL, NULL, obj, NULL, NULL, vtype, NULL);
```

In C++, Java, and Python, you use the `addVar` method on the `Model` object (`AddVar` in C#). In Java, this looks like:

```
GRBVar x = model.addVar(0.0, 1.0, -1.0, GRB.BINARY, "x");
```

The new variable's lower bound, upper bound, objective coefficient, type, and name are specified as arguments. In C++ and Python, you can omit these arguments and use default values; see the [Gurobi Reference Manual](#) for details.

After adding variables to the model, the next step is to call the update function (`GRBupdatemodel()` in C, `model.update()` in C++, Java, and Python, `model.Update()` in C#). Model modifications are performed in a *lazy* fashion in the Gurobi optimizer — they don't affect the model until the next update or optimize call. You *cannot* utilize the new variables (e.g., in constraints) until you call the update function.

The next step is to add constraints to the model. Linear constraints are added through the `GRBaddconstr` function in C:

```
error = GRBaddconstr(model, 3, ind, val, GRB_LESS_EQUAL, 4.0, "c0");
```

To add a linear constraint in C, you must specify a list of variable indices and coefficients for the left-hand side, a sense for the constraint (e.g., `GRB_LESS_EQUAL`), and a right-hand side constant. You can also give the constraint a name; if you omit the name, Gurobi will assign a default name for the constraint.

In C++, C#, Java, and Python, you build a linear constraint by first building linear expressions for the left- and right-hand sides. In Java, which doesn't support operator overloading, you build an expression as follows:

```
GRBLinExpr expr = new GRBLinExpr();
expr.addTerm(1.0, x); expr.addTerm(2.0, y); expr.addTerm(3.0, z);
```

You then use the `addConstr` method on the `Model` object to add a constraint using these linear expressions for the left- and right-hand sides:

```
model.addConstr(expr, GRB_LESS_EQUAL, 4.0, "c0");
```

For C++, C#, and Python, the standard mathematical operators such as `+`, `*`, `<=` have been overloaded so that the linear expression resembles a traditional mathematical expression. In C++:

```
model.addConstr(x + 2 * y + 3 * z <= 4, "c0");
```

Adding an special ordered set (SOS) constraint is similar. In C, you add one or more SOS constraint using the `GRBaddsos` function:

```
error = GRBaddsos(model, 1, 2, sostype, sosbeg, sosind, soswt);
```

For each SOS constraint, you must specify a list of members and a weight for each member.

In C++, C#, Java, and Python, you use the `addSOS` method on the `Model` object:

```
model.addSOS(sosv1, soswt1, GRB.SOS_TYPE1);
```

Once the model has been built, the typical next step is to optimize it (using `GRBoptimize` in C, `model.optimize` in C++, Java, and Python, or `model.Optimize` in C#). You can then query the `X` attribute on the variables to retrieve the solution (and the `VarName` attribute to retrieve the variable name for each variable). In C, the `X` attribute is retrieved as follows:

```
error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, 3, sol);
```

In C++:

```
cout << x.get(GRB_StringAttr_VarName) << " "
      << x.get(GRB_DoubleAttr_X) << endl;
cout << y.get(GRB_StringAttr_VarName) << " "
      << y.get(GRB_DoubleAttr_X) << endl;
cout << z.get(GRB_StringAttr_VarName) << " "
      << z.get(GRB_DoubleAttr_X) << endl;
```

In Java:

```
System.out.println(x.get(GRB.StringAttr.VarName) +
                  " " + x.get(GRB.DoubleAttr.X));
System.out.println(y.get(GRB.StringAttr.VarName) +
                  " " + y.get(GRB.DoubleAttr.X));
System.out.println(z.get(GRB.StringAttr.VarName) +
                  " " + z.get(GRB.DoubleAttr.X));
```

In C#:

```

Console.WriteLine(x.Get(GRB.StringAttr.VarName) +
    " " + x.Get(GRB.DoubleAttr.X));
Console.WriteLine(y.Get(GRB.StringAttr.VarName) +
    " " + y.Get(GRB.DoubleAttr.X));
Console.WriteLine(z.Get(GRB.StringAttr.VarName) +
    " " + z.Get(GRB.DoubleAttr.X));

```

In Python:

```

for v in m.getVars():
    print v.varName, v.x

```

When querying or modifying attribute values for an array of constraints or variables, it is generally more efficient to perform the action on the whole array at once. This is quite natural in the C interface, where most of the attribute routines take array arguments. In the C++, C#, and Java interface, you can use the `get` and `set` methods on the `Model` object to work directly with arrays of attribute values. In the `sudoku` Java example, this is done as follows:

```

double[] [] [] x = model.get(GRB.DoubleAttr.X, vars);

```

Note that the Python interface doesn't have array query routines. Python is an interpreted language, and overheads associated with queries on individual attributes are a small contributor to overall runtime.

## 2.3 Modify a model

**Examples:** `diet`, `feasopt`, `fixanddive`, `lpmod`, `sensitivity`, `workforce3`, `workforce4`

This section considers model modification. Modification can take many forms, including adding constraints or variables, deleting constraints or variables, modifying constraint and variable attributes, changing constraint coefficients, etc. Here is a sample of some types of model modification.

### diet

This example builds a linear model that solves the classic diet problem: to find the minimum cost diet that satisfies a set of daily nutritional requirements. Once the model has been formulated and solved, the example adds an additional constraint to limit the number of servings of dairy products, and solves the model again. Let's focus on the model modification.

Adding constraints to a model that has already been solved is no different from adding constraints when constructing an initial model. In Python, we can introduce a limit of 6 dairy servings through the following constraint:

```

m.addConstr(buy[7] + buy[8] <= 6, "limit_dairy")

```

For linear models, the previously computed solution can be used as an efficient *warm start* for the modified model. The Gurobi solver retains the previous solution, so the next `optimize` call automatically starts from the previous solution.

## lpmod

Changing a variable bound is also straightforward. The `lpmod` example changes a single variable bound, then re-solves the model in two different ways. A variable bound can be changed by modifying the UB or LB attribute of the variable. In C:

```
error = GRBsetdblattr(element(model, GRB_DBL_ATTR_UB, var, 0.0));
```

In Python:

```
minVar.ub = 0
```

The model is re-solved simply by calling the `optimize` method again. For a continuous model, this starts the optimization from the previous solution. To illustrate the difference when solving the model from an initial, unsolved state, the `lpmod` example calls the `reset` function. In C:

```
error = GRBresetmodel(model);
```

In C++, Java, and Python:

```
m.reset()
```

In C#:

```
m.Reset()
```

When we call the `optimize` method after resetting the model, optimization starts from scratch. Although the difference in computation time is insignificant for this tiny example, the warm start can make a big difference for larger models.

## fixanddive

The `fixanddive` example provides another example of bound modification. In this case, we repeatedly modify a set of variable bounds, utilizing warm starts each time. In C, variables are fixed as follows:

```
for (j = 0; j < nfix; ++j)
{
    fixval = floor(fractional[j].X + 0.5);
    error = GRBsetdblattr(element(model, "LB", fractional[j].index, fixval);
    if (error) goto QUIT;
    error = GRBsetdblattr(element(model, "UB", fractional[j].index, fixval);
    if (error) goto QUIT;
}
```

In Python, they are fixed as follows:

```
for i in range(nfix):
    v = fractional[i]
    fixval = int(v.x + 0.5)
    v.lb = fixval
    v.ub = fixval
```

Again, the subsequent call to `optimize` starts from the previous solution.

## sensitivity

The `sensitivity` example computes the amount by which the optimal objective changes if each binary variable is fixed at either 0 or 1. For each binary variable, the example creates and solves a copy of the model with new upper and lower bounds. This example is a MIP, so Gurobi can not make use of advanced start information. As a result, the model is solved from scratch after each bound modification.

## feasopt

The last modification example we consider is `feasopt`, which adds variables to existing constraints and also changes the optimization objective. Setting the objective to zero is straightforward: simply call `setObjective` with a zero argument:

```
m.setObjective(0)
```

Adding new variables is somewhat more complex. In the example, we want to add artificial variable(s) to each constraint in order to allow the constraint to be relaxed. We use two artificial variables for equality constraints and one for all other constraints. The Python code for adding a single artificial variable to constraint `c` is:

```
feasModel.addVar(obj=1.0, name="ArtP_" + c.Constrname, column=Column([1], [c]))
```

We use the `column` argument of the `addVar` method to specify the set of constraints in which the new variable participates, as well as the associated coefficients. In this example, the new variable only participates in the constraint to be relaxed. Default values are used here for all variables attributes except the objective and the variable name.

## 2.4 Change parameters

**Examples:** `callback`, `fixanddive`, `lp`, `lpmethod`, `mip2`, `params`, `sensitivity`

This section illustrates the use of Gurobi parameters. Example `params` reads a MIP model from a file, then solves the model using four different values of the `MIPFocus` parameter, running for five seconds per value (`MIPFocus` chooses the high-level strategy that the MIP solver uses to solve the problem). It then chooses the parameter value that produced the smallest MIP gap, and continues solving the model until it achieves optimality.

The mechanics of setting a parameter are quite simple. To set the `MIPFocus` parameter in C, do the following:

```
GRBsetintparam(GRBgetenv(model), GRB_INT_PAR_MIPFOCUS, i);
```

In C++:

```
model.getEnv().set(GRB_IntParam_MIPFocus, i);
```

In Java:

```
model.getEnv().set(GRB.IntParam.MIPFocus, i);
```

In C#:

```
model.GetEnv().Set(GRB.IntParam.MIPFocus, i);
```

In Python:

```
model.params.MIPFocus = i
```

Note how parameter settings affect the behavior of the different models. When we set the `TimeLimit` parameter on the base model, then make a copy of that model, the parameter setting is carried over to the copy. The copy gets its own environment that is a copy of the original. When we set the `MIPFocus` parameter on the copy, that parameter change has no effect on the other copies, nor on the original model.

## 2.5 Automated Parameter Tuning

**Example:** `tune`

The next example we consider is `tune`, which demonstrates the use of our automated parameter tuning tool. This tool searches for parameter settings that improve performance on a model. While you would typically invoke the tool through the command line, using our `grbtune` program, it can also be invoked from our APIs. We'll provide only a cursory description of the tool here. We recommend that you consult the *Parameter Tuning Tool* section of the [Gurobi Reference Manual](#) for more precise details.

Our tuning example demonstrates a typical use of the tuning tool. You would start by invoking the tool on a model. In C:

```
error = GRBtunemodel(model);
```

In Java:

```
model.tune();
```

This routine solves the model multiple times, with different parameter settings, to find settings that improve performance.

Once tuning is complete, you would then use `GetTuneResult` to retrieve the result. In C:

```
error = GRBgettunerresult(model, 0);
```

In Java:

```
model.getTuneResult(0);
```

The numerical argument indicates which tuning result to retrieve (0 is the best result, 1 is the second-best, etc.). This routine loads the requested parameter set into the environment associated with the argument model.

Once the tune parameter settings have been loaded into the model, you can then call `Optimize` to use these parameters to solve the model, or you can call `Write` to write these parameters to a `.prm` file.

## 2.6 Diagnose and cope with infeasibility

**Examples:** `feasopt`, `lp`, `workforce1`, `workforce2`, `workforce3`, `workforce4`

When solving optimization models, there are some situations where the specified constraints cannot be satisfied. When this happens, you often need to either identify and repair the root cause

of the infeasibility, or alternatively find a set of constraints to relax in order to obtain a feasible model. The `workforce1`, `workforce2`, and `workforce3` illustrate these different strategies.

Starting with the simplest of the three examples, `workforce1` formulates a simple workforce scheduling model and solves it. If the model is infeasible, it computes an Irreducible Inconsistent Subsystem (IIS). The user can then inspect this information to understand and hopefully address the source of the infeasibility in the model.

Example `workforce2` is similar, except that if the model is infeasible, the example repeatedly identifies an IIS and removes one of the associated constraints from the model until the model becomes feasible. Note that it is sufficient to remove one constraint from the IIS to address that source of infeasibility, but that one IIS may not capture all sources of infeasibility. It is therefore necessary to repeat the process until the model is feasible.

Example `workforce3` takes a different approach to addressing infeasibility. Rather than identifying and removing IIS members, it allows the constraints of the model to be relaxed. Like the `feasopt` example, an artificial variable is added to each constraint. The example sets the objective on the original variables to zero, and then solves a model that minimizes the total magnitude of the constraint relaxation.

The `feasopt` example demonstrates another approach to relaxing an infeasible model. It computes a *feasibility relaxation* for the infeasible model. A feasibility relaxation is a model that, when solved, minimizes the amount by which the solution violates the bounds and linear constraints of the original model. This method is invoked as follows:

In C:

```
error = GRBfeasrelax(feasmodel, GRB_FEASRELAX_LINEAR, 1,
                    NULL, NULL, rhspen, &feasobj);
```

In C++:

```
feasmodel1.feasRelax(GRB_FEASRELAX_LINEAR, true, false, true);
```

In C#:

```
feasmodel1.FeasRelax(GRB.FEASRELAX_LINEAR, true, false, true);
```

In Java:

```
feasmodel1.feasRelax(GRB.FEASRELAX_LINEAR, true, false, true);
```

In Python:

```
feasmodel1.FeasRelaxS(0, True, False, True);
```

The arguments to this method select the objective function for the relaxed model, the specific set of bounds and constraints that are allowed to be relaxed, and the penalties for relaxing specific bounds and constraints.

## 2.7 MIP starts

**Example:** `facility`

A MIP modeler often knows how to compute a feasible solution to their problem. In cases where the MIP solver is slow in finding an initial feasible solution, it can be helpful for the modeler to provide

a feasible solution along with the model itself. This is done through the `Start` attribute on the variables. This is illustrated in the `facility` example.

The `facility` example solves a simple facility location problem. The model contains a set of warehouses, and a set of plants that produce the products required in the warehouses. Each plant has a maximum production capacity and a fixed operating cost. Additionally, there is a cost associated with shipping products from a plant to a warehouse. The goal is to decide which plants should satisfy the demand for the product, given the associated capacities and costs.

The example uses a simple heuristic for choosing an initial solution: it closes the plant with the highest fixed cost. The associated solution may not be optimal, but it could produce a reasonable starting solution for the MIP optimization. The MIP start is passed to the MIP solver by setting the `Start` attribute before the optimization begins. In C, we set the start attribute to open all plants using the following code:

```
for (p = 0; p < nPlants; ++p)
{
    error = GRBsetdblattrelement(model, "Start", opencol(p), 1.0);
    if (error) goto QUIT;
}
```

In Python:

```
for p in range(nPlants):
    open[p].start = 1.0
```

When you run the example, the MIP solver reports that the start produced a feasible initial solution:

```
Loaded MIP start with objective 210500
```

This initial solution turns out to be optimal for the sample data. Although the computation difference is insignificant for this tiny example, providing a good starting solution can sometimes help for more difficult models.

Note that the MIP start in this example only specifies values for some of the variables – the variables that determine which plants to leave open and which plants to close. The Gurobi MIP solve uses whatever start information is provided to try to construct a complete solution.

## 2.8 Model-Data Separation in Python

**Examples:** `diet2.py`, `diet3.py`, `diet4.py`

When building an optimization model in a modeling language, it is typical to separate the optimization model itself from the data used to create an instance of the model. These two model ingredients are often stored in completely different files. We show how a similar result can be achieved in our Python interface with our `diet2.py`, `diet3.py`, and `diet4.py` examples. These examples illustrate alternate approaches to providing data to the optimization model: `diet2.py` embeds the data in the source file, `diet3.py` reads the data from an SQL database (using the Python `sqlite3` package), and `diet4.py` reads the data from an Excel spreadsheet (using the Python `xlrd` package). `dietmodel.py` contains the optimization model itself. The same model is used by `diet2.py`, `diet3.py`, and `diet4.py`.

The key construct that enables the separation of the model from the data is the Python module. A module is simply a set of functions and variables, stored in a file. You import a module into a program using the `import` statement. `diet2.py`, `diet3.py`, and `diet4.py` all populate a set of variables, and then pass them to the `solve` function of the `dietmodel` module using the following pair of statements:

```
import dietmodel
dietmodel.solve(categories, minNutrition, maxNutrition, foods, cost, nutritionValues)
```

The first statement imports the `dietmodel` module, which must be stored in file `dietmodel.py` in the current directory. The second passes the model data to the `solve` function in the newly imported module.

## 2.9 Callbacks

### Example: callback

The final example we consider is `callback`, which demonstrates the use of Gurobi callbacks. Callbacks are used to report on the progress of the optimization or to modify the behavior of the Gurobi solver. To use a callback, the user writes a routine that implements the desired behavior. The routine is passed to the Gurobi optimizer when optimization begins, and the routine is called regularly during the optimization process. One argument of the user routine is a `where` value, which indicates from where in the optimization process the callback is invoked. The user callback routine can call the optimization library to query certain values. We refer the reader to the callback section of the [Gurobi Reference Manual](#) for more precise details.

Our callback example implements a simple termination scheme: the user passes a node count into the callback, and the callback asks the optimizer to terminate when that node count is reached. This is implemented in C as follows:

```
GRBcbget(cbdata, where, GRB_CB_MIP_NODCNT, &nodecnt);
if (nodecnt > limit)
    GRBterminate(model);
```

In Python, this is implemented as:

```
nodecnt = model.cbGet(GRB.callback.MIP_NODCNT)
if nodecnt > model._mynodelimit:
    model.terminate()
```

To obtain the current node count, the user routine calls the `cbget` routine (the `GRBcbget` function in C, or the `cbGet` method on the model object in C++, C#, Java, and Python).

Our callback example also prints progress information. In C:

```
GRBcbget(cbdata, where, GRB_CB_MIP_NODCNT, &nodecnt);
if (nodecnt - mydata->lastmsg >= 100) {
    ...
    printf("%7.0f ...", nodecnt, ...);
}
```

In Python:

```
nodecnt = model.cbGet(GRB.callback.MIP_NODCNT)
if nodecnt % 100 == 0:
    print int(nodecnt), ...
```

Again, the user callback calls the `cbGet` routine to query the state of the optimization.

We have included source code for all of the distributed examples in this section. The identical example source code is included in the `examples` directory in the Gurobi distribution.

## 3.1 C Examples

This section includes source code for all of the Gurobi C examples. The same source code can be found in the `examples/c` directory of the Gurobi distribution.

### `callback_c.c`

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP or a MIP from a file, sets a callback
   to monitor the optimization progress and to output some progress
   information to the screen and to a log file. If it is a MIP and 10%
   gap is reached, then it aborts */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

/* Define structure to pass my data to the callback function */

struct callback_data {
    double lastnode;
    double lasttiter;
    FILE *logfile;
    double *solution;
};

int __stdcall
mycallback(GRBmodel *model,
           void *cbdata,
           int where,
           void *usrdata)
{
    struct callback_data *mydata = (struct callback_data *) usrdata;
    char *msg;
```

```

if (where == GRB_CB_POLLING) {
    /* Ignore polling callback */
} else if (where == GRB_CB_MESSAGE) {
    GRBcbget(cbdata, where, GRB_CB_MSG_STRING, &msg);
    fprintf(mydata->logfile, "%s", msg);
} else if (where == GRB_CB_SIMPLEX) {
    double pinf, dinf, obj, itrcnt;
    int    ispert;
    char   ch;
    GRBcbget(cbdata, where, GRB_CB_SPX_ITRCNT, &itrcnt);
    if (itrcnt - mydata->lastiter >= 100) {
        mydata->lastiter = itrcnt;
        GRBcbget(cbdata, where, GRB_CB_SPX_ISPERT, &ispert);
        GRBcbget(cbdata, where, GRB_CB_SPX_OBJVAL, &obj);
        GRBcbget(cbdata, where, GRB_CB_SPX_PRIMINF, &pinf);
        GRBcbget(cbdata, where, GRB_CB_SPX_DUALINF, &dinf);
        if (ispert == 0) ch = ' ';
        else if (ispert == 1) ch = 'S';
        else ch = 'P';
        printf("%7.0f %14.7e%c %13.6e %13.6e\n", itrcnt, obj, ch, pinf, dinf);
    }
} else if (where == GRB_CB_PRESOLVE) {
    int cdels, rdels;
    GRBcbget(cbdata, where, GRB_CB_PRE_COLDEL, &cdels);
    GRBcbget(cbdata, where, GRB_CB_PRE_ROWDEL, &rdels);
    if (cdels || rdels) {
        printf("%7d columns and %7d rows are removed\n", cdels, rdels);
    }
} else if (where == GRB_CB_MIP) {
    double objbst, objbnd, nodecnt, actnodes, itrcnt;
    int    cutcnt, solcnt;
    GRBcbget(cbdata, where, GRB_CB_MIP_NODCNT, &nodecnt);
    if (nodecnt - mydata->lastnode >= 100) {
        mydata->lastnode = nodecnt;
        GRBcbget(cbdata, where, GRB_CB_MIP_OBJBST, &objbst);
        GRBcbget(cbdata, where, GRB_CB_MIP_OBJBND, &objbnd);
        /* if gap is small, then quit */
        if (fabs(objbst - objbnd) < 0.1 * (1.0 + fabs(objbst))) {
            printf("Stop early - 10%% gap achieved\n");
            GRBterminate(model);
        }
    }
    GRBcbget(cbdata, where, GRB_CB_MIP_NODLFT, &actnodes);
    GRBcbget(cbdata, where, GRB_CB_MIP_ITRCNT, &itrcnt);
    GRBcbget(cbdata, where, GRB_CB_MIP_SOLCNT, &solcnt);

```

```

        GRBcbget(cbdata, where, GRB_CB_MIP_CUTCNT, &cutcnt);
        printf("%7.0f %7.0f %8.0f %13.6e %13.6e %7d %7d\n",
            nodecnt, actnodes, itrCnt, objbst, objbnd, solcnt, cutcnt);
    }
} else if (where == GRB_CB_MIPSOL) {
    double obj, nodecnt;
    int solcnt;
    GRBcbget(cbdata, where, GRB_CB_MIPSOL_OBJ, &obj);
    GRBcbget(cbdata, where, GRB_CB_MIPSOL_NODCNT, &nodecnt);
    GRBcbget(cbdata, where, GRB_CB_MIPSOL_SOLCNT, &solcnt);
    GRBcbget(cbdata, where, GRB_CB_MIPSOL_SOL, mydata->solution);

    printf("**** New solution at node %.0f, obj %g, sol %d, x[0] = %.2f ****\n",
        nodecnt, obj, solcnt, mydata->solution[0]);
} else if (where == GRB_CB_BARRIER) {
    double primobj, dualobj, priminf, dualinf, compl;
    int iter;
    GRBcbget(cbdata, where, GRB_CB_BARRIER_ITRCNT, &iter);
    GRBcbget(cbdata, where, GRB_CB_BARRIER_PRIMOBJ, &primobj);
    GRBcbget(cbdata, where, GRB_CB_BARRIER_DUALOBJ, &dualobj);
    GRBcbget(cbdata, where, GRB_CB_BARRIER_PRIMINF, &priminf);
    GRBcbget(cbdata, where, GRB_CB_BARRIER_DUALINF, &dualinf);
    GRBcbget(cbdata, where, GRB_CB_BARRIER_COMPL, &compl);

    printf("Barrier iter: %d %.4e %.4e %.4e %.4e %.4e\n",
        iter, primobj, dualobj, priminf, dualinf, compl);
}
return 0;
}

int
main(int argc,
    char *argv[])
{
    GRBenv *env = NULL;
    GRBmodel *model = NULL;
    int error = 0;
    int vars, optimstatus;
    double objval;
    struct callback_data mydata;

    mydata.lastnode = -GRB_INFINITY;
    mydata.lastiter = -GRB_INFINITY;
    mydata.logfile = NULL;
    mydata.solution = NULL;

```

```

if (argc < 2) {
    fprintf(stderr, "Usage: callback_c filename\n");
    goto QUIT;
}

mydata.logfile = fopen("cb.log", "w");
if (!mydata.logfile) {
    fprintf(stderr, "Cannot open cb.log for callback message\n");
    goto QUIT;
}

/* Create environment */

error = GRBloadenv(&env, NULL);
if (error) goto QUIT;

/* Turn off display */

error = GRBsetintparam(env, GRB_INT_PAR_OUTPUTFLAG, 0);
if (error) goto QUIT;

/* Read model from file */

error = GRBreadmodel(env, argv[1], &model);
if (error) goto QUIT;

/* Allocate space for solution */

error = GRBgetintattr(model, GRB_INT_ATTR_NUMVARS, &vars);
if (error) goto QUIT;

mydata.solution = malloc(vars*sizeof(double));
if (mydata.solution == NULL) {
    fprintf(stderr, "Failed to allocate memory\n");
    exit(1);
}

/* Set callback function */

error = GRBsetcallbackfunc(model, mycallback, (void *) &mydata);
if (error) goto QUIT;

/* Solve model */

```

```

error = GRBoptimize(model);
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL)
    printf("Optimal objective: %.4e\n", objval);
else if (optimstatus == GRB_INF_OR_UNBD)
    printf("Model is infeasible or unbounded\n");
else
    printf("Optimization was stopped early\n");
printf("\n");

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Close file */

if (mydata.logfile)
    fclose(mydata.logfile);

/* Free solution */

if (mydata.solution)
    free(mydata.solution);

/* Free model */

GRBfreemodel(model);

/* Free environment */

```

```
GRBfreeenv(env);  
return 0;  
}
```

## dense\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QP model:

    minimize    x + y + x^2 + x*y + y^2 + y*z + z^2
    subject to  x + 2 y + 3 z >= 4
                x +   y       >= 1

The example illustrates the use of dense matrices to store A and Q
(and dense vectors for the other relevant data). We don't recommend
that you use dense matrices, but this example may be helpful if you
already have your data in this format.
*/

#include <stdlib.h>
#include <stdio.h>
#include "gurobi_c.h"

/*
Solve an LP/QP/MILP/MIQP represented using dense matrices. This
routine assumes that A and Q are both stored in row-major order.
It returns 1 if the optimization succeeds. When successful,
it returns the optimal objective value in 'objvalP', and the
optimal solution vector in 'solution'.
*/

static int
dense_optimize(GRBEnv *env,
               int     rows,
               int     cols,
               double *c,    /* linear portion of objective function */
               double *Q,    /* quadratic portion of objective function */
               double *A,    /* constraint matrix */
               char   *sense, /* constraint senses */
               double *rhs,  /* RHS vector */
               double *lb,   /* variable lower bounds */
               double *ub,   /* variable upper bounds */
               char   *vtype, /* variable types (continuous, binary, etc.) */
               double *solution,
               double *objvalP)
{
    GRBmodel *model = NULL;
    int      i, j, optimstatus;
    int      error = 0;
```

```

int      success = 0;

/* Create an empty model */

error = GRBnewmodel(env, &model, "dense", cols, c, lb, ub, vtype, NULL);
if (error) goto QUIT;

error = GRBaddconstrs(model, rows, 0, NULL, NULL, NULL, sense, rhs, NULL);
if (error) goto QUIT;

/* Integrate new rows and columns */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Populate A matrix */

for (i = 0; i < rows; i++) {
    for (j = 0; j < cols; j++) {
        if (A[i*cols+j] != 0) {
            error = GRBchgcoeffs(model, 1, &i, &j, &A[i*cols+j]);
            if (error) goto QUIT;
        }
    }
}

/* Populate Q matrix */

if (Q) {
    for (i = 0; i < cols; i++) {
        for (j = 0; j < cols; j++) {
            if (Q[i*cols+j] != 0) {
                error = GRBaddqpters(model, 1, &i, &j, &Q[i*cols+j]);
                if (error) goto QUIT;
            }
        }
    }
}

/* Integrate new coefficients */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Write model to 'dense.lp' */

```

```

error = GRBwrite(model, "dense.lp");
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

if (optimstatus == GRB_OPTIMAL) {

    error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, objvalP);
    if (error) goto QUIT;

    error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, cols, solution);
    if (error) goto QUIT;

    success = 1;
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

return success;
}

int
main(int  argc,
      char *argv[])
{

```

```

GRBenv *env      = NULL;
int      error   = 0;
double  c[]      = {1, 1, 0};
double  Q[3][3] = {{1, 1, 0}, {0, 1, 1}, {0, 0, 1}};
double  A[2][3] = {{1, 2, 3}, {1, 1, 0}};
char    sense[] = {'>', '>'};
double  rhs[]   = {4, 1};
double  lb[]    = {0, 0, 0};
double  sol[3];
int     solved;
double  objval;

/* Create environment */

error = GRBloadenv(&env, "dense.log");
if (error) goto QUIT;

/* Solve the model */

solved = dense_optimize(env, 2, 3, c, &Q[0][0], &A[0][0], sense, rhs, lb,
                        NULL, NULL, sol, &objval);

if (solved)
    printf("Solved: x=%.4f, y=%.4f, z=%.4f\n", sol[0], sol[1], sol[2]);

QUIT:

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## diet\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve the classic diet model, showing how to add constraints
   to an existing model. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

int printSolution(GRBmodel* model, int nCategories, int nFoods);

int
main(int  argc,
     char *argv[])
{
    GRBenv  *env  = NULL;
    GRBmodel *model = NULL;
    int      error = 0;
    int      i, j;
    int      *cbeg, *cind, idx;
    double   *cval, *rhs;
    char     *sense;

    /* Nutrition guidelines, based on
       USDA Dietary Guidelines for Americans, 2005
       http://www.health.gov/DietaryGuidelines/dga2005/ */

    const int nCategories = 4;
    char *Categories[] =
        { "calories", "protein", "fat", "sodium" };
    double minNutrition[] = { 1800, 91, 0, 0 };
    double maxNutrition[] = { 2200, GRB_INFINITY, 65, 1779 };

    /* Set of foods */
    const int nFoods = 9;
    char* Foods[] =
        { "hamburger", "chicken", "hot dog", "fries",
          "macaroni", "pizza", "salad", "milk", "ice cream" };
    double cost[] =
        { 2.49, 2.89, 1.50, 1.89, 2.09, 1.99, 2.49, 0.89, 1.59 };

    /* Nutrition values for the foods */
```

```

double nutritionValues[][4] = {
    { 410, 24, 26, 730 },
    { 420, 32, 10, 1190 },
    { 560, 20, 32, 1800 },
    { 380, 4, 19, 270 },
    { 320, 12, 10, 930 },
    { 320, 15, 12, 820 },
    { 320, 31, 12, 1230 },
    { 100, 8, 2.5, 125 },
    { 330, 8, 10, 180 }
};

/* Create environment */
error = GRBloadenv(&env, "diet.log");
if (error) goto QUIT;

/* Create initial model */
error = GRBnewmodel(env, &model, "diet", nFoods + nCategories,
    NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Initialize decision variables for the foods to buy */
for (j = 0; j < nFoods; ++j)
{
    error = GRBsetdblattrelement(model, "Obj", j, cost[j]);
    if (error) goto QUIT;
    error = GRBsetstrattrelement(model, "VarName", j, Foods[j]);
    if (error) goto QUIT;
}

/* Initialize decision variables for the nutrition information,
   which we limit via bounds */
for (j = 0; j < nCategories; ++j)
{
    error = GRBsetdblattrelement(model, "LB", j + nFoods, minNutrition[j]);
    if (error) goto QUIT;
    error = GRBsetdblattrelement(model, "UB", j + nFoods, maxNutrition[j]);
    if (error) goto QUIT;
    error = GRBsetstrattrelement(model, "VarName", j + nFoods, Categories[j]);
    if (error) goto QUIT;
}

/* The objective is to minimize the costs */
error = GRBsetintattr(model, "ModelSense", 1);
if (error) goto QUIT;

```

```

/* Nutrition constraints */
cbeg = malloc(sizeof(int) * nCategories);
if (!cbeg) goto QUIT;
cind = malloc(sizeof(int) * nCategories * (nFoods + 1));
if (!cind) goto QUIT;
cval = malloc(sizeof(double) * nCategories * (nFoods + 1));
if (!cval) goto QUIT;
rhs = malloc(sizeof(double) * nCategories);
if (!rhs) goto QUIT;
sense = malloc(sizeof(char) * nCategories);
if (!sense) goto QUIT;
idx = 0;
for (i = 0; i < nCategories; ++i)
{
    cbeg[i] = idx;
    rhs[i] = 0.0;
    sense[i] = GRB_EQUAL;
    for (j = 0; j < nFoods; ++j)
    {
        cind[idx] = j;
        cval[idx++] = nutritionValues[j][i];
    }
    cind[idx] = nFoods + i;
    cval[idx++] = -1.0;
}

error = GRBaddconstrs(model, nCategories, idx, cbeg, cind, cval, sense,
                    rhs, Categories);
if (error) goto QUIT;

/* Solve */
error = GRBoptimize(model);
if (error) goto QUIT;
error = printSolution(model, nCategories, nFoods);
if (error) goto QUIT;

printf("\nAdding constraint: at most 6 servings of dairy\n");
cind[0] = 7;
cval[0] = 1.0;
cind[1] = 8;
cval[1] = 1.0;
error = GRBaddconstr(model, 2, cind, cval, GRB_LESS_EQUAL, 6.0,
                    "limit_dairy");
if (error) goto QUIT;

```

```

/* Solve */
error = GRBoptimize(model);
if (error) goto QUIT;
error = printSolution(model, nCategories, nFoods);
if (error) goto QUIT;

QUIT:

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free data */

free(cbeg);
free(cind);
free(cval);
free(rhs);
free(sense);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

int printSolution(GRBmodel* model, int nCategories, int nFoods)
{
    int error, status, i, j;
    double obj, x;
    char* vname;

    error = GRBgetintattr(model, "Status", &status);

```

```

if (error) return error;
if (status == GRB_OPTIMAL)
{
    error = GRBgetdblattr(model, "ObjVal", &obj);
    if (error) return error;
    printf("\nCost: %f\n\nBuy:\n", obj);
    for (j = 0; j < nFoods; ++j)
    {
        error = GRBgetdblattrelement(model, "X", j, &x);
        if (error) return error;
        if (x > 0.0001)
        {
            error = GRBgetstrattrelement(model, "VarName", j, &vname);
            if (error) return error;
            printf("%s %f\n", vname, x);
        }
    }
    printf("\nNutrition:\n");
    for (i = 0; i < nCategories; ++i)
    {
        error = GRBgetdblattrelement(model, "X", i + nFoods, &x);
        if (error) return error;
        error = GRBgetstrattrelement(model, "VarName", i + nFoods, &vname);
        if (error) return error;
        printf("%s %f\n", vname, x);
    }
}
else
{
    printf("No solution\n");
}

return 0;
}

```

## facility\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Facility location: a company currently ships its product from 5 plants
   to 4 warehouses. It is considering closing some plants to reduce
   costs. What plant(s) should the company close, in order to minimize
   transportation and fixed costs?

   Based on an example from Frontline Systems:
   http://www.solver.com/disfacility.htm
   Used with permission.
*/

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

#define opencol(p)          p
#define transportcol(w,p) nPlants*(w+1)+p
#define MAXSTR             128

int
main(int  argc,
      char *argv[])
{
  GRBenv  *env   = NULL;
  GRBmodel *model = NULL;
  int     error = 0;
  int     p, w, col;
  int     *cbeg = NULL;
  int     *cind = NULL;
  int     idx, rowct;
  double  *cval = NULL;
  double  *rhs = NULL;
  char     *sense = NULL;
  char     vname[MAXSTR];
  int     cnamect = 0;
  char     **cname = NULL;
  double  maxFixed = -GRB_INFINITY, sol, obj;

  /* Number of plants and warehouses */
  const int nPlants = 5;
  const int nWarehouses = 4;
```

```

/* Warehouse demand in thousands of units */
double Demand[] = { 15, 18, 14, 20 };

/* Plant capacity in thousands of units */
double Capacity[] = { 20, 22, 17, 19, 18 };

/* Fixed costs for each plant */
double FixedCosts[] =
    { 12000, 15000, 17000, 13000, 16000 };

// Transportation costs per thousand units
double TransCosts[4][5] = {
    { 4000, 2000, 3000, 2500, 4500 },
    { 2500, 2600, 3400, 3000, 4000 },
    { 1200, 1800, 2600, 4100, 3000 },
    { 2200, 2600, 3100, 3700, 3200 }
};

/* Create environment */
error = GRBloadenv(&env, "facility.log");
if (error) goto QUIT;

/* Create initial model */
error = GRBnewmodel(env, &model, "facility", nPlants * (nWarehouses + 1),
    NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Initialize decision variables for plant open variables */
for (p = 0; p < nPlants; ++p)
{
    col = opencol(p);
    error = GRBsetcharattrelement(model, "VType", col, GRB_BINARY);
    if (error) goto QUIT;
    error = GRBsetdblattrelement(model, "Obj", col, FixedCosts[p]);
    if (error) goto QUIT;
    sprintf(vname, "Open%i", p);
    error = GRBsetstrattrelement(model, "VarName", col, vname);
    if (error) goto QUIT;
}

/* Initialize decision variables for transportation decision variables:
    how much to transport from a plant p to a warehouse w */
for (w = 0; w < nWarehouses; ++w)
{

```

```

for (p = 0; p < nPlants; ++p)
{
    col = transportcol(w, p);
    error = GRBsetdblattrelement(model, "Obj", col, TransCosts[w][p]);
    if (error) goto QUIT;
    sprintf(vname, "Trans%i.%i", p, w);
    error = GRBsetstrattrelement(model, "VarName", col, vname);
    if (error) goto QUIT;
}
}

/* The objective is to minimize the total fixed and variable costs */
error = GRBsetintattr(model, "ModelSense", 1);
if (error) goto QUIT;

/* Make space for constraint data */
rowct = (nPlants > nWarehouses) ? nPlants : nWarehouses;
cbeg = malloc(sizeof(int) * rowct);
if (!cbeg) goto QUIT;
cind = malloc(sizeof(int) * (nPlants * (nWarehouses + 1)));
if (!cind) goto QUIT;
cval = malloc(sizeof(double) * (nPlants * (nWarehouses + 1)));
if (!cval) goto QUIT;
rhs = malloc(sizeof(double) * rowct);
if (!rhs) goto QUIT;
sense = malloc(sizeof(char) * rowct);
if (!sense) goto QUIT;
cname = calloc(rowct, sizeof(char*));
if (!cname) goto QUIT;

/* Production constraints
   Note that the limit sets the production to zero if
   the plant is closed */
idx = 0;
for (p = 0; p < nPlants; ++p)
{
    cbeg[p] = idx;
    rhs[p] = 0.0;
    sense[p] = GRB_LESS_EQUAL;
    cname[p] = malloc(sizeof(char) * MAXSTR);
    if (!cname[p]) goto QUIT;
    cnamect++;
    sprintf(cname[p], "Capacity%i", p);
    for (w = 0; w < nWarehouses; ++w)
    {

```

```

        cind[idx] = transportcol(w, p);
        cval[idx++] = 1.0;
    }
    cind[idx] = opencol(p);
    cval[idx++] = -Capacity[p];
}
error = GRBaddconstrs(model, nPlants, idx, cbeg, cind, cval, sense,
                    rhs, cname);
if (error) goto QUIT;

/* Demand constraints */
idx = 0;
for (w = 0; w < nWarehouses; ++w)
{
    cbeg[w] = idx;
    sense[w] = GRB_EQUAL;
    sprintf(cname[w], "Demand%i", w);
    for (p = 0; p < nPlants; ++p)
    {
        cind[idx] = transportcol(w, p);
        cval[idx++] = 1.0;
    }
}
error = GRBaddconstrs(model, nWarehouses, idx, cbeg, cind, cval, sense,
                    Demand, cname);
if (error) goto QUIT;

/* Guess at the starting point: close the plant with the highest
   fixed costs; open all others */

/* First, open all plants */
for (p = 0; p < nPlants; ++p)
{
    error = GRBsetdblattrelement(model, "Start", opencol(p), 1.0);
    if (error) goto QUIT;
}

/* Now close the plant with the highest fixed cost */
printf("Initial guess:\n");
for (p = 0; p < nPlants; ++p)
{
    if (FixedCosts[p] > maxFixed)
    {
        maxFixed = FixedCosts[p];
    }
}

```

```

}
for (p = 0; p < nPlants; ++p)
{
    if (FixedCosts[p] == maxFixed)
    {
        error = GRBsetdblattrelement(model, "Start", opencol(p), 0.0);
        if (error) goto QUIT;
        printf("Closing plant %i\n\n", p);
        break;
    }
}

/* Use barrier to solve root relaxation */
error = GRBsetintparam(GRBgetenv(model),
                      GRB_INT_PAR_METHOD,
                      GRB_METHOD_BARRIER);
if (error) goto QUIT;

/* Solve */
error = GRBoptimize(model);
if (error) goto QUIT;

/* Print solution */
error = GRBgetdblattr(model, "ObjVal", &obj);
if (error) goto QUIT;
printf("\nTOTAL COSTS: %f\n", obj);
printf("SOLUTION:\n");
for (p = 0; p < nPlants; ++p)
{
    error = GRBgetdblattrelement(model, "X", opencol(p), &sol);
    if (error) goto QUIT;
    if (sol == 1.0)
    {
        printf("Plant %i open:\n", p);
        for (w = 0; w < nWarehouses; ++w)
        {
            error = GRBgetdblattrelement(model, "X", transportcol(w, p), &sol);
            if (error) goto QUIT;
            if (sol > 0.0001)
            {
                printf("  Transport %f units to warehouse %i\n", sol, w);
            }
        }
    }
}
else

```

```
    {
        printf("Plant %i closed!\n", p);
    }
}
```

QUIT:

```
/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free data */

free(cbeg);
free(cind);
free(cval);
free(rhs);
free(sense);
for (p = 0; p < cnamect; ++p) {
    free(cname[p]);
}
free(cname);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}
```

## feasopt\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, adds artificial
   variables to each constraint, and then minimizes the sum of the
   artificial variables. A solution with objective zero corresponds
   to a feasible solution to the input model.
   We can also use FeasRelax feature to do it. In this example, we
   use minrelax=1, i.e. optimizing the returned model finds a solution
   that minimizes the original objective, but only from among those
   solutions that minimize the sum of the artificial variables. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
  GRBenv  *env      = NULL;
  GRBmodel *model   = NULL;
  GRBmodel *feasmodel = NULL;
  double  *rhspen   = NULL;
  int      error = 0;
  int      i, j;
  int      numvars, numconstrs;
  char     sense;
  int      vind[1];
  double   vval[1];
  double   feasobj;
  char     *cname, *vname;

  if (argc < 2)
  {
    fprintf(stderr, "Usage: feasopty_c filename\n");
    exit(1);
  }

  error = GRBloadenv(&env, "feasopt.log");
  if (error) goto QUIT;

  error = GRBreadmodel(env, argv[1], &model);
```

```

if (error) goto QUIT;

/* Create a copy to use FeasRelax feature later */

feasmodel = GRBcopymodel(model);
if (error) goto QUIT;

/* clear objective */
error = GRBgetintattr(model, "NumVars", &numvars);
if (error) goto QUIT;
for (j = 0; j < numvars; ++j)
{
    error = GRBsetdblattrelement(model, "Obj", j, 0.0);
    if (error) goto QUIT;
}

/* add slack variables */
error = GRBgetintattr(model, "NumConstrs", &numconstrs);
if (error) goto QUIT;
for (i = 0; i < numconstrs; ++i)
{
    error = GRBgetcharattrelement(model, "Sense", i, &sense);
    if (error) goto QUIT;
    if (sense != '>>')
    {
        error = GRBgetstrattrelement(model, "ConstrName", i, &cname);
        if (error) goto QUIT;
        vname = malloc(sizeof(char) * (6 + strlen(cname)));
        if (!vname) goto QUIT;
        strcpy(vname, "ArtN_");
        strcat(vname, cname);
        vind[0] = i;
        vval[0] = -1.0;
        error = GRBaddvar(model, 1, vind, vval, 1.0, 0.0, GRB_INFINITY,
                           GRB_CONTINUOUS, vname);
        if (error) goto QUIT;
        free(vname);
    }
    if (sense != '<<')
    {
        error = GRBgetstrattrelement(model, "ConstrName", i, &cname);
        if (error) goto QUIT;
        vname = malloc(sizeof(char) * (6 + strlen(cname)));
        if (!vname) goto QUIT;
        strcpy(vname, "ArtP_");
    }
}

```

```

    strcat(vname, cname);
    vind[0] = i;
    vval[0] = 1.0;
    error = GRBaddvar(model, 1, vind, vval, 1.0, 0.0, GRB_INFINITY,
                      GRB_CONTINUOUS, vname);
    if (error) goto QUIT;
    free(vname);
}
}
error = GRBupdatemodel(model);
if (error) goto QUIT;

/* optimize modified model */
error = GRBwrite(model, "feasopt.lp");
if (error) goto QUIT;

error = GRBoptimize(model);
if (error) goto QUIT;

/* Use FeasRelax feature */

rhspen = (double *) malloc(numconstrs*sizeof(double));
if (rhspen == NULL) {
    printf("ERROR: out of memory\n");
    goto QUIT;
}

/* set penalties for artificial variables */
for (i = 0; i < numconstrs; i++) rhspen[i] = 1;

/* create a FeasRelax model with the original objective recovered
   and enforcement on minimum of artificial variables */
error = GRBfeasrelax(feasmodel, GRB_FEASRELAX_LINEAR, 1,
                    NULL, NULL, rhspen, &feasobj);
if (error) goto QUIT;

/* optimize FeasRelax model */
error = GRBwrite(feasmodel, "feasopt1.lp");
if (error) goto QUIT;

error = GRBoptimize(feasmodel);
if (error) goto QUIT;

QUIT:

```

```
/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free models, env and etc. */

if (rhspen) free(rhspen);

GRBfreemodel(model);
GRBfreemodel(feasmodel);

GRBfreeenv(env);

return 0;
}
```

## fixanddive\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Implement a simple MIP heuristic. Relax the model,
   sort variables based on fractionality, and fix the 25% of
   the fractional variables that are closest to integer variables.
   Repeat until either the relaxation is integer feasible or
   linearly infeasible. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

typedef struct
{
    int index;
    double X;
}
var_t ;

int vcomp(const void* v1, const void* v2);

int
main(int  argc,
      char *argv[])
{
    GRBenv  *env    = NULL, *modelenv = NULL;
    GRBmodel *model = NULL;
    int     error = 0;
    int     j, iter, nfix;
    int     numvars, numintvars, numfractional;
    int     *intvars = NULL;
    int     status;
    char     vtype, *vname;
    double  sol, obj, fixval;
    var_t   *fractional = NULL;

    if (argc < 2)
    {
        fprintf(stderr, "Usage: fixanddive_c filename\n");
        exit(1);
    }
}
```

```

error = GRBloadenv(&env, "fixanddive.log");
if (error) goto QUIT;

/* Read model */
error = GRBreadmodel(env, argv[1], &model);
if (error) goto QUIT;

/* Collect integer variables and relax them */
error = GRBgetintattr(model, "NumVars", &numvars);
if (error) goto QUIT;
error = GRBgetintattr(model, "NumIntVars", &numintvars);
if (error) goto QUIT;
intvars = malloc(sizeof(int) * numintvars);
if (!intvars) goto QUIT;
fractional = malloc(sizeof(var_t) * numintvars);
if (!fractional) goto QUIT;
numfractional = 0;
for (j = 0; j < numvars; j++)
{
    error = GRBgetcharattrelement(model, "VType", j, &vtype);
    if (error) goto QUIT;
    if (vtype != GRB_CONTINUOUS)
    {
        intvars[numfractional++] = j;
        error = GRBsetcharattrelement(model, "VType", j, GRB_CONTINUOUS);
        if (error) goto QUIT;
    }
}

modelenv = GRBgetenv(model);
if (!modelenv) goto QUIT;
error = GRBsetintparam(modelenv, "OutputFlag", 0);
if (error) goto QUIT;
error = GRBoptimize(model);
if (error) goto QUIT;

/* Perform multiple iterations. In each iteration, identify the first
   quartile of integer variables that are closest to an integer value
   in the relaxation, fix them to the nearest integer, and repeat. */

for (iter = 0; iter < 1000; ++iter)
{

    /* create a list of fractional variables, sorted in order of
       increasing distance from the relaxation solution to the nearest

```

```

integer value */

numfractional = 0;
for (j = 0; j < numintvars; ++j)
{
    error = GRBgetdblattrelement(model, "X", intvars[j], &sol);
    if (error) goto QUIT;
    if (fabs(sol - floor(sol + 0.5)) > 1e-5)
    {
        fractional[numfractional].index = intvars[j];
        fractional[numfractional++].X = sol;
    }
}

error = GRBgetdblattr(model, "ObjVal", &obj);
if (error) goto QUIT;
printf("Iteration %i, obj %f, fractional %i\n",
        iter, obj, numfractional);

if (numfractional == 0)
{
    printf("Found feasible solution - objective %f\n", obj);
    break;
}

/* Fix the first quartile to the nearest integer value */
qsort(fractional, numfractional, sizeof(var_t), vcomp);
nfix = numfractional / 4;
nfix = (nfix > 1) ? nfix : 1;
for (j = 0; j < nfix; ++j)
{
    fixval = floor(fractional[j].X + 0.5);
    error = GRBsetdblattrelement(model, "LB", fractional[j].index, fixval);
    if (error) goto QUIT;
    error = GRBsetdblattrelement(model, "UB", fractional[j].index, fixval);
    if (error) goto QUIT;
    error = GRBgetstrattrelement(model, "VarName",
                                fractional[j].index, &vname);

    if (error) goto QUIT;
    printf(" Fix %s to %f ( rel %f )\n", vname, fixval, fractional[j].X);
}

error = GRBoptimize(model);
if (error) goto QUIT;

```

```

    /* Check optimization result */

    error = GRBgetintattr(model, "Status", &status);
    if (error) goto QUIT;
    if (status != GRB_OPTIMAL)
    {
        printf("Relaxation is infeasible\n");
        break;
    }
}

QUIT:

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free data */

free(intvars);
free(fractional);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

int vcomp(const void* v1, const void* v2)
{
    double sol1, sol2, frac1, frac2;
    sol1 = fabs(((var_t *)v1)->X);
    sol2 = fabs(((var_t *)v2)->X);
    frac1 = fabs(sol1 - floor(sol1 + 0.5));

```

```
frac2 = fabs(sol2 - floor(sol2 + 0.5));  
return (frac1 < frac2) ? -1 : ((frac1 == frac2) ? 0 : 1);  
}
```

## lp\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model is infeasible or unbounded, the example turns off
   presolve and solves the model again. If the model is infeasible,
   the example computes an Irreducible Infeasible Subsystem (IIS),
   and writes it to a file */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
  GRBenv  *masterenv = NULL;
  GRBmodel *model    = NULL;
  GRBenv  *modelenv  = NULL;
  int     error      = 0;
  int     optimstatus;
  double  objval;

  if (argc < 2) {
    fprintf(stderr, "Usage: lp_c filename\n");
    exit(1);
  }

  /* Create environment */

  error = GRBloadenv(&masterenv, "lp.log");
  if (error) goto QUIT;

  /* Read model from file */

  error = GRBreadmodel(masterenv, argv[1], &model);
  if (error) goto QUIT;

  /* Solve model */

  error = GRBoptimize(model);
  if (error) goto QUIT;
```

```

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

/* If model is infeasible or unbounded, turn off presolve and resolve */

if (optimstatus == GRB_INF_OR_UNBD) {
    modelenv = GRBgetenv(model);
    if (!modelenv) {
        fprintf(stderr, "Error: could not get model environment\n");
        goto QUIT;
    }

    /* Change parameter on model environment. The model now has
       a copy of the master environment, so changing the master will
       no longer affect the model. */

    error = GRBsetintparam(modelenv, "PRESOLVE", 0);
    if (error) goto QUIT;

    error = GRBoptimize(model);
    if (error) goto QUIT;

    error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
    if (error) goto QUIT;
}

if (optimstatus == GRB_OPTIMAL) {
    error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
    if (error) goto QUIT;
    printf("Optimal objective: %.4e\n\n", objval);
} else if (optimstatus == GRB_INFEASIBLE) {
    printf("Model is infeasible\n\n");

    error = GRBcomputeIIS(model);
    if (error) goto QUIT;

    error = GRBwrite(model, "model.ilp");
    if (error) goto QUIT;
} else if (optimstatus == GRB_UNBOUNDED) {
    printf("Model is unbounded\n\n");
} else {
    printf("Optimization was stopped with status = %d\n\n", optimstatus);
}

```

QUIT:

```
/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrormsg(masterenv));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(masterenv);

return 0;
}
```

## lpmethod\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve a model with different values of the Method parameter;
   show which value gives the shortest solve time. */

#include <stdlib.h>
#include <stdio.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
  GRBenv  *env = NULL, *menv;
  GRBmodel *m = NULL;
  int     error = 0;
  int     i;
  int     optimstatus;
  int     bestMethod = -1;
  double  bestTime;

  if (argc < 2)
  {
    fprintf(stderr, "Usage: lpmethod_c filename\n");
    exit(1);
  }

  error = GRBloadenv(&env, "lpmethod.log");
  if (error) goto QUIT;

  /* Read model */
  error = GRBreadmodel(env, argv[1], &m);
  if (error) goto QUIT;
  menv = GRBgetenv(m);
  error = GRBgetdblparam(menv, "TimeLimit", &bestTime);
  if (error) goto QUIT;

  /* Solve the model with different values of Method */
  for (i = 0; i <= 2; ++i)
  {
    error = GRBresetmodel(m);
    if (error) goto QUIT;
    error = GRBsetintparam(menv, "Method", i);
    if (error) goto QUIT;
  }
}
```

```

error = GRBoptimize(m);
if (error) goto QUIT;
error = GRBgetintattr(m, "Status", &optimstatus);
if (error) goto QUIT;
if (optimstatus == GRB_OPTIMAL) {
    error = GRBgetdblattr(m, "Runtime", &bestTime);
    if (error) goto QUIT;
    bestMethod = i;
    /* Reduce the TimeLimit parameter to save time
       with other methods */
    error = GRBsetdblparam(menv, "TimeLimit", bestTime);
    if (error) goto QUIT;
}
}

/* Report which method was fastest */
if (bestMethod == -1) {
    printf("Unable to solve this model\n");
} else {
    printf("Solved in %f seconds with Method: %i\n",
          bestTime, bestMethod);
}

QUIT:

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrormsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(m);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## lpmod\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model can be solved, then it finds the smallest positive variable,
   sets its upper bound to zero, and resolves the model two ways:
   first with an advanced start, then without an advanced start
   (i.e. 'from scratch'). */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
  GRBEnv  *env   = NULL;
  GRBmodel *model = NULL;
  int     error = 0;
  int     j;
  int     numvars, isMIP, status, minVar = 0;
  double  minVal = GRB_INFINITY, sol, lb;
  char    *varname;
  double  warmCount, warmTime, coldCount, coldTime;

  if (argc < 2)
  {
    fprintf(stderr, "Usage: lpmod_c filename\n");
    exit(1);
  }

  error = GRBloadenv(&env, "lpmod.log");
  if (error) goto QUIT;

  /* Read model and determine whether it is an LP */
  error = GRBreadmodel(env, argv[1], &model);
  if (error) goto QUIT;
  error = GRBgetintattr(model, "IsMIP", &isMIP);
  if (error) goto QUIT;
  if (isMIP)
  {
    printf("The model is not a linear program\n");
  }
}
```

```

    goto QUIT;
}

error = GRBoptimize(model);
if (error) goto QUIT;

error = GRBgetintattr(model, "Status", &status);
if (error) goto QUIT;

if ((status == GRB_INF_OR_UNBD) || (status == GRB_INFEASIBLE) ||
    (status == GRB_UNBOUNDED))
{
    printf("The model cannot be solved because it is ");
    printf("infeasible or unbounded\n");
    goto QUIT;
}

if (status != GRB_OPTIMAL)
{
    printf("Optimization was stopped with status %i\n", status);
    goto QUIT;
}

/* Find the smallest variable value */
error = GRBgetintattr(model, "NumVars", &numvars);
if (error) goto QUIT;
for (j = 0; j < numvars; ++j)
{
    error = GRBgetdblattrelement(model, "X", j, &sol);
    if (error) goto QUIT;
    error = GRBgetdblattrelement(model, "LB", j, &lb);
    if (error) goto QUIT;
    if ((sol > 0.0001) && (sol < minVal) &&
        (lb == 0.0))
    {
        minVal = sol;
        minVar = j;
    }
}

error = GRBgetstrattrelement(model, "VarName", minVar, &varname);
if (error) goto QUIT;
printf("\n*** Setting %s from %f to zero ***\n\n", varname, minVal);
error = GRBsetdblattrelement(model, "LB", minVar, 0.0);
if (error) goto QUIT;

```

```

/* Solve from this starting point */
error = GRBoptimize(model);
if (error) goto QUIT;

/* Save iteration & time info */
error = GRBgetdblattr(model, "IterCount", &warmCount);
if (error) goto QUIT;
error = GRBgetdblattr(model, "Runtime", &warmTime);
if (error) goto QUIT;

/* Reset the model and resolve */
printf("\n*** Resetting and solving ");
printf("without an advanced start ***\n\n");
error = GRBresetmodel(model);
if (error) goto QUIT;
error = GRBoptimize(model);
if (error) goto QUIT;

/* Save iteration & time info */
error = GRBgetdblattr(model, "IterCount", &coldCount);
if (error) goto QUIT;
error = GRBgetdblattr(model, "Runtime", &coldTime);
if (error) goto QUIT;

printf("\n*** Warm start: %f iterations, %f seconds\n",
        warmCount, warmTime);
printf("*** Cold start: %f iterations, %f seconds\n",
        coldCount, coldTime);

QUIT:

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

```

```
/* Free environment */  
GRBfreeenv(env);  
  
return 0;  
}
```

## mip1\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple MIP model:

    maximize    x +  y + 2 z
    subject to  x + 2 y + 3 z <= 4
                x +  y      >= 1
    x, y, z binary
*/

#include <stdlib.h>
#include <stdio.h>
#include "gurobi_c.h"

int
main(int  argc,
      char *argv[])
{
    GRBenv  *env   = NULL;
    GRBmodel *model = NULL;
    int     error = 0;
    double  sol[3];
    int     ind[3];
    double  val[3];
    double  obj[3];
    char    vtype[3];
    int     optimstatus;
    double  objval;

    /* Create environment */

    error = GRBloadenv(&env, "mip1.log");
    if (error) goto QUIT;

    /* Create an empty model */

    error = GRBnewmodel(env, &model, "mip1", 0, NULL, NULL, NULL, NULL, NULL);
    if (error) goto QUIT;

    /* Add variables */

    obj[0] = 1; obj[1] = 1; obj[2] = 2;
    vtype[0] = GRB_BINARY; vtype[1] = GRB_BINARY; vtype[2] = GRB_BINARY;
```

```

error = GRBaddvars(model, 3, 0, NULL, NULL, NULL, obj, NULL, NULL, vtype,
                  NULL);
if (error) goto QUIT;

/* Change objective sense to maximization */

error = GRBsetintattr(model, GRB_INT_ATTR_MODELSENSE, GRB_MAXIMIZE);
if (error) goto QUIT;

/* Integrate new variables */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* First constraint:  $x + 2y + 3z \leq 4$  */

ind[0] = 0; ind[1] = 1; ind[2] = 2;
val[0] = 1; val[1] = 2; val[2] = 3;

error = GRBaddconstr(model, 3, ind, val, GRB_LESS_EQUAL, 4.0, "c0");
if (error) goto QUIT;

/* Second constraint:  $x + y \geq 1$  */

ind[0] = 0; ind[1] = 1;
val[0] = 1; val[1] = 1;

error = GRBaddconstr(model, 2, ind, val, GRB_GREATER_EQUAL, 1.0, "c1");
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Write model to 'mip1.lp' */

error = GRBwrite(model, "mip1.lp");
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

```

```

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, 3, sol);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL) {
    printf("Optimal objective: %.4e\n", objval);

    printf(" x=%.0f, y=%.0f, z=%.0f\n", sol[0], sol[1], sol[2]);
} else if (optimstatus == GRB_INF_OR_UNBD) {
    printf("Model is infeasible or unbounded\n");
} else {
    printf("Optimization was stopped early\n");
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrormsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## mip2\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, solves it and
   prints the objective values from all feasible solutions
   generated while solving the MIP. Then it creates the fixed
   model and solves that model. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
    GRBenv  *env  = NULL;
    GRBmodel *model = NULL;
    GRBmodel *fixed = NULL;
    int      error = 0;
    int      ismip;
    int      j, k, solcount, numvars;
    double   objn, vobj, xn;
    int      optimstatus, foptimstatus;
    double   objval, fobjval;
    char     *varname;
    double   x;

    /* To change settings for a loaded model, we need to get
       the model environment, which will be freed when the model
       is freed. */

    GRBenv  *menv, *fenv;

    if (argc < 2) {
        fprintf(stderr, "Usage: mip2_c filename\n");
        exit(1);
    }

    /* Create environment */

    error = GRBloadenv(&env, "mip2.log");
    if (error) goto QUIT;
```

```

/* Read model from file */

error = GRBreadmodel(env, argv[1], &model);
if (error) goto QUIT;

error = GRBgetintattr(model, "IsMIP", &ismip);
if (error) goto QUIT;

if (ismip == 0) {
    printf("Model is not a MIP\n");
    goto QUIT;
}

/* Get model environment */

menv = GRBgetenv(model);
if (!menv) {
    fprintf(stderr, "Error: could not get model environment\n");
    goto QUIT;
}

/* Solve model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL) {
    error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
    if (error) goto QUIT;
    printf("Optimal objective: %.4e\n\n", objval);
} else if (optimstatus == GRB_INF_OR_UNBD) {
    printf("Model is infeasible or unbounded\n\n");
    goto QUIT;
} else if (optimstatus == GRB_INFEASIBLE) {
    printf("Model is infeasible\n\n");
    goto QUIT;
} else if (optimstatus == GRB_UNBOUNDED) {
    printf("Model is unbounded\n\n");
    goto QUIT;
}

```

```

} else {
    printf("Optimization was stopped with status = %d\n\n", optimstatus);
    goto QUIT;
}

/* Iterate over the solutions and compute the objectives */

error = GRBsetintparam(menv, "OutputFlag", 0);
if (error) goto QUIT;
error = GRBgetintattr(model, "SolCount", &solcount);
if (error) goto QUIT;
error = GRBgetintattr(model, "NumVars", &numvars);
if (error) goto QUIT;

printf("\n");
for ( k = 0; k < solcount; ++k ) {
    error = GRBsetintparam(menv, "SolutionNumber", k);
    objn = 0.0;
    for ( j = 0; j < numvars; ++j ) {
        error = GRBgetdblattrelement(model, "Obj", j, &vobj);
        if (error) goto QUIT;
        error = GRBgetdblattrelement(model, "Xn", j, &xn);
        if (error) goto QUIT;
        objn += vobj * xn;
    }
    printf("Solution %i has objective: %f\n", k, objn);
}
printf("\n");

error = GRBsetintparam(menv, "OutputFlag", 1);
if (error) goto QUIT;

/* Create a fixed model, turn off presolve and solve */

fixed = GRBfixedmodel(model);
if (!fixed) {
    fprintf(stderr, "Error: could not create fixed model\n");
    goto QUIT;
}

fenv = GRBgetenv(fixed);
if (!fenv) {
    fprintf(stderr, "Error: could not get fixed model environment\n");
    goto QUIT;
}

```

```

error = GRBsetintparam(fenv, "PRESOLVE", 0);
if (error) goto QUIT;

error = GRBoptimize(fixed);
if (error) goto QUIT;

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &foptimstatus);
if (error) goto QUIT;

if (foptimstatus != GRB_OPTIMAL) {
    fprintf(stderr, "Error: fixed model isn't optimal\n");
    goto QUIT;
}

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &fobjval);
if (error) goto QUIT;

if (fabs(fobjval - objval) > 1.0e-6 * (1.0 + fabs(objval))) {
    fprintf(stderr, "Error: objective values are different\n");
}

/* Print values of nonzero variables */
for ( j = 0; j < numvars; ++j ) {
    error = GRBgetstrattrelement(fixed, "VarName", j, &varname);
    if (error) goto QUIT;
    error = GRBgetdblattrelement(fixed, "X", j, &x);
    if (error) goto QUIT;
    if (x != 0.0) {
        printf("%s %f\n", varname, x);
    }
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free models */

```

```
GRBfreemodel(model);
GRBfreemodel(fixed);

/* Free environment */

GRBfreeenv(env);

return 0;
}
```

## params\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Use parameters that are associated with a model.

   A MIP is solved for 5 seconds with different sets of parameters.
   The one with the smallest MIP gap is selected, and the optimization
   is resumed until the optimal solution is found.
*/

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

int gap(GRBmodel*, double*);

int
main(int  argc,
      char *argv[])
{
  GRBenv  *env   = NULL, *baseenv = NULL, *menv = NULL, *bestenv = NULL;
  GRBmodel *base = NULL, *m = NULL, *bestModel = NULL;
  int      error = 0;
  int      i;
  int      ismip;
  int      mipfocus;
  double   bestGap = GRB_INFINITY, currGap;

  if (argc < 2)
  {
    fprintf(stderr, "Usage: params_c filename\n");
    exit(1);
  }

  error = GRBloadenv(&env, "params.log");
  if (error) goto QUIT;

  /* Read model and verify that it is a MIP */
  error = GRBreadmodel(env, argv[1], &base);
  if (error) goto QUIT;
  error = GRBgetintattr(base, "IsMIP", &ismip);
  if (error) goto QUIT;
  if (ismip == 0)
  {
```

```

    printf("The model is not an integer program\n");
    goto QUIT;
}

/* Set a 5 second time limit */
baseenv = GRBgetenv(base);
if (!baseenv) goto QUIT;
error = GRBsetdblparam(baseenv, "TimeLimit", 5);
if (error) goto QUIT;

/* Now solve the model with different values of MIPFocus */
for (i = 0; i <= 3; ++i)
{
    m = GRBcopymodel(base);
    if (!m) goto QUIT;
    menv = GRBgetenv(m);
    if (!menv) goto QUIT;
    error = GRBsetintparam(menv, "MIPFocus", i);
    if (error) goto QUIT;
    error = GRBoptimize(m);
    if (error) goto QUIT;
    error = gap(m, &currGap);
    if (error) goto QUIT;
    if (bestModel == NULL || bestGap > currGap)
    {
        GRBfreemodel(bestModel);
        bestModel = m;
        bestGap = currGap;
    }
    else
    {
        GRBfreemodel(m);
    }
}

/* Finally, reset the time limit and continue to solve the
   best model to optimality */
bestenv = GRBgetenv(bestModel);
if (!bestenv) goto QUIT;
error = GRBsetdblparam(bestenv, "TimeLimit", GRB_INFINITY);
if (error) goto QUIT;
error = GRBoptimize(bestModel);
if (error) goto QUIT;
error = GRBgetintparam(bestenv, "MIPFocus", &mipfocus);
if (error) goto QUIT;

```

```

printf("Solved with MIPFocus: %i\n", mipfocus);

QUIT:

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrormsg(env));
    exit(1);
}

/* Free models */

GRBfreemodel(bestModel);
GRBfreemodel(base);

/* Free environment */

GRBfreeenv(env);

return 0;
}

/* Simple function to determine the MIP gap */
int gap(GRBmodel *model, double *gap)
{
    int error;
    int solcount;
    double objval, objbound;

    error = GRBgetintattr(model, "SolCount", &solcount);
    if (error) return error;
    error = GRBgetdblattr(model, "ObjVal", &objval);
    if (error) return error;

    if ((solcount == 0) || (fabs(objval) < 1e-6))
    {
        *gap = GRB_INFINITY;
        return 0;
    }
    error = GRBgetdblattr(model, "ObjBound", &objbound);
    if (error) return error;
}

```

```
*gap = fabs(objbound - objval) / fabs(objval);  
return 0;  
}
```

## qcp\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QCP model:

    maximize    x
    subject to  x + y + z = 1
                x^2 + y^2 <= z^2 (second-order cone)
                x^2 <= yz        (rotated second-order cone)
*/

#include <stdlib.h>
#include <stdio.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
    GRBenv  *env   = NULL;
    GRBmodel *model = NULL;
    int     error = 0;
    double  sol[3];
    int     ind[3];
    double  val[3];
    double  obj[] = {1, 0, 0};
    int     grow[3];
    int     qcol[3];
    double  qval[3];
    int     optimstatus;
    double  objval;

    /* Create environment */

    error = GRBloadenv(&env, "qcp.log");
    if (error) goto QUIT;

    /* Create an empty model */

    error = GRBnewmodel(env, &model, "qcp", 0, NULL, NULL, NULL, NULL, NULL);
    if (error) goto QUIT;

    /* Add variables */
```

```

error = GRBaddvars(model, 3, 0, NULL, NULL, NULL, obj, NULL, NULL, NULL,
                  NULL);
if (error) goto QUIT;

/* Change sense to maximization */

error = GRBsetintattr(model, GRB_INT_ATTR_MODELSENSE, GRB_MAXIMIZE);
if (error) goto QUIT;

/* Integrate new variables */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Linear constraint: x + y + z = 1 */

ind[0] = 0; ind[1] = 1; ind[2] = 2;
val[0] = 1; val[1] = 1; val[2] = 1;

error = GRBaddconstr(model, 3, ind, val, GRB_EQUAL, 1.0, "c0");
if (error) goto QUIT;

/* Cone: x^2 + y^2 <= z^2 */

qrow[0] = 0; qcol[0] = 0; qval[0] = 1.0;
qrow[1] = 1; qcol[1] = 1; qval[1] = 1.0;
qrow[2] = 2; qcol[2] = 2; qval[2] = -1.0;

error = GRBaddqconstr(model, 0, NULL, NULL, 3, qrow, qcol, qval,
                    GRB_LESS_EQUAL, 0.0, "qc0");
if (error) goto QUIT;

/* Rotated cone: x^2 <= yz */

qrow[0] = 0; qcol[0] = 0; qval[0] = 1.0;
qrow[1] = 1; qcol[1] = 2; qval[1] = -1.0;

error = GRBaddqconstr(model, 0, NULL, NULL, 2, qrow, qcol, qval,
                    GRB_LESS_EQUAL, 0.0, "qc1");
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

```

```

/* Write model to 'qcp.lp' */

error = GRBwrite(model, "qcp.lp");
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, 3, sol);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL) {
    printf("Optimal objective: %.4e\n", objval);

    printf(" x=%.2f, y=%.2f, z=%.2f\n", sol[0], sol[1], sol[2]);
} else if (optimstatus == GRB_INF_OR_UNBD) {
    printf("Model is infeasible or unbounded\n");
} else {
    printf("Optimization was stopped early\n");
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

```

```
    return 0;  
}
```

## qp\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */
```

```
/* This example formulates and solves the following simple QP model:
```

```
    minimize    x^2 + x*y + y^2 + y*z + z^2 + 2 x
    subject to  x + 2 y + 3 z >= 4
                x +   y       >= 1
```

```
    It solves it once as a continuous model, and once as an integer model.
*/
```

```
#include <stdlib.h>
```

```
#include <stdio.h>
```

```
#include "gurobi_c.h"
```

```
int
```

```
main(int  argc,
      char *argv[])
```

```
{
```

```
    GRBenv  *env   = NULL;
```

```
    GRBmodel *model = NULL;
```

```
    int      error = 0;
```

```
    double   sol[3];
```

```
    int      ind[3];
```

```
    double   val[3];
```

```
    int      qrow[5];
```

```
    int      qcol[5];
```

```
    double   qval[5];
```

```
    char     vtype[3];
```

```
    int      optimstatus;
```

```
    double   objval;
```

```
    /* Create environment */
```

```
    error = GRBloadenv(&env, "qp.log");
```

```
    if (error) goto QUIT;
```

```
    /* Create an empty model */
```

```
    error = GRBnewmodel(env, &model, "qp", 0, NULL, NULL, NULL, NULL, NULL);
```

```
    if (error) goto QUIT;
```

```
    /* Add variables */
```

```

error = GRBaddvars(model, 3, 0, NULL, NULL, NULL, NULL, NULL, NULL, NULL,
                  NULL);
if (error) goto QUIT;

/* Integrate new variables */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Quadratic objective terms */

qrow[0] = 0; qrow[1] = 0; qrow[2] = 1; qrow[3] = 1; qrow[4] = 2;
qcol[0] = 0; qcol[1] = 1; qcol[2] = 1; qcol[3] = 2; qcol[4] = 2;
qval[0] = 1; qval[1] = 1; qval[2] = 1; qval[3] = 1; qval[4] = 1;

error = GRBaddqpterm(model, 5, qrow, qcol, qval);
if (error) goto QUIT;

/* Linear objective term */

error = GRBsetdblattr(model, GRB_DBL_ATTR_OBJ, 0, 2.0);
if (error) goto QUIT;

/* First constraint: x + 2 y + 3 z <= 4 */

ind[0] = 0; ind[1] = 1; ind[2] = 2;
val[0] = 1; val[1] = 2; val[2] = 3;

error = GRBaddconstr(model, 3, ind, val, GRB_GREATER_EQUAL, 4.0, "c0");
if (error) goto QUIT;

/* Second constraint: x + y >= 1 */

ind[0] = 0; ind[1] = 1;
val[0] = 1; val[1] = 1;

error = GRBaddconstr(model, 2, ind, val, GRB_GREATER_EQUAL, 1.0, "c1");
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Write model to 'qp.lp' */

```

```

error = GRBwrite(model, "qp.lp");
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, 3, sol);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL) {
    printf("Optimal objective: %.4e\n", objval);

    printf(" x=%.4f, y=%.4f, z=%.4f\n", sol[0], sol[1], sol[2]);
} else if (optimstatus == GRB_INF_OR_UNBD) {
    printf("Model is infeasible or unbounded\n");
} else {
    printf("Optimization was stopped early\n");
}

/* Modify variable types */

vtype[0] = GRB_INTEGER; vtype[1] = GRB_INTEGER; vtype[2] = GRB_INTEGER;

error = GRBsetcharattrarray(model, GRB_CHAR_ATTR_VTYPE, 0, 3, vtype);
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Write model to 'qp2.lp' */

error = GRBwrite(model, "qp2.lp");
if (error) goto QUIT;

/* Capture solution information */

```

```

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, 3, sol);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL) {
    printf("Optimal objective: %.4e\n", objval);

    printf(" x=%.4f, y=%.4f, z=%.4f\n", sol[0], sol[1], sol[2]);
} else if (optimstatus == GRB_INF_OR_UNBD) {
    printf("Model is infeasible or unbounded\n");
} else {
    printf("Optimization was stopped early\n");
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## sensitivity\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Simple MIP sensitivity analysis example.
   For each integer variable, fix it to its lower and upper bound
   and check the impact on the objective. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

int
main(int  argc,
      char *argv[])
{
    GRBenv   *env = NULL, *aenv;
    GRBmodel *a = NULL, *b = NULL;
    int      error = 0;
    int      i, numvars, status;
    char     vtype, *vname;
    double   x, bnd, aobj, bobj, objchg;

    if (argc < 2)
    {
        fprintf(stderr, "Usage: sensitivity_c filename\n");
        exit(1);
    }

    error = GRBloadenv(&env, "sensitivity.log");
    if (error) goto QUIT;

    /* Read model */
    error = GRBreadmodel(env, argv[1], &a);
    if (error) goto QUIT;
    error = GRBoptimize(a);
    if (error) goto QUIT;
    error = GRBgetdblattr(a, "ObjVal", &aobj);
    if (error) goto QUIT;
    aenv = GRBgetenv(a);
    if (!aenv) goto QUIT;
    error = GRBsetintparam(aenv, "OutputFlag", 0);
    if (error) goto QUIT;

    /* Iterate over all variables */
```

```

error = GRBgetintattr(a, "NumVars", &numvars);
if (error) goto QUIT;
for (i = 0; i < numvars; ++i)
{
    error = GRBgetcharattrelement(a, "VType", i, &vtype);
    if (error) goto QUIT;

    if (vtype == GRB_BINARY)
    {

        /* Create clone and fix variable */
        b = GRBcopymodel(a);
        if (!b) goto QUIT;
        error = GRBgetstrattrelement(a, "VarName", i, &vname);
        if (error) goto QUIT;
        error = GRBgetdblattrelement(a, "X", i, &x);
        if (error) goto QUIT;
        error = GRBgetdblattrelement(a, "LB", i, &bnd);
        if (error) goto QUIT;
        if (x - bnd < 0.5)
        {
            error = GRBgetdblattrelement(b, "UB", i, &bnd);
            if (error) goto QUIT;
            error = GRBsetdblattrelement(b, "LB", i, bnd);
            if (error) goto QUIT;
        }
        else
        {
            error = GRBgetdblattrelement(b, "LB", i, &bnd);
            if (error) goto QUIT;
            error = GRBsetdblattrelement(b, "UB", i, bnd);
            if (error) goto QUIT;
        }

        error = GRBoptimize(b);
        if (error) goto QUIT;

        error = GRBgetintattr(b, "Status", &status);
        if (error) goto QUIT;
        if (status == GRB_OPTIMAL)
        {
            error = GRBgetdblattr(b, "ObjVal", &bobj);
            if (error) goto QUIT;
            objchg = bobj - aobj;
            if (objchg < 0)

```

```

    {
        objchg = 0;
    }
    printf("Objective sensitivity for variable %s is %f\n", vname, objchg);
}
else
{
    printf("Objective sensitivity for variable %s is infinite\n", vname);
}

GRBfreemodel(b);
b = NULL;
}
}

```

QUIT:

```

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrormsg(env));
    exit(1);
}

/* Free models */

GRBfreemodel(a);
GRBfreemodel(b);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## SOS\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example creates a very simple Special Ordered Set (SOS) model.
   The model consists of 3 continuous variables, no linear constraints,
   and a pair of SOS constraints of type 1. */

#include <stdlib.h>
#include <stdio.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
  GRBenv  *env   = NULL;
  GRBmodel *model = NULL;
  int     error = 0;
  double  x[3];
  double  obj[3];
  double  ub[3];
  int     sostype[2];
  int     sosbeg[2];
  int     sosind[4];
  double  soswt[4];
  int     optimstatus;
  double  objval;
  int     zero = 0;

  /* Create environment */

  error = GRBloadenv(&env, "sos.log");
  if (error) goto QUIT;

  /* Create an empty model */

  error = GRBnewmodel(env, &model, "sos", 0, NULL, NULL, NULL, NULL, NULL);
  if (error) goto QUIT;

  /* Add variables */

  obj[0] = -2; obj[1] = -1; obj[2] = -1;
  ub[0] = 1.0; ub[1] = 1.0; ub[2] = 2.0;
  error = GRBaddvars(model, 3, 0, NULL, NULL, NULL, obj, NULL, ub, NULL,
```

```

        NULL);
if (error) goto QUIT;

/* Integrate new variables */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Build first SOS1: x0=0 or x1=0 */

sosind[0] = 0; sosind[1] = 1;
soswt[0] = 1.0; soswt[1] = 2.0;
sosbeg[0] = 0; sostype[0] = GRB_SOS_TYPE1;

/* Build second SOS1: x0=0 or x2=0 */

sosind[2] = 0; sosind[3] = 2;
soswt[2] = 1.0; soswt[3] = 2.0;
sosbeg[1] = 2; sostype[1] = GRB_SOS_TYPE1;

/* Add SOSs to model */

error = GRBaddsos(model, 2, 4, sostype, sosbeg, sosind, soswt);
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Write model to 'sos.lp' */

error = GRBwrite(model, "sos.lp");
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

error = GRBgetdblattrarray(model, GRB_DBL_ATTR_X, 0, 3, x);
if (error) goto QUIT;

```

```

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL) {
    printf("Optimal objective: %.4e\n", objval);

    printf("  x=%.4f, y=%.4f, z=%.4f\n", x[0], x[1], x[2]);
} else if (optimstatus == GRB_INF_OR_UNBD) {
    printf("Model is infeasible or unbounded\n");
} else {
    printf("Optimization was stopped early\n");
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## sudoku\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */
/*
   Sudoku example.

   The Sudoku board is a 9x9 grid, which is further divided into a 3x3 grid
   of 3x3 grids. Each cell in the grid must take a value from 0 to 9.
   No two grid cells in the same row, column, or 3x3 subgrid may take the
   same value.

   In the MIP formulation, binary variables x[i,j,v] indicate whether
   cell <i,j> takes value 'v'. The constraints are as follows:
   1. Each cell must take exactly one value (sum_v x[i,j,v] = 1)
   2. Each value is used exactly once per row (sum_i x[i,j,v] = 1)
   3. Each value is used exactly once per column (sum_j x[i,j,v] = 1)
   4. Each value is used exactly once per 3x3 subgrid (sum_grid x[i,j,v] = 1)

   Input datasets for this example can be found in examples/data/sudoku*.
*/

#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include "gurobi_c.h"

#define SUBDIM 3
#define DIM (SUBDIM*SUBDIM)

int
main(int argc,
      char *argv[])
{
  FILE *fp = NULL;
  GRBenv *env = NULL;
  GRBmodel *model = NULL;
  int board[DIM][DIM];
  char inputline[100];
  int ind[DIM];
  double val[DIM];
  double lb[DIM*DIM*DIM];
  char vtype[DIM*DIM*DIM];
  char *names[DIM*DIM*DIM];
  char namestorage[10*DIM*DIM*DIM];
  char *cursor;
  int optimstatus;
```

```

double    objval;
int       zero = 0;
int       i, j, v, ig, jg, count;
int       error = 0;

if (argc < 2) {
    fprintf(stderr, "Usage: sudoku_c datafile\n");
    exit(1);
}

fp = fopen(argv[1], "r");
if (fp == NULL) {
    fprintf(stderr, "Error: unable to open input file %s\n", argv[1]);
    exit(1);
}

for (i = 0; i < DIM; i++) {
    fgets(inputline, 100, fp);
    if (strlen(inputline) < 9) {
        fprintf(stderr, "Error: not enough board positions specified\n");
        exit(1);
    }
    for (j = 0; j < DIM; j++) {
        board[i][j] = (int) inputline[j] - (int) '1';
        if (board[i][j] < 0 || board[i][j] >= DIM)
            board[i][j] = -1;
    }
}

/* Create an empty model */

cursor = namestorage;
for (i = 0; i < DIM; i++) {
    for (j = 0; j < DIM; j++) {
        for (v = 0; v < DIM; v++){
            if (board[i][j] == v)
                lb[i*DIM*DIM+j*DIM+v] = 1;
            else
                lb[i*DIM*DIM+j*DIM+v] = 0;
            vtype[i*DIM*DIM+j*DIM+v] = GRB_BINARY;

            names[i*DIM*DIM+j*DIM+v] = cursor;
            sprintf(names[i*DIM*DIM+j*DIM+v], "x[%d,%d,%d]", i, j, v+1);
            cursor += strlen(names[i*DIM*DIM+j*DIM+v]) + 1;
        }
    }
}

```

```

    }
}

/* Create environment */

error = GRBloadenv(&env, "sudoku.log");
if (error) goto QUIT;

/* Create new model */

error = GRBnewmodel(env, &model, "sudoku", DIM*DIM*DIM, NULL, lb, NULL,
                    vtype, names);
if (error) goto QUIT;

/* Each cell gets a value */

for (i = 0; i < DIM; i++) {
    for (j = 0; j < DIM; j++) {
        for (v = 0; v < DIM; v++) {
            ind[v] = i*DIM*DIM + j*DIM + v;
            val[v] = 1.0;
        }

        error = GRBaddconstr(model, DIM, ind, val, GRB_EQUAL, 1.0, NULL);
        if (error) goto QUIT;
    }
}

/* Each value must appear once in each row */

for (v = 0; v < DIM; v++) {
    for (j = 0; j < DIM; j++) {
        for (i = 0; i < DIM; i++) {
            ind[i] = i*DIM*DIM + j*DIM + v;
            val[i] = 1.0;
        }

        error = GRBaddconstr(model, DIM, ind, val, GRB_EQUAL, 1.0, NULL);
        if (error) goto QUIT;
    }
}

/* Each value must appear once in each column */

for (v = 0; v < DIM; v++) {

```

```

for (i = 0; i < DIM; i++) {
    for (j = 0; j < DIM; j++) {
        ind[j] = i*DIM*DIM + j*DIM + v;
        val[j] = 1.0;
    }

    error = GRBaddconstr(model, DIM, ind, val, GRB_EQUAL, 1.0, NULL);
    if (error) goto QUIT;
}
}

/* Each value must appear once in each subgrid */

for (v = 0; v < DIM; v++) {
    for (ig = 0; ig < SUBDIM; ig++) {
        for (jg = 0; jg < SUBDIM; jg++) {
            count = 0;
            for (i = ig*SUBDIM; i < (ig+1)*SUBDIM; i++) {
                for (j = jg*SUBDIM; j < (jg+1)*SUBDIM; j++) {
                    ind[count] = i*DIM*DIM + j*DIM + v;
                    val[count] = 1.0;
                    count++;
                }
            }
        }

        error = GRBaddconstr(model, DIM, ind, val, GRB_EQUAL, 1.0, NULL);
        if (error) goto QUIT;
    }
}

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Write model to 'sudoku.lp' */

error = GRBwrite(model, "sudoku.lp");
if (error) goto QUIT;

/* Capture solution information */

error = GRBgetintattr(model, GRB_INT_ATTR_STATUS, &optimstatus);
if (error) goto QUIT;

```

```

error = GRBgetdblattr(model, GRB_DBL_ATTR_OBJVAL, &objval);
if (error) goto QUIT;

printf("\nOptimization complete\n");
if (optimstatus == GRB_OPTIMAL)
    printf("Optimal objective: %.4e\n", objval);
else if (optimstatus == GRB_INF_OR_UNBD)
    printf("Model is infeasible or unbounded\n");
else
    printf("Optimization was stopped early\n");
printf("\n");

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## tsp\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/*
  Solve a traveling salesman problem on a randomly generated set of
  points using lazy constraints.  The base MIP model only includes
  'degree-2' constraints, requiring each node to have exactly
  two incident edges.  Solutions to this model may contain subtours -
  tours that don't visit every node.  The lazy constraint callback
  adds new constraints to cut them off.
*/

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

/* Define structure to pass data to the callback function */

struct callback_data {
  int n;
};

/* Given an integer-feasible solution 'sol', find the smallest
  sub-tour.  Result is returned in 'tour', and length is
  returned in 'tourlenP'. */

static void
findsubtour(int    n,
            double *sol,
            int    *tourlenP,
            int    *tour)
{
  int i, node, len, start;
  int bestind, bestlen;
  int *seen = NULL;

  seen = (int *) malloc(n*sizeof(int));
  if (seen == NULL) {
    fprintf(stderr, "Out of memory\n");
    exit(1);
  }
}
```

```

for (i = 0; i < n; i++)
    seen[i] = 0;

start = 0;
bestlen = n+1;
bestind = -1;
while (start < n) {
    for (node = 0; node < n; node++)
        if (seen[node] == 0)
            break;
    if (node == n)
        break;
    for (len = 0; len < n; len++) {
        tour[start+len] = node;
        seen[node] = 1;
        for (i = 0; i < n; i++) {
            if (sol[node*n+i] > 0.5 && !seen[i]) {
                node = i;
                break;
            }
        }
        if (i == n) {
            len++;
            if (len < bestlen) {
                bestlen = len;
                bestind = start;
            }
            start += len;
            break;
        }
    }
}

for (i = 0; i < bestlen; i++)
    tour[i] = tour[bestind+i];
*tourlenP = bestlen;

free(seen);
}

/* Subtour elimination callback. Whenever a feasible solution is found,
find the shortest subtour, and add a subtour elimination constraint
if that tour doesn't visit every node. */

```

```

int __stdcall
subtourelim(GRBmodel *model,
            void      *cbdata,
            int       where,
            void      *usrdata)
{
    struct callback_data *mydata = (struct callback_data *) usrdata;
    int n = mydata->n;
    int *tour = NULL;
    double *sol = NULL;
    int i, j, len, nz;
    int error = 0;

    if (where == GRB_CB_MIPSOL) {
        sol = (double *) malloc(n*n*sizeof(double));
        tour = (int *) malloc(n*sizeof(int));
        if (sol == NULL || tour == NULL) {
            fprintf(stderr, "Out of memory\n");
            exit(1);
        }

        GRBcbget(cbdata, where, GRB_CB_MIPSOL_SOL, sol);

        findsubtour(n, sol, &len, tour);

        if (len < n) {
            int *ind = NULL;
            double *val = NULL;

            ind = (int *) malloc(len*(len-1)/2*sizeof(int));
            val = (double *) malloc(len*(len-1)/2*sizeof(double));

            if (ind == NULL || val == NULL) {
                fprintf(stderr, "Out of memory\n");
                exit(1);
            }

            /* Add subtour elimination constraint */

            nz = 0;
            for (i = 0; i < len; i++)
                for (j = i+1; j < len; j++)
                    ind[nz++] = tour[i]*n+tour[j];
            for (i = 0; i < nz; i++)
                val[i] = 1.0;

```

```

    error = GRBcblazy(cbdata, nz, ind, val, GRB_LESS_EQUAL, len-1);

    free(ind);
    free(val);
}

free(sol);
free(tour);
}

return error;
}

/* Euclidean distance between points 'i' and 'j'. */

static double
distance(double *x,
         double *y,
         int    i,
         int    j)
{
    double dx = x[i] - x[j];
    double dy = y[i] - y[j];

    return sqrt(dx*dx + dy*dy);
}

int
main(int  argc,
     char *argv[])
{
    GRBenv *env = NULL;
    GRBmodel *model = NULL;
    int    i, j, len, n, solcount;
    int    error = 0;
    char   name[100];
    double *x = NULL;
    double *y = NULL;
    int    *ind = NULL;
    double *val = NULL;
    struct callback_data mydata;

    if (argc < 2) {
        fprintf(stderr, "Usage: tsp_c size\n");

```

```

    exit(1);
}

n = atoi(argv[1]);
if (n == 0) {
    fprintf(stderr, "Argument must be a positive integer.\n");
} else if (n > 100) {
    printf("It will be a challenge to solve a TSP this large.\n");
}

x = (double *) malloc(n*sizeof(double));
y = (double *) malloc(n*sizeof(double));
ind = (int *) malloc(n*sizeof(int));
val = (double *) malloc(n*sizeof(double));

if (x == NULL || y == NULL || ind == NULL || val == NULL) {
    fprintf(stderr, "Out of memory\n");
    exit(1);
}

/* Create random points */

for (i = 0; i < n; i++) {
    x[i] = ((double) rand())/RAND_MAX;
    y[i] = ((double) rand())/RAND_MAX;
}

/* Create environment */

error = GRBloadenv(&env, "tsp.log");
if (error) goto QUIT;

/* Create an empty model */

error = GRBnewmodel(env, &model, "tsp", 0, NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Add variables - one for every pair of nodes */

for (i = 0; i < n; i++) {
    for (j = 0; j < n; j++) {
        sprintf(name, "x_%d_%d", i, j);
        error = GRBaddvar(model, 0, NULL, NULL, distance(x, y, i, j),
            0.0, 1.0, GRB_BINARY, name);
    }
}

```

```

        if (error) goto QUIT;
    }
}

/* Integrate new variables */

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Degree-2 constraints */

for (i = 0; i < n; i++) {
    for (j = 0; j < n; j++) {
        ind[j] = i*n+j;
        val[j] = 1.0;
    }

    sprintf(name, "deg2_%d", i);

    error = GRBaddconstr(model, n, ind, val, GRB_EQUAL, 2, name);
    if (error) goto QUIT;
}

/* Forbid edge from node back to itself */

for (i = 0; i < n; i++) {
    error = GRBsetdblattrelement(model, GRB_DBL_ATTR_UB, i*n+i, 0);
    if (error) goto QUIT;
}

/* Symmetric TSP */

for (i = 0; i < n; i++) {
    for (j = 0; j < i; j++) {
        ind[0] = i*n+j;
        ind[1] = i+j*n;
        val[0] = 1;
        val[1] = -1;
        error = GRBaddconstr(model, 2, ind, val, GRB_EQUAL, 0, NULL);
        if (error) goto QUIT;
    }
}

/* Set callback function */

```

```

mydata.n = n;

error = GRBsetcallbackfunc(model, subtourelim, (void *) &mydata);
if (error) goto QUIT;

/* Must set LazyConstraints parameter when using lazy constraints */

error = GRBsetintparam(GRBgetenv(model), GRB_INT_PAR_LAZYCONSTRAINTS, 1);
if (error) goto QUIT;

/* Optimize model */

error = GRBoptimize(model);
if (error) goto QUIT;

/* Extract solution */

error = GRBgetintattr(model, GRB_INT_ATTR_SOLCOUNT, &solcount);
if (error) goto QUIT;

if (solcount > 0) {
    int *tour = NULL;
    double *sol = NULL;

    sol = (double *) malloc(n*n*sizeof(double));
    tour = (int *) malloc(n*sizeof(int));
    if (sol == NULL || tour == NULL) {
        fprintf(stderr, "Out of memory\n");
        exit(1);
    }

    error = GRBgetdblattrrarray(model, GRB_DBL_ATTR_X, 0, n*n, sol);
    if (error) goto QUIT;

    /* Print tour */

    findsubtour(n, sol, &len, tour);

    printf("Tour: ");
    for (i = 0; i < len; i++)
        printf("%d ", tour[i]);
    printf("\n");

    free(tour);
    free(sol);
}

```

```
    }  
  
QUIT:  
  
    /* Free data */  
  
    free(x);  
    free(y);  
    free(ind);  
    free(val);  
  
    /* Error reporting */  
  
    if (error) {  
        printf("ERROR: %s\n", GRBgeterrormsg(env));  
        exit(1);  
    }  
  
    /* Free model */  
  
    GRBfreemodel(model);  
  
    /* Free environment */  
  
    GRBfreeenv(env);  
  
    return 0;  
}
```

## tune\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a model from a file and tunes it.
   It then writes the best parameter settings to a file
   and solves the model using these parameters. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

int
main(int  argc,
     char *argv[])
{
    GRBenv  *env  = NULL;
    GRBmodel *model = NULL;
    int     tunerresultcount;
    int     error = 0;

    if (argc < 2) {
        fprintf(stderr, "Usage: tune_c filename\n");
        exit(1);
    }

    /* Create environment */

    error = GRBloadenv(&env, "tune_c.log");
    if (error) goto QUIT;

    /* Read model from file */

    error = GRBreadmodel(env, argv[1], &model);
    if (error) goto QUIT;

    /* Set the TuneResults parameter to 1 */

    error = GRBsetintparam(GRBgetenv(model), GRB_INT_PAR_TUNERESULTS, 1);
    if (error) goto QUIT;

    /* Tune the model */

    error = GRBtunemodel(model);
    if (error) goto QUIT;
}
```

```

/* Get the number of tuning results */

error = GRBgetintattr(model, GRB_INT_ATTR_TUNE_RESULTCOUNT, &tunerresultcount);
if (error) goto QUIT;

if (tunerresultcount > 0) {

    /* Load the best tuned parameters into the model's environment */

    error = GRBgettunerresult(model, 0);
    if (error) goto QUIT;

    /* Write tuned parameters to a file */

    error = GRBwrite(model, "tune.prm");
    if (error) goto QUIT;

    /* Solve the model using the tuned parameters */

    error = GRBoptimize(model);
    if (error) goto QUIT;
}

QUIT:

/* Error reporting */

if (error) {
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

```

## workforce1\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
   particular day. If the problem cannot be solved, use IIS to find a set of
   conflicting constraints. Note that there may be additional conflicts
   besides what is reported via IIS. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include "gurobi_c.h"

#define xcol(w,s)  nShifts*w+s
#define MAXSTR    128

int
main(int  argc,
     char *argv[])
{
  GRBenv  *env   = NULL;
  GRBmodel *model = NULL;
  int     error = 0, status;
  int     s, w, col;
  int     *cbeg = NULL;
  int     *cind = NULL;
  int     idx;
  double  *cval = NULL;
  char    *sense = NULL;
  char    vname[MAXSTR];
  double  obj;
  int     i, iis, numconstrs;
  char    *cname;

  /* Sample data */
  const int nShifts = 14;
  const int nWorkers = 7;

  /* Sets of days and workers */
  char* Shifts[] =
  { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
    "Sun14" };

```

```

char* Workers[] =
    { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

/* Number of workers required for each shift */
double shiftRequirements[] =
    { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

/* Amount each worker is paid to work one shift */
double pay[] = { 10, 12, 10, 8, 8, 9, 11 };

/* Worker availability: 0 if the worker is unavailable for a shift */
double availability[][14] =
    { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
      { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
      { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
      { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
      { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

/* Create environment */
error = GRBloadenv(&env, "workforce1.log");
if (error) goto QUIT;

/* Create initial model */
error = GRBnewmodel(env, &model, "workforce1", nWorkers * nShifts,
    NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Initialize assignment decision variables:
   x[w][s] == 1 if worker w is assigned
   to shift s. Since an assignment model always produces integer
   solutions, we use continuous variables and solve as an LP. */
for (w = 0; w < nWorkers; ++w)
{
    for (s = 0; s < nShifts; ++s)
    {
        col = xcol(w, s);
        sprintf(vname, "%s.%s", Workers[w], Shifts[s]);
        error = GRBsetdblattrelement(model, "UB", col, availability[w][s]);
        if (error) goto QUIT;
        error = GRBsetdblattrelement(model, "Obj", col, pay[w]);
        if (error) goto QUIT;
        error = GRBsetstrattrelement(model, "VarName", col, vname);
        if (error) goto QUIT;
    }
}

```

```

    }
}

/* The objective is to minimize the total pay costs */
error = GRBsetintattr(model, "ModelSense", 1);
if (error) goto QUIT;

/* Make space for constraint data */
cbeg = malloc(sizeof(int) * nShifts);
if (!cbeg) goto QUIT;
cind = malloc(sizeof(int) * nShifts * nWorkers);
if (!cind) goto QUIT;
cval = malloc(sizeof(double) * nShifts * nWorkers);
if (!cval) goto QUIT;
sense = malloc(sizeof(char) * nShifts);
if (!sense) goto QUIT;

/* Constraint: assign exactly shiftRequirements[s] workers
   to each shift s */
idx = 0;
for (s = 0; s < nShifts; ++s)
{
    cbeg[s] = idx;
    sense[s] = GRB_EQUAL;
    for (w = 0; w < nWorkers; ++w)
    {
        cind[idx] = xcol(w, s);
        cval[idx++] = 1.0;
    }
}
error = GRBaddconstrs(model, nShifts, idx, cbeg, cind, cval, sense,
                    shiftRequirements, Shifts);
if (error) goto QUIT;

/* Optimize */
error = GRBoptimize(model);
if (error) goto QUIT;
error = GRBgetintattr(model, "Status", &status);
if (error) goto QUIT;
if (status == GRB_UNBOUNDED)
{
    printf("The model cannot be solved because it is unbounded\n");
    goto QUIT;
}
if (status == GRB_OPTIMAL)

```

```

{
    error = GRBgetdblattr(model, "ObjVal", &obj);
    if (error) goto QUIT;
    printf("The optimal objective is %f\n", obj);
    goto QUIT;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    printf("Optimization was stopped with status %i\n", status);
    goto QUIT;
}

/* do IIS */
printf("The model is infeasible; computing IIS\n");
error = GRBcomputeIIS(model);
if (error) goto QUIT;
printf("\nThe following constraint(s) cannot be satisfied:\n");
error = GRBgetintattr(model, "NumConstrs", &numconstrs);
if (error) goto QUIT;
for (i = 0; i < numconstrs; ++i)
{
    error = GRBgetintattrelement(model, "IISConstr", i, &iis);
    if (error) goto QUIT;
    if (iis)
    {
        error = GRBgetstrattrelement(model, "ConstrName", i, &cname);
        if (error) goto QUIT;
        printf("%s\n", cname);
    }
}
}

```

QUIT:

```

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrormsg(env));
    exit(1);
}

/* Free data */

```

```
free(cbeg);
free(cind);
free(cval);
free(sense);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}
```

## workforce2\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
   particular day. If the problem cannot be solved, use IIS iteratively to
   find all conflicting constraints. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include "gurobi_c.h"

#define xcol(w,s)  nShifts*w+s
#define MAXSTR    128

int
main(int  argc,
      char *argv[])
{
  GRBEnv  *env   = NULL;
  GRBmodel *model = NULL;
  int     error = 0, status;
  int     s, w, col;
  int     *cbeg = NULL;
  int     *cind = NULL;
  int     idx;
  double  *cval = NULL;
  char    *sense = NULL;
  char    vname[MAXSTR];
  double  obj;
  int     i, iis, numconstrs, numremoved = 0;
  char    *cname;
  char    **removed = NULL;

  /* Sample data */
  const int nShifts = 14;
  const int nWorkers = 7;

  /* Sets of days and workers */
  char* Shifts[] =
  { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
```

```

    "Sun14" };
char* Workers[] =
    { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

/* Number of workers required for each shift */
double shiftRequirements[] =
    { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

/* Amount each worker is paid to work one shift */
double pay[] = { 10, 12, 10, 8, 8, 9, 11 };

/* Worker availability: 0 if the worker is unavailable for a shift */
double availability[][14] =
    { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
      { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
      { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
      { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
      { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

/* Create environment */
error = GRBloadenv(&env, "workforce2.log");
if (error) goto QUIT;

/* Create initial model */
error = GRBnewmodel(env, &model, "workforce2", nWorkers * nShifts,
    NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Initialize assignment decision variables:
   x[w][s] == 1 if worker w is assigned
   to shift s. Since an assignment model always produces integer
   solutions, we use continuous variables and solve as an LP. */
for (w = 0; w < nWorkers; ++w)
{
    for (s = 0; s < nShifts; ++s)
    {
        col = xcol(w, s);
        sprintf(vname, "%s.%s", Workers[w], Shifts[s]);
        error = GRBsetdblattrelement(model, "UB", col, availability[w][s]);
        if (error) goto QUIT;
        error = GRBsetdblattrelement(model, "Obj", col, pay[w]);
        if (error) goto QUIT;
        error = GRBsetstrattrelement(model, "VarName", col, vname);
    }
}

```

```

    if (error) goto QUIT;
}
}

/* The objective is to minimize the total pay costs */
error = GRBsetintattr(model, "ModelSense", 1);
if (error) goto QUIT;

/* Make space for constraint data */
cbeg = malloc(sizeof(int) * nShifts);
if (!cbeg) goto QUIT;
cind = malloc(sizeof(int) * nShifts * nWorkers);
if (!cind) goto QUIT;
cval = malloc(sizeof(double) * nShifts * nWorkers);
if (!cval) goto QUIT;
sense = malloc(sizeof(char) * nShifts);
if (!sense) goto QUIT;

/* Constraint: assign exactly shiftRequirements[s] workers
to each shift s */
idx = 0;
for (s = 0; s < nShifts; ++s)
{
    cbeg[s] = idx;
    sense[s] = GRB_EQUAL;
    for (w = 0; w < nWorkers; ++w)
    {
        cind[idx] = xcol(w, s);
        cval[idx++] = 1.0;
    }
}
error = GRBaddconstrs(model, nShifts, idx, cbeg, cind, cval, sense,
                    shiftRequirements, Shifts);
if (error) goto QUIT;

/* Optimize */
error = GRBoptimize(model);
if (error) goto QUIT;
error = GRBgetintattr(model, "Status", &status);
if (error) goto QUIT;
if (status == GRB_UNBOUNDED)
{
    printf("The model cannot be solved because it is unbounded\n");
    goto QUIT;
}

```

```

if (status == GRB_OPTIMAL)
{
    error = GRBgetdblattr(model, "ObjVal", &obj);
    if (error) goto QUIT;
    printf("The optimal objective is %f\n", obj);
    goto QUIT;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    printf("Optimization was stopped with status %i\n", status);
    goto QUIT;
}

/* do IIS */
printf("The model is infeasible; computing IIS\n");

/* Loop until we reduce to a model that can be solved */
error = GRBgetintattr(model, "NumConstrs", &numconstrs);
if (error) goto QUIT;
removed = calloc(numconstrs, sizeof(char*));
if (!removed) goto QUIT;
while (1)
{
    error = GRBcomputeIIS(model);
    if (error) goto QUIT;
    printf("\nThe following constraint cannot be satisfied:\n");
    for (i = 0; i < numconstrs; ++i)
    {
        error = GRBgetintattrelement(model, "IISConstr", i, &iis);
        if (error) goto QUIT;
        if (iis)
        {
            error = GRBgetstrattrelement(model, "ConstrName", i, &cname);
            if (error) goto QUIT;
            printf("%s\n", cname);
            /* Remove a single constraint from the model */
            removed[numremoved] = malloc(sizeof(char) * (1+strlen(cname)));
            if (!removed[numremoved]) goto QUIT;
            strcpy(removed[numremoved++], cname);
            cind[0] = i;
            error = GRBdelconstrs(model, 1, cind);
            if (error) goto QUIT;
            break;
        }
    }
}
}

```

```

printf("\n");
error = GRBoptimize(model);
if (error) goto QUIT;
error = GRBgetintattr(model, "Status", &status);
if (error) goto QUIT;
if (status == GRB_UNBOUNDED)
{
    printf("The model cannot be solved because it is unbounded\n");
    goto QUIT;
}
if (status == GRB_OPTIMAL)
{
    break;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    printf("Optimization was stopped with status %i\n", status);
    goto QUIT;
}
}

printf("\nThe following constraints were removed to get a feasible LP:\n");
for (i = 0; i < numremoved; ++i)
{
    printf("%s ", removed[i]);
}
printf("\n");

```

QUIT:

```

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free data */

free(cbeg);
free(cind);

```

```
free(cval);
free(sense);
for (i=0; i<numremoved; ++i) {
    free(removed[i]);
}
free(removed);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}
```

## workforce3\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
   particular day. If the problem cannot be solved, add slack variables
   to determine which constraints cannot be satisfied, and how much
   they need to be relaxed. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include "gurobi_c.h"

#define xcol(w,s)  nShifts*w+s
#define MAXSTR    128

int
main(int  argc,
     char *argv[])
{
  GRBenv  *env = NULL;
  GRBmodel *model = NULL;
  int      error = 0, status;
  int      s, w, col;
  int      *cbeg = NULL;
  int      *cind = NULL;
  int      idx;
  double   *cval = NULL;
  char     *sense = NULL;
  char     vname[MAXSTR];
  double   obj;
  int      i, j, numvars, numconstrs;
  int      *vbeg = NULL;
  int      *vind = NULL;
  double   *vval = NULL;
  double   *vobj = NULL;
  double   sol;
  char     *cname, *sname;
  int      varnamesct = 0;
  char     **varnames = NULL;

  /* Sample data */
```

```

const int nShifts = 14;
const int nWorkers = 7;

/* Sets of days and workers */
char* Shifts[] =
    { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
      "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
      "Sun14" };
char* Workers[] =
    { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

/* Number of workers required for each shift */
double shiftRequirements[] =
    { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

/* Amount each worker is paid to work one shift */
double pay[] = { 10, 12, 10, 8, 8, 9, 11 };

/* Worker availability: 0 if the worker is unavailable for a shift */
double availability[][14] =
    { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
      { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
      { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
      { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
      { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

/* Create environment */
error = GRBloadenv(&env, "workforce3.log");
if (error) goto QUIT;

/* Create initial model */
error = GRBnewmodel(env, &model, "workforce3", nWorkers * nShifts,
    NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Initialize assignment decision variables:
   x[w][s] == 1 if worker w is assigned
   to shift s. Since an assignment model always produces integer
   solutions, we use continuous variables and solve as an LP. */
for (w = 0; w < nWorkers; ++w)
{
    for (s = 0; s < nShifts; ++s)
    {

```

```

    col = xcol(w, s);
    sprintf(vname, "%s.%s", Workers[w], Shifts[s]);
    error = GRBsetdblattrelement(model, "UB", col, availability[w][s]);
    if (error) goto QUIT;
    error = GRBsetdblattrelement(model, "Obj", col, pay[w]);
    if (error) goto QUIT;
    error = GRBsetstrattrelement(model, "VarName", col, vname);
    if (error) goto QUIT;
}
}

/* The objective is to minimize the total pay costs */
error = GRBsetintattr(model, "ModelSense", 1);
if (error) goto QUIT;

/* Make space for constraint data */
cbeg = malloc(sizeof(int) * nShifts);
if (!cbeg) goto QUIT;
cind = malloc(sizeof(int) * nShifts * nWorkers);
if (!cind) goto QUIT;
cval = malloc(sizeof(double) * nShifts * nWorkers);
if (!cval) goto QUIT;
sense = malloc(sizeof(char) * nShifts);
if (!sense) goto QUIT;

/* Constraint: assign exactly shiftRequirements[s] workers
   to each shift s */
idx = 0;
for (s = 0; s < nShifts; ++s)
{
    cbeg[s] = idx;
    sense[s] = GRB_EQUAL;
    for (w = 0; w < nWorkers; ++w)
    {
        cind[idx] = xcol(w, s);
        cval[idx++] = 1.0;
    }
}
error = GRBaddconstrs(model, nShifts, idx, cbeg, cind, cval, sense,
                    shiftRequirements, Shifts);
if (error) goto QUIT;

/* Optimize */
error = GRBoptimize(model);
if (error) goto QUIT;

```

```

error = GRBgetintattr(model, "Status", &status);
if (error) goto QUIT;
if (status == GRB_UNBOUNDED)
{
    printf("The model cannot be solved because it is unbounded\n");
    goto QUIT;
}
if (status == GRB_OPTIMAL)
{
    error = GRBgetdblattr(model, "ObjVal", &obj);
    if (error) goto QUIT;
    printf("The optimal objective is %f\n", obj);
    goto QUIT;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    printf("Optimization was stopped with status %i\n", status);
    goto QUIT;
}

/* Add slack variables to make the model feasible */
printf("The model is infeasible; adding slack variables\n");

/* Determine the matrix size before adding the slacks */
error = GRBgetintattr(model, "NumVars", &numvars);
if (error) goto QUIT;
error = GRBgetintattr(model, "NumConstrs", &numconstrs);
if (error) goto QUIT;

/* Set original objective coefficients to zero */
for (j = 0; j < numvars; ++j)
{
    error = GRBsetdblattrelement(model, "Obj", j, 0.0);
    if (error) goto QUIT;
}

/* Add a new slack variable to each shift constraint so that the shifts
    can be satisfied */
vbeg = malloc(sizeof(int) * numconstrs);
if (!vbeg) goto QUIT;
vind = malloc(sizeof(int) * numconstrs);
if (!vind) goto QUIT;
vval = malloc(sizeof(double) * numconstrs);
if (!vval) goto QUIT;
vobj = malloc(sizeof(double) * numconstrs);

```

```

if (!vobj) goto QUIT;
varnames = calloc(numconstrs, sizeof(char*));
if (!varnames) goto QUIT;
for (i = 0; i < numconstrs; ++i)
{
    vbeg[i] = i;
    vind[i] = i;
    vval[i] = 1.0;
    vobj[i] = 1.0;
    error = GRBgetstrattrelement(model, "ConstrName", i, &cname);
    if (error) goto QUIT;
    varnames[i] = malloc(sizeof(char*) * (6 + strlen(cname)));
    if (!varnames[i]) goto QUIT;
    varnamesct++;
    strcpy(varnames[i], cname);
    strcat(varnames[i], "Slack");
}
error = GRBaddvars(model, numconstrs, numconstrs,
                  vbeg, vind, vval, vobj, NULL, NULL, NULL, varnames);
if (error) goto QUIT;

error = GRBupdatemodel(model);
if (error) goto QUIT;

/* Solve the model with slacks */
error = GRBoptimize(model);
if (error) goto QUIT;
error = GRBgetintattr(model, "Status", &status);
if (error) goto QUIT;
if ((status == GRB_INF_OR_UNBD) || (status == GRB_INFEASIBLE) ||
    (status == GRB_UNBOUNDED))
{
    printf("The model with slacks cannot be solved "
          "because it is infeasible or unbounded\n");
    goto QUIT;
}
if (status != GRB_OPTIMAL)
{
    printf("Optimization was stopped with status %i\n", status);
    goto QUIT;
}

printf("\nSlack values:\n");
for (j = numvars; j < numvars + numconstrs; ++j)
{

```

```

error = GRBgetdblattrelement(model, "X", j, &sol);
if (error) goto QUIT;
if (sol > 1e-6)
{
    error = GRBgetstrattrelement(model, "VarName", j, &sname);
    if (error) goto QUIT;
    printf("%s = %f\n", sname, sol);
}
}

```

QUIT:

```

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrmsg(env));
    exit(1);
}

/* Free data */

free(cbeg);
free(cind);
free(cval);
free(sense);
free(vbeg);
free(vind);
free(vval);
free(vobj);
for (i = 0; i < varnamesct; ++i)
{
    free(varnames[i]);
}
free(varnames);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

```

```
    return 0;  
}
```

## workforce4\_c.c

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. We use Pareto optimization to solve the model:
first, we minimize the linear sum of the slacks. Then, we constrain
the sum of the slacks, and we minimize a quadratic objective that
tries to balance the workload among the workers. */

#include <stdlib.h>
#include <stdio.h>
#include <math.h>
#include <string.h>
#include "gurobi_c.h"

int solveAndPrint(GRBmodel* model,
                 int nShifts, int nWorkers, char** Workers,
                 int* status);

#define xcol(w,s)          nShifts*w+s
#define slackcol(s)       nShifts*nWorkers+s
#define totSlackcol       nShifts*(nWorkers+1)
#define totShiftscol(w)   nShifts*(nWorkers+1)+1+w
#define avgShiftscol      (nShifts+1)*(nWorkers+1)
#define diffShiftscol(w) (nShifts+1)*(nWorkers+1)+1+w
#define MAXSTR           128

int
main(int  argc,
      char *argv[])
{
  GRBenv  *env = NULL;
  GRBmodel *model = NULL;
  int      error = 0, status;
  int      s, w, col;
  int      *cbeg = NULL;
  int      *cind = NULL;
  int      idx;
  double   *cval = NULL;
  char     *sense = NULL;
  char     vname[MAXSTR], cname[MAXSTR];
  double   val;
```

```

/* Sample data */
const int nShifts = 14;
const int nWorkers = 7;

/* Sets of days and workers */
char* Shifts[] =
    { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
      "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
      "Sun14" };
char* Workers[] =
    { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

/* Number of workers required for each shift */
double shiftRequirements[] =
    { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

/* Worker availability: 0 if the worker is unavailable for a shift */
double availability[][14] =
    { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
      { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
      { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
      { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
      { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

/* Create environment */
error = GRBloadenv(&env, "workforce4.log");
if (error) goto QUIT;

/* Create initial model */
error = GRBnewmodel(env, &model, "workforce4",
                   (nShifts + 1) * (nWorkers + 1),
                   NULL, NULL, NULL, NULL, NULL);
if (error) goto QUIT;

/* Initialize assignment decision variables:
   x[w][s] == 1 if worker w is assigned to shift s.
   This is no longer a pure assignment model, so we must
   use binary variables. */
for (w = 0; w < nWorkers; ++w)
{
    for (s = 0; s < nShifts; ++s)
    {
        col = xcol(w, s);
    }
}

```

```

    sprintf(vname, "%s.%s", Workers[w], Shifts[s]);
    error = GRBsetcharattrelement(model, "VType", col, GRB_BINARY);
    if (error) goto QUIT;
    error = GRBsetdblattrelement(model, "UB", col, availability[w][s]);
    if (error) goto QUIT;
    error = GRBsetstrattrelement(model, "VarName", col, vname);
    if (error) goto QUIT;
}
}

/* Initialize slack decision variables */
for (s = 0; s < nShifts; ++s)
{
    sprintf(vname, "%sSlack", Shifts[s]);
    error = GRBsetstrattrelement(model, "VarName", slackcol(s), vname);
    if (error) goto QUIT;
}

/* Initialize total slack decision variable */
error = GRBsetstrattrelement(model, "VarName", totSlackcol, "totSlack");
if (error) goto QUIT;

/* Initialize variables to count the total shifts worked by each worker */
for (w = 0; w < nWorkers; ++w)
{
    sprintf(vname, "%sTotShifts", Workers[w]);
    error = GRBsetstrattrelement(model, "VarName", totShiftscol(w), vname);
    if (error) goto QUIT;
}

/* The objective is to minimize the sum of the slacks */
error = GRBsetintattr(model, "ModelSense", 1);
if (error) goto QUIT;
error = GRBsetdblattrelement(model, "Obj", totSlackcol, 1.0);
if (error) goto QUIT;

/* Make space for constraint data */
cbeg = malloc(sizeof(int) * nShifts);
if (!cbeg) goto QUIT;
cind = malloc(sizeof(int) * nShifts * (nWorkers + 1));
if (!cind) goto QUIT;
cval = malloc(sizeof(double) * nShifts * (nWorkers + 1));
if (!cval) goto QUIT;
sense = malloc(sizeof(char) * nShifts);
if (!sense) goto QUIT;

```

```

/* Constraint: assign exactly shiftRequirements[s] workers
   to each shift s, plus the slack */
idx = 0;
for (s = 0; s < nShifts; ++s)
{
    cbeg[s] = idx;
    sense[s] = GRB_EQUAL;
    for (w = 0; w < nWorkers; ++w)
    {
        cind[idx] = xcol(w, s);
        cval[idx++] = 1.0;
    }
    cind[idx] = slackcol(s);
    cval[idx++] = 1.0;
}
error = GRBaddconstrs(model, nShifts, idx, cbeg, cind, cval, sense,
                      shiftRequirements, Shifts);
if (error) goto QUIT;

/* Constraint: set totSlack column equal to the total slack */
idx = 0;
for (s = 0; s < nShifts; ++s)
{
    cind[idx] = slackcol(s);
    cval[idx++] = 1.0;
}
cind[idx] = totSlackcol;
cval[idx++] = -1.0;
error = GRBaddconstr(model, idx, cind, cval, GRB_EQUAL,
                     0.0, "totSlack");
if (error) goto QUIT;

/* Constraint: compute the total number of shifts for each worker */
for (w = 0; w < nWorkers; ++w)
{
    idx = 0;
    for (s = 0; s < nShifts; ++s)
    {
        cind[idx] = xcol(w,s);
        cval[idx++] = 1.0;
    }
    sprintf(cname, "totShifts%s", Workers[w]);
    cind[idx] = totShiftscol(w);
    cval[idx++] = -1.0;
}

```

```

    error = GRBaddconstr(model, idx, cind, cval, GRB_EQUAL, 0.0, cname);
    if (error) goto QUIT;
}

/* Optimize */
error = solveAndPrint(model, nShifts, nWorkers, Workers, &status);
if (error) goto QUIT;
if (status != GRB_OPTIMAL) goto QUIT;

/* Constrain the slack by setting its upper and lower bounds */
error = GRBgetdblattrelement(model, "X", totSlackcol, &val);
if (error) goto QUIT;
error = GRBsetdblattrelement(model, "UB", totSlackcol, val);
if (error) goto QUIT;
error = GRBsetdblattrelement(model, "LB", totSlackcol, val);
if (error) goto QUIT;

/* Variable to count the average number of shifts worked */
error = GRBaddvar(model, 0, NULL, NULL, 0, 0, GRB_INFINITY, GRB_CONTINUOUS,
    "avgShifts");
if (error) goto QUIT;

/* Variables to count the difference from average for each worker;
   note that these variables can take negative values. */
error = GRBaddvars(model, nWorkers, 0, NULL, NULL, NULL, NULL, NULL, NULL,
    NULL, NULL);
if (error) goto QUIT;

error = GRBupdatemodel(model);
if (error) goto QUIT;

for (w = 0; w < nWorkers; ++w)
{
    sprintf(vname, "%sDiff", Workers[w]);
    error = GRBsetstrattrelement(model, "VarName", diffShiftscol(w), vname);
    if (error) goto QUIT;
    error = GRBsetdblattrelement(model, "LB", diffShiftscol(w), -GRB_INFINITY);
    if (error) goto QUIT;
}

/* Constraint: compute the average number of shifts worked */
idx = 0;
for (w = 0; w < nWorkers; ++w) {
    cind[idx] = totShiftscol(w);
    cval[idx++] = 1.0;
}

```

```

}
cind[idx] = avgShiftscol;
cval[idx++] = -nWorkers;
error = GRBaddconstr(model, idx, cind, cval, GRB_EQUAL, 0.0, "avgShifts");
if (error) goto QUIT;

// Constraint: compute the difference from the average number of shifts
for (w = 0; w < nWorkers; ++w) {
    cind[0] = totShiftscol(w);
    cval[0] = 1.0;
    cind[1] = avgShiftscol;
    cval[1] = -1.0;
    cind[2] = diffShiftscol(w);
    cval[2] = -1.0;
    sprintf(cname, "%sDiff", Workers[w]);
    error = GRBaddconstr(model, 3, cind, cval, GRB_EQUAL, 0.0, cname);
    if (error) goto QUIT;
}

/* Objective: minimize the sum of the square of the difference from the
   average number of shifts worked */
error = GRBsetdblattrelement(model, "Obj", totSlackcol, 0.0);
if (error) goto QUIT;

for (w = 0; w < nWorkers; ++w)
{
    cind[w] = diffShiftscol(w);
    cval[w] = 1.0;
}
error = GRBaddqpterms(model, nWorkers, cind, cind, cval);
if (error) goto QUIT;

/* Optimize */
error = solveAndPrint(model, nShifts, nWorkers, Workers, &status);
if (error) goto QUIT;
if (status != GRB_OPTIMAL) goto QUIT;

QUIT:

/* Error reporting */

if (error)
{
    printf("ERROR: %s\n", GRBgeterrormsg(env));
}

```

```

    exit(1);
}

/* Free data */

free(cbeg);
free(cind);
free(cval);
free(sense);

/* Free model */

GRBfreemodel(model);

/* Free environment */

GRBfreeenv(env);

return 0;
}

int solveAndPrint(GRBmodel* model,
                 int nShifts, int nWorkers, char** Workers,
                 int* status)
{
    int error, w;
    double val;

    error = GRBoptimize(model);
    if (error) return error;

    error = GRBgetintattr(model, "Status", status);
    if (error) return error;

    if ((*status == GRB_INF_OR_UNBD) || (*status == GRB_INFEASIBLE) ||
        (*status == GRB_UNBOUNDED))
    {
        printf("The model cannot be solved "
              "because it is infeasible or unbounded\n");
        return 0;
    }
    if (*status != GRB_OPTIMAL)
    {
        printf("Optimization was stopped with status %i\n", *status);
    }
}

```

```
    return 0;
}

/* Print total slack and the number of shifts worked for each worker */
error = GRBgetdblattrelement(model, "X", totSlackcol, &val);
if (error) return error;

printf("\nTotal slack required: %f\n", val);
for (w = 0; w < nWorkers; ++w)
{
    error = GRBgetdblattrelement(model, "X", totShiftscol(w), &val);
    if (error) return error;
    printf("%s worked %f shifts\n", Workers[w], val);
}
printf("\n");
return 0;
}
```

## 3.2 C++ Examples

This section includes source code for all of the Gurobi C++ examples. The same source code can be found in the `examples/c++` directory of the Gurobi distribution.

### `callback_c++.cpp`

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP or a MIP from a file, sets a callback
   to monitor the optimization progress and to output some progress
   information to the screen and to a log file. If it is a MIP and 10%
   gap is reached, then it aborts */

#include "gurobi_c++.h"
#include <cmath>
using namespace std;

class mycallback: public GRBCallback
{
public:
    GRBVar* vars;
    int numvars;
    double lastnode;
    double lasttiter;
    mycallback(GRBVar* xvars, int xnumvars) {
        vars = xvars;
        numvars = xnumvars;
        lastnode = lasttiter = -1;
    }
protected:
    void callback () {
        try {
            if (where == GRB_CB_MESSAGE) {
                // Message callback
                string msg = getStringInfo(GRB_CB_MSG_STRING);
                cout << msg;
            } else if (where == GRB_CB_PRESOLVE) {
                // Presolve callback
                int cdels = getIntInfo(GRB_CB_PRE_COLDEL);
                int rdels = getIntInfo(GRB_CB_PRE_ROWDEL);
                cout << cdels << " columns and " << rdels
                    << " rows are removed" << endl;
            } else if (where == GRB_CB_SIMPLEX) {
                // Simplex callback
                double itcnt = getDoubleInfo(GRB_CB_SPX_ITRCNT);
```

```

if (itcnt - lastiter >= 100) {
    lastiter = itcnt;
    double obj = getDoubleInfo(GRB_CB_SPX_OBJVAL);
    double pinf = getDoubleInfo(GRB_CB_SPX_PRIMINF);
    double dinf = getDoubleInfo(GRB_CB_SPX_DUALINF);
    int ispert = getIntInfo(GRB_CB_SPX_ISPERT);
    char ch;
    if (ispert == 0) ch = ' ';
    else if (ispert == 1) ch = 'S';
    else ch = 'P';
    cout << itcnt << " " << obj << ch << " " << pinf
         << " " << dinf << endl;
}
} else if (where == GRB_CB_MIP) {
    // General MIP callback
    double nodecnt = getDoubleInfo(GRB_CB_MIP_NODCNT);
    if (nodecnt - lastnode >= 100) {
        lastnode = nodecnt;
        double objbst = getDoubleInfo(GRB_CB_MIP_OBJBST);
        double objbnd = getDoubleInfo(GRB_CB_MIP_OBJBND);
        if (fabs(objbst - objbnd) < 0.1 * (1.0 + fabs(objbst)))
            abort();
        int actnodes = (int) getDoubleInfo(GRB_CB_MIP_NODLFT);
        int itcnt = (int) getDoubleInfo(GRB_CB_MIP_ITRCNT);
        int solcnt = getIntInfo(GRB_CB_MIP_SOLCNT);
        int cutcnt = getIntInfo(GRB_CB_MIP_CUTCNT);
        cout << nodecnt << " " << actnodes << " " << itcnt << " "
             << objbst << " " << objbnd << " " << solcnt << " "
             << cutcnt << endl;
    }
} else if (where == GRB_CB_MIPSOL) {
    // MIP solution callback
    double obj = getDoubleInfo(GRB_CB_MIPSOL_OBJ);
    int nodecnt = (int) getDoubleInfo(GRB_CB_MIPSOL_NODCNT);
    double* x = getSolution(vars, numvars);
    cout << "**** New solution at node " << nodecnt << ", obj "
         << obj << ", x[0] = " << x[0] << "****" << endl;
    delete[] x;
}
} catch (GRBException e) {
    cout << "Error number: " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during callback" << endl;
}
}

```

```

    }
};

int
main(int   argc,
     char *argv[])
{
    if (argc < 2) {
        cout << "Usage: callback_c++ filename" << endl;
        return 1;
    }

    GRBEnv *env = 0;
    GRBVar *vars = 0;
    try {
        env = new GRBEnv();
        GRBModel model = GRBModel(*env, argv[1]);

        model.getEnv().set(GRB_IntParam_OutputFlag, 0);

        int numvars = model.get(GRB_IntAttr_NumVars);

        vars = model.getVars();

        // Create a callback object and associate it with the model
        mycallback cb = mycallback(vars, numvars);
        model.setCallback(&cb);

        model.optimize();

        for (int j = 0; j < numvars; j++) {
            GRBVar v = vars[j];
            cout << v.get(GRB_StringAttr_VarName) << " "
                 << v.get(GRB_DoubleAttr_X) << endl;
        }
    } catch (GRBException e) {
        cout << "Error number: " << e.getErrorCode() << endl;
        cout << e.getMessage() << endl;
    } catch (...) {
        cout << "Error during optimization" << endl;
    }

    delete[] vars;
    delete env;
}

```

```
    return 0;  
}
```

## dense\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */
```

```
/* This example formulates and solves the following simple QP model:
```

```
    minimize    x + y + x^2 + x*y + y^2 + y*z + z^2
    subject to  x + 2 y + 3 z >= 4
                x +   y       >= 1
```

The example illustrates the use of dense matrices to store A and Q (and dense vectors for the other relevant data). We don't recommend that you use dense matrices, but this example may be helpful if you already have your data in this format.

```
*/
```

```
#include "gurobi_c++.h"
```

```
using namespace std;
```

```
static bool
```

```
dense_optimize(GRBEnv* env,
               int      rows,
               int      cols,
               double* c,    /* linear portion of objective function */
               double* Q,    /* quadratic portion of objective function */
               double* A,    /* constraint matrix */
               char*  sense, /* constraint senses */
               double* rhs,  /* RHS vector */
               double* lb,   /* variable lower bounds */
               double* ub,   /* variable upper bounds */
               char*  vtype, /* variable types (continuous, binary, etc.) */
               double* solution,
               double* objvalP)
```

```
{
```

```
  GRBModel model = GRBModel(*env);
```

```
  int i, j;
```

```
  bool success = false;
```

```
  /* Add variables to the model */
```

```
  GRBVar* vars = model.addVars(lb, ub, NULL, vtype, NULL, cols);
```

```
  model.update();
```

```
  /* Populate A matrix */
```

```
  for (i = 0; i < rows; i++) {
```

```

    GRBLinExpr lhs = 0;
    for (j = 0; j < cols; j++)
        if (A[i*cols+j] != 0)
            lhs += A[i*cols+j]*vars[j];
    model.addConstr(lhs, sense[i], rhs[i]);
}

GRBQuadExpr obj = 0;

for (j = 0; j < cols; j++)
    obj += c[j]*vars[j];
for (i = 0; i < cols; i++)
    for (j = 0; j < cols; j++)
        if (Q[i*cols+j] != 0)
            obj += Q[i*cols+j]*vars[i]*vars[j];

model.setObjective(obj);

model.update();
model.write("dense.lp");

model.optimize();

if (model.get(GRB_IntAttr_Status) == GRB_OPTIMAL) {
    *objvalP = model.get(GRB_DoubleAttr_ObjVal);
    for (i = 0; i < cols; i++)
        solution[i] = vars[i].get(GRB_DoubleAttr_X);
    success = true;
}

delete[] vars;

return success;
}

int
main(int argc,
     char *argv[])
{
    GRBEnv* env = 0;
    try {
        env = new GRBEnv();
        double c[] = {1, 1, 0};
        double Q[3][3] = {{1, 1, 0}, {0, 1, 1}, {0, 0, 1}};
        double A[2][3] = {{1, 2, 3}, {1, 1, 0}};
    }

```

```

char    sense[] = {'>', '>'};
double  rhs[]   = {4, 1};
double  lb[]    = {0, 0, 0};
bool    success;
double  objval, sol[3];

success = dense_optimize(env, 2, 3, c, &Q[0][0], &A[0][0], sense, rhs,
                        lb, NULL, NULL, sol, &objval);

cout << "x: " << sol[0] << " y: " << sol[1] << " z: " << sol[2] << endl;

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch(...) {
    cout << "Exception during optimization" << endl;
}

delete env;
return 0;
}

```

## diet\_++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve the classic diet model, showing how to add constraints
   to an existing model. */

#include "gurobi_c++.h"
using namespace std;

void printSolution(GRBModel& model, int nCategories, int nFoods,
                  GRBVar* buy, GRBVar* nutrition) throw(GRBException);

int
main(int argc,
     char *argv[])
{
  GRBEnv* env = 0;
  GRBVar* nutrition = 0;
  GRBVar* buy = 0;
  try
  {

    // Nutrition guidelines, based on
    // USDA Dietary Guidelines for Americans, 2005
    // http://www.health.gov/DietaryGuidelines/dga2005/
    const int nCategories = 4;
    string Categories[] =
      { "calories", "protein", "fat", "sodium" };
    double minNutrition[] = { 1800, 91, 0, 0 };
    double maxNutrition[] = { 2200, GRB_INFINITY, 65, 1779 };

    // Set of foods
    const int nFoods = 9;
    string Foods[] =
      { "hamburger", "chicken", "hot dog", "fries",
        "macaroni", "pizza", "salad", "milk", "ice cream" };
    double cost[] =
      { 2.49, 2.89, 1.50, 1.89, 2.09, 1.99, 2.49, 0.89, 1.59 };

    // Nutrition values for the foods
    double nutritionValues[][nCategories] = {
      { 410, 24, 26, 730 }, // hamburger
      { 420, 32, 10, 1190 }, // chicken
      { 560, 20, 32, 1800 }, // hot dog
      { 380, 4, 19, 270 }, // fries
    }
  }
}
```

```

        { 320, 12, 10, 930 },    // macaroni
        { 320, 15, 12, 820 },    // pizza
        { 320, 31, 12, 1230 },  // salad
        { 100, 8, 2.5, 125 },   // milk
        { 330, 8, 10, 180 }     // ice cream
    };

// Model
env = new GRBEnv();
GRBModel model = GRBModel(*env);
model.set(GRB_StringAttr_ModelName, "diet");

// Create decision variables for the nutrition information,
// which we limit via bounds
nutrition = model.addVars(minNutrition, maxNutrition, 0, 0,
                          Categories, nCategories);

// Create decision variables for the foods to buy
buy = model.addVars(0, 0, cost, 0, Foods, nFoods);

// The objective is to minimize the costs
model.set(GRB_IntAttr_ModelSense, 1);

// Update model to integrate new variables
model.update();

// Nutrition constraints
for (int i = 0; i < nCategories; ++i)
{
    GRBLinExpr ntot = 0;
    for (int j = 0; j < nFoods; ++j)
    {
        ntot += nutritionValues[j][i] * buy[j];
    }
    model.addConstr(ntot == nutrition[i], Categories[i]);
}

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

cout << "\nAdding constraint: at most 6 servings of dairy" << endl;
model.addConstr(buy[7] + buy[8] <= 6.0, "limit_dairy");

// Solve

```

```

    model.optimize();
    printSolution(model, nCategories, nFoods, buy, nutrition);

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Exception during optimization" << endl;
}

delete[] nutrition;
delete[] buy;
delete env;
return 0;
}

void printSolution(GRBModel& model, int nCategories, int nFoods,
                  GRBVar* buy, GRBVar* nutrition) throw(GRBException)
{
    if (model.get(GRB_IntAttr_Status) == GRB_OPTIMAL)
    {
        cout << "\nCost: " << model.get(GRB_DoubleAttr_ObjVal) << endl;
        cout << "\nBuy:" << endl;
        for (int j = 0; j < nFoods; ++j)
        {
            if (buy[j].get(GRB_DoubleAttr_X) > 0.0001)
            {
                cout << buy[j].get(GRB_StringAttr_VarName) << " " <<
                    buy[j].get(GRB_DoubleAttr_X) << endl;
            }
        }
        cout << "\nNutrition:" << endl;
        for (int i = 0; i < nCategories; ++i)
        {
            cout << nutrition[i].get(GRB_StringAttr_VarName) << " " <<
                nutrition[i].get(GRB_DoubleAttr_X) << endl;
        }
    }
    else
    {
        cout << "No solution" << endl;
    }
}

```

}  
}

## facility\_++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Facility location: a company currently ships its product from 5 plants
   to 4 warehouses. It is considering closing some plants to reduce
   costs. What plant(s) should the company close, in order to minimize
   transportation and fixed costs?

   Based on an example from Frontline Systems:
   http://www.solver.com/disfacility.htm
   Used with permission.
*/

#include "gurobi_c++.h"
#include <sstream>
using namespace std;

int
main(int argc,
     char *argv[])
{
  GRBEnv* env = 0;
  GRBVar* open = 0;
  GRBVar** transport = 0;
  int transportCt = 0;
  try
  {

    // Number of plants and warehouses
    const int nPlants = 5;
    const int nWarehouses = 4;

    // Warehouse demand in thousands of units
    double Demand[] = { 15, 18, 14, 20 };

    // Plant capacity in thousands of units
    double Capacity[] = { 20, 22, 17, 19, 18 };

    // Fixed costs for each plant
    double FixedCosts[] =
      { 12000, 15000, 17000, 13000, 16000 };

    // Transportation costs per thousand units
    double TransCosts[][nPlants] = {
      { 4000, 2000, 3000, 2500, 4500 },
```

```

        { 2500, 2600, 3400, 3000, 4000 },
        { 1200, 1800, 2600, 4100, 3000 },
        { 2200, 2600, 3100, 3700, 3200 }
    };

    // Model
    env = new GRBEnv();
    GRBModel model = GRBModel(*env);
    model.set(GRB_StringAttr_ModelName, "facility");

    // Plant open decision variables: open[p] == 1 if plant p is open.
    open = model.addVars(nPlants, GRB_BINARY);
    model.update();
    int p;
    for (p = 0; p < nPlants; ++p)
    {
        ostringstream vname;
        vname << "Open" << p;
        open[p].set(GRB_DoubleAttr_Obj, FixedCosts[p]);
        open[p].set(GRB_StringAttr_VarName, vname.str());
    }

    // Transportation decision variables: how much to transport from
    // a plant p to a warehouse w
    transport = new GRBVar* [nWarehouses];
    int w;
    for (w = 0; w < nWarehouses; ++w)
    {
        transport[w] = model.addVars(nPlants);
        transportCt++;
        model.update();
        for (p = 0; p < nPlants; ++p)
        {
            ostringstream vname;
            vname << "Trans" << p << "." << w;
            transport[w][p].set(GRB_DoubleAttr_Obj, TransCosts[w][p]);
            transport[w][p].set(GRB_StringAttr_VarName, vname.str());
        }
    }

    // The objective is to minimize the total fixed and variable costs
    model.set(GRB_IntAttr_ModelSense, 1);

    // Update model to integrate new variables
    model.update();

```

```

// Production constraints
// Note that the right-hand limit sets the production to zero if
// the plant is closed
for (p = 0; p < nPlants; ++p)
{
    GRBLinExpr ptot = 0;
    for (w = 0; w < nWarehouses; ++w)
    {
        ptot += transport[w][p];
    }
    ostringstream cname;
    cname << "Capacity" << p;
    model.addConstr(ptot <= Capacity[p] * open[p], cname.str());
}

// Demand constraints
for (w = 0; w < nWarehouses; ++w)
{
    GRBLinExpr dtot = 0;
    for (p = 0; p < nPlants; ++p)
    {
        dtot += transport[w][p];
    }
    ostringstream cname;
    cname << "Demand" << w;
    model.addConstr(dtot == Demand[w], cname.str());
}

// Guess at the starting point: close the plant with the highest
// fixed costs; open all others

// First, open all plants
for (p = 0; p < nPlants; ++p)
{
    open[p].set(GRB_DoubleAttr_Start, 1.0);
}

// Now close the plant with the highest fixed cost
cout << "Initial guess:" << endl;
double maxFixed = -GRB_INFINITY;
for (p = 0; p < nPlants; ++p)
{
    if (FixedCosts[p] > maxFixed)
    {

```

```

        maxFixed = FixedCosts[p];
    }
}
for (p = 0; p < nPlants; ++p)
{
    if (FixedCosts[p] == maxFixed)
    {
        open[p].set(GRB_DoubleAttr_Start, 0.0);
        cout << "Closing plant " << p << endl << endl;
        break;
    }
}

// Use barrier to solve root relaxation
model.getEnv().set(GRB_IntParam_Method, GRB_METHOD_BARRIER);

// Solve
model.optimize();

// Print solution
cout << "\nTOTAL COSTS: " << model.get(GRB_DoubleAttr_ObjVal) << endl;
cout << "SOLUTION:" << endl;
for (p = 0; p < nPlants; ++p)
{
    if (open[p].get(GRB_DoubleAttr_X) == 1.0)
    {
        cout << "Plant " << p << " open:" << endl;
        for (w = 0; w < nWarehouses; ++w)
        {
            if (transport[w][p].get(GRB_DoubleAttr_X) > 0.0001)
            {
                cout << "  Transport " <<
                    transport[w][p].get(GRB_DoubleAttr_X) <<
                    " units to warehouse " << w << endl;
            }
        }
    }
    else
    {
        cout << "Plant " << p << " closed!" << endl;
    }
}
}
catch (GRBException e)

```

```
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Exception during optimization" << endl;
}

delete[] open;
for (int i = 0; i < transportCt; ++i) {
    delete[] transport[i];
}
delete[] transport;
delete env;
return 0;
}
```

## feasopt\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, adds artificial
   variables to each constraint, and then minimizes the sum of the
   artificial variables. A solution with objective zero corresponds
   to a feasible solution to the input model.
   We can also use FeasRelax feature to do it. In this example, we
   use minrelax=1, i.e. optimizing the returned model finds a solution
   that minimizes the original objective, but only from among those
   solutions that minimize the sum of the artificial variables. */

#include "gurobi_c++.h"
using namespace std;

int
main(int argc,
     char *argv[])
{
    if (argc < 2)
    {
        cout << "Usage: feasoip_c++ filename" << endl;
        return 1;
    }

    GRBEnv* env = 0;
    GRBConstr* c = 0;
    try
    {
        env = new GRBEnv();
        GRBModel feasmodel = GRBModel(*env, argv[1]);

        // Create a copy to use FeasRelax feature later */
        GRBModel feasmodel1 = GRBModel(feasmodel);

        // clear objective
        feasmodel.setObjective(GRBLinExpr(0.0));

        // add slack variables
        c = feasmodel.getConstrs();
        for (int i = 0; i < feasmodel.get(GRB_IntAttr_NumConstrs); ++i)
        {
            char sense = c[i].get(GRB_CharAttr_Sense);
            if (sense != '>>')
            {
```

```

    double coef = -1.0;
    feamodel.addVar(0.0, GRB_INFINITY, 1.0, GRB_CONTINUOUS, 1,
                   &c[i], &coef, "ArtN_" +
                   c[i].get(GRB_StringAttr_ConstrName));
}
if (sense != '<')
{
    double coef = 1.0;
    feamodel.addVar(0.0, GRB_INFINITY, 1.0, GRB_CONTINUOUS, 1,
                   &c[i], &coef, "ArtP_" +
                   c[i].get(GRB_StringAttr_ConstrName));
}
}
feamodel.update();

// optimize modified model
feamodel.write("feasopt.lp");
feamodel.optimize();

// use FeasRelax feature */
feamodel1.feasRelax(GRB_FEASRELAX_LINEAR, true, false, true);
feamodel1.write("feasopt1.lp");
feamodel1.optimize();
}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Error during optimization" << endl;
}

delete[] c;
delete env;
return 0;
}

```

## fixanddive\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Implement a simple MIP heuristic. Relax the model,
   sort variables based on fractionality, and fix the 25% of
   the fractional variables that are closest to integer variables.
   Repeat until either the relaxation is integer feasible or
   linearly infeasible. */

#include "gurobi_c++.h"
#include <algorithm>
#include <cmath>
#include <deque>
using namespace std;

bool vcomp(GRBVar*, GRBVar*) throw(GRBException);

int
main(int argc,
     char *argv[])
{
    if (argc < 2)
    {
        cout << "Usage: fixanddive_c++ filename" << endl;
        return 1;
    }

    GRBEnv* env = 0;
    GRBVar* x = 0;
    try
    {
        // Read model
        env = new GRBEnv();
        GRBModel model = GRBModel(*env, argv[1]);

        // Collect integer variables and relax them
        // Note that we use GRBVar* to copy variables
        deque<GRBVar*> intvars;
        x = model.getVars();
        for (int j = 0; j < model.get(GRB_IntAttr_NumVars); ++j)
        {
            if (x[j].get(GRB_CharAttr_VType) != GRB_CONTINUOUS)
            {
                intvars.push_back(&x[j]);
                x[j].set(GRB_CharAttr_VType, GRB_CONTINUOUS);
            }
        }
    }
}
```

```

    }
}

model.getEnv().set(GRB_IntParam_OutputFlag, 0);
model.optimize();

// Perform multiple iterations. In each iteration, identify the first
// quartile of integer variables that are closest to an integer value
// in the relaxation, fix them to the nearest integer, and repeat.

for (int iter = 0; iter < 1000; ++iter)
{
    // create a list of fractional variables, sorted in order of
    // increasing distance from the relaxation solution to the nearest
    // integer value

    deque<GRBVar*> fractional;
    for (size_t j = 0; j < intvars.size(); ++j)
    {
        double sol = fabs(intvars[j]->get(GRB_DoubleAttr_X));
        if (fabs(sol - floor(sol + 0.5)) > 1e-5)
        {
            fractional.push_back(intvars[j]);
        }
    }

    cout << "Iteration " << iter << ", obj " <<
    model.get(GRB_DoubleAttr_ObjVal) << ", fractional " <<
    fractional.size() << endl;

    if (fractional.size() == 0)
    {
        cout << "Found feasible solution - objective " <<
        model.get(GRB_DoubleAttr_ObjVal) << endl;
        break;
    }

    // Fix the first quartile to the nearest integer value
    sort(fractional.begin(), fractional.end(), vcomp);
    int nfix = fractional.size() / 4;
    nfix = (nfix > 1) ? nfix : 1;
    for (int i = 0; i < nfix; ++i)
    {
        GRBVar* v = fractional[i];

```

```

    double fixval = floor(v->get(GRB_DoubleAttr_X) + 0.5);
    v->set(GRB_DoubleAttr_LB, fixval);
    v->set(GRB_DoubleAttr_UB, fixval);
    cout << " Fix " << v->get(GRB_StringAttr_VarName) << " to " <<
    fixval << " ( rel " << v->get(GRB_DoubleAttr_X) << " )" <<
    endl;
}

model.optimize();

// Check optimization result

if (model.get(GRB_IntAttr_Status) != GRB_OPTIMAL)
{
    cout << "Relaxation is infeasible" << endl;
    break;
}
}

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Error during optimization" << endl;
}

delete[] x;
delete env;
return 0;
}

bool vcomp(GRBVar* v1,
           GRBVar* v2) throw(GRBException)
{
    double sol1 = fabs(v1->get(GRB_DoubleAttr_X));
    double sol2 = fabs(v2->get(GRB_DoubleAttr_X));
    double frac1 = fabs(sol1 - floor(sol1 + 0.5));
    double frac2 = fabs(sol2 - floor(sol2 + 0.5));
    return (frac1 < frac2);
}

```

## lp\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model is infeasible or unbounded, the example turns off
   presolve and solves the model again. If the model is infeasible,
   the example computes an Irreducible Infeasible Subsystem (IIS),
   and writes it to a file */

#include "gurobi_c++.h"
using namespace std;

int
main(int   argc,
     char *argv[])
{
  if (argc < 2) {
    cout << "Usage: lp_c++ filename" << endl;
    return 1;
  }

  try {
    GRBEnv env = GRBEnv();
    GRBModel model = GRBModel(env, argv[1]);

    model.optimize();

    int optimstatus = model.get(GRB_IntAttr_Status);

    if (optimstatus == GRB_INF_OR_UNBD) {
      model.getEnv().set(GRB_IntParam_Presolve, 0);
      model.optimize();
      optimstatus = model.get(GRB_IntAttr_Status);
    }

    if (optimstatus == GRB_OPTIMAL) {
      double objval = model.get(GRB_DoubleAttr_ObjVal);
      cout << "Optimal objective: " << objval << endl;
    } else if (optimstatus == GRB_INFEASIBLE) {
      cout << "Model is infeasible" << endl;

      // compute and write out IIS

      model.computeIIS();
      model.write("model.ilp");
    }
  }
}
```

```
    } else if (optimstatus == GRB_UNBOUNDED) {
        cout << "Model is unbounded" << endl;
    } else {
        cout << "Optimization was stopped with status = "
            << optimstatus << endl;
    }

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during optimization" << endl;
}

return 0;
}
```

## lpmethod\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve a model with different values of the Method parameter;
   show which value gives the shortest solve time. */

#include "gurobi_c++.h"
using namespace std;

int
main(int  argc,
     char *argv[])
{

    if (argc < 2)
    {
        cout << "Usage: lpmethod_c++ filename" << endl;
        return 1;
    }

    try {
        // Read model
        GRBEnv env = GRBEnv();
        GRBModel m = GRBModel(env, argv[1]);
        GRBEnv menv = m.getEnv();

        // Solve the model with different values of Method
        int  bestMethod = -1;
        double bestTime = menv.get(GRB_DoubleParam_TimeLimit);
        for (int i = 0; i <= 2; ++i) {
            m.reset();
            menv.set(GRB_IntParam_Method, i);
            m.optimize();
            if (m.get(GRB_IntAttr_Status) == GRB_OPTIMAL) {
                bestTime = m.get(GRB_DoubleAttr_Runtime);
                bestMethod = i;
                // Reduce the TimeLimit parameter to save time
                // with other methods
                menv.set(GRB_DoubleParam_TimeLimit, bestTime);
            }
        }

        // Report which method was fastest
        if (bestMethod == -1) {
            cout << "Unable to solve this model" << endl;
        }
    }
}
```

```
    } else {
        cout << "Solved in " << bestTime
            << " seconds with Method: " << bestMethod << endl;
    }
} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch(...) {
    cout << "Exception during optimization" << endl;
}

return 0;
}
```

## lpmod\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model can be solved, then it finds the smallest positive variable,
   sets its upper bound to zero, and resolves the model two ways:
   first with an advanced start, then without an advanced start
   (i.e. 'from scratch'). */

#include "gurobi_c++.h"
using namespace std;

int
main(int argc,
     char *argv[])
{
    if (argc < 2)
    {
        cout << "Usage: lpmod_c++ filename" << endl;
        return 1;
    }

    GRBEnv* env = 0;
    GRBVar* v = 0;
    try
    {
        // Read model and determine whether it is an LP
        env = new GRBEnv();
        GRBModel model = GRBModel(*env, argv[1]);
        if (model.get(GRB_IntAttr_IsMIP) != 0)
        {
            cout << "The model is not a linear program" << endl;
            return 1;
        }

        model.optimize();

        int status = model.get(GRB_IntAttr_Status);

        if ((status == GRB_INF_OR_UNBD) || (status == GRB_INFEASIBLE) ||
            (status == GRB_UNBOUNDED))
        {
            cout << "The model cannot be solved because it is "
                 << "infeasible or unbounded" << endl;
            return 1;
        }
    }
}
```

```

}

if (status != GRB_OPTIMAL)
{
    cout << "Optimization was stopped with status " << status << endl;
    return 0;
}

// Find the smallest variable value
double minVal = GRB_INFINITY;
int minVar = 0;
v = model.getVars();
for (int j = 0; j < model.get(GRB_IntAttr_NumVars); ++j)
{
    double sol = v[j].get(GRB_DoubleAttr_X);
    if ((sol > 0.0001) && (sol < minVal) &&
        (v[j].get(GRB_DoubleAttr_LB) == 0.0))
    {
        minVal = sol;
        minVar = j;
    }
}

cout << "\n*** Setting " << v[minVar].get(GRB_StringAttr_VarName)
<< " from " << minVal << " to zero ***" << endl << endl;
v[minVar].set(GRB_DoubleAttr_UB, 0.0);

// Solve from this starting point
model.optimize();

// Save iteration & time info
double warmCount = model.get(GRB_DoubleAttr_IterCount);
double warmTime = model.get(GRB_DoubleAttr_Runtime);

// Reset the model and resolve
cout << "\n*** Resetting and solving "
<< "without an advanced start ***\n" << endl;
model.reset();
model.optimize();

// Save iteration & time info
double coldCount = model.get(GRB_DoubleAttr_IterCount);
double coldTime = model.get(GRB_DoubleAttr_Runtime);

cout << "\n*** Warm start: " << warmCount << " iterations, " <<

```

```
warmTime << " seconds" << endl;
cout << "*** Cold start: " << coldCount << " iterations, " <<
coldTime << " seconds" << endl;

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Error during optimization" << endl;
}

delete[] v;
delete env;
return 0;
}
```

## mip1\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple MIP model:

    maximize    x +  y + 2 z
    subject to  x + 2 y + 3 z <= 4
                x +  y          >= 1
    x, y, z binary
*/

#include "gurobi_c++.h"
using namespace std;

int
main(int  argc,
      char *argv[])
{
  try {
    GRBEnv env = GRBEnv();

    GRBModel model = GRBModel(env);

    // Create variables

    GRBVar x = model.addVar(0.0, 1.0, 0.0, GRB_BINARY, "x");
    GRBVar y = model.addVar(0.0, 1.0, 0.0, GRB_BINARY, "y");
    GRBVar z = model.addVar(0.0, 1.0, 0.0, GRB_BINARY, "z");

    // Integrate new variables

    model.update();

    // Set objective: maximize x + y + 2 z

    model.setObjective(x + y + 2 * z, GRB_MAXIMIZE);

    // Add constraint: x + 2 y + 3 z <= 4

    model.addConstr(x + 2 * y + 3 * z <= 4, "c0");

    // Add constraint: x + y >= 1

    model.addConstr(x + y >= 1, "c1");
```

```
// Optimize model

model.optimize();

cout << x.get(GRB_StringAttr_VarName) << " "
     << x.get(GRB_DoubleAttr_X) << endl;
cout << y.get(GRB_StringAttr_VarName) << " "
     << y.get(GRB_DoubleAttr_X) << endl;
cout << z.get(GRB_StringAttr_VarName) << " "
     << z.get(GRB_DoubleAttr_X) << endl;

cout << "Obj: " << model.get(GRB_DoubleAttr_ObjVal) << endl;

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch(...) {
    cout << "Exception during optimization" << endl;
}

return 0;
}
```

## mip2\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, solves it and
   prints the objective values from all feasible solutions
   generated while solving the MIP. Then it creates the fixed
   model and solves that model. */

#include "gurobi_c++.h"
#include <cmath>
using namespace std;

int
main(int  argc,
     char *argv[])
{
  if (argc < 2) {
    cout << "Usage: mip2_c++ filename" << endl;
    return 1;
  }

  GRBEnv *env = 0;
  GRBVar *vars = 0, *fvars = 0;
  try {
    env = new GRBEnv();
    GRBModel model = GRBModel(*env, argv[1]);

    if (model.get(GRB_IntAttr_IsMIP) == 0) {
      throw GRBException("Model is not a MIP");
    }

    model.optimize();

    int optimstatus = model.get(GRB_IntAttr_Status);

    cout << "Optimization complete" << endl;
    double objval = 0;
    if (optimstatus == GRB_OPTIMAL) {
      objval = model.get(GRB_DoubleAttr_ObjVal);
      cout << "Optimal objective: " << objval << endl;
    } else if (optimstatus == GRB_INF_OR_UNBD) {
      cout << "Model is infeasible or unbounded" << endl;
      return 0;
    } else if (optimstatus == GRB_INFEASIBLE) {
      cout << "Model is infeasible" << endl;
    }
  }
}
```

```

    return 0;
} else if (optimstatus == GRB_UNBOUNDED) {
    cout << "Model is unbounded" << endl;
    return 0;
} else {
    cout << "Optimization was stopped with status = "
        << optimstatus << endl;
    return 0;
}

/* Iterate over the solutions and compute the objectives */

int numvars = model.get(GRB_IntAttr_NumVars);
vars = model.getVars();
model.getEnv().set(GRB_IntParam_OutputFlag, 0);

cout << endl;
for ( int k = 0; k < model.get(GRB_IntAttr_SolCount); ++k ) {
    model.getEnv().set(GRB_IntParam_SolutionNumber, k);
    double objn = 0.0;

    for (int j = 0; j < numvars; j++) {
        GRBVar v = vars[j];
        objn += v.get(GRB_DoubleAttr_Obj) * v.get(GRB_DoubleAttr_Xn);
    }

    cout << "Solution " << k << " has objective: " << objn << endl;
}
cout << endl;
model.getEnv().set(GRB_IntParam_OutputFlag, 1);

/* Create a fixed model, turn off presolve and solve */

GRBModel fixed = model.fixedModel();

fixed.getEnv().set(GRB_IntParam_Presolve, 0);

fixed.optimize();

int foptimstatus = fixed.get(GRB_IntAttr_Status);

if (foptimstatus != GRB_OPTIMAL) {
    cerr << "Error: fixed model isn't optimal" << endl;
    return 0;
}

```

```

double fobjval = fixed.get(GRB_DoubleAttr_ObjVal);

if (fabs(fobjval - objval) > 1.0e-6 * (1.0 + fabs(objval))) {
    cerr << "Error: objective values are different" << endl;
    return 0;
}

/* Print values of nonzero variables */
fvars = fixed.getVars();
for (int j = 0; j < numvars; j++) {
    GRBVar v = fvars[j];
    if (v.get(GRB_DoubleAttr_X) != 0.0) {
        cout << v.get(GRB_StringAttr_VarName) << " "
            << v.get(GRB_DoubleAttr_X) << endl;
    }
}

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during optimization" << endl;
}

delete[] fvars;
delete[] vars;
delete env;
return 0;
}

```

## params\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Use parameters that are associated with a model.

   A MIP is solved for 5 seconds with different sets of parameters.
   The one with the smallest MIP gap is selected, and the optimization
   is resumed until the optimal solution is found.
*/

#include "gurobi_c++.h"
#include <cmath>
using namespace std;

double gap(GRBModel *model) throw(GRBException);

int
main(int argc,
     char *argv[])
{
  if (argc < 2)
  {
    cout << "Usage: params_c++ filename" << endl;
    return 1;
  }

  GRBEnv* env = 0;
  GRBModel *bestModel = 0, *m = 0;
  try
  {
    // Read model and verify that it is a MIP
    env = new GRBEnv();
    GRBModel base = GRBModel(*env, argv[1]);
    if (base.get(GRB_IntAttr_IsMIP) == 0)
    {
      cout << "The model is not an integer program" << endl;
      return 1;
    }

    // Set a 5 second time limit
    base.getEnv().set(GRB_DoubleParam_TimeLimit, 5);

    // Now solve the model with different values of MIPFocus,
    // using a pointer to save the best model
    double bestGap = GRB_INFINITY;
```

```

for (int i = 0; i <= 3; ++i)
{
    m = new GRBModel(base);
    m->getEnv().set(GRB_IntParam_MIPFocus, i);
    m->optimize();
    if (bestModel == 0 || bestGap > gap(m))
    {
        delete bestModel;
        bestModel = m;
        m = 0;
        bestGap = gap(bestModel);
    }
    else
    {
        delete m;
        m = 0;
    }
}

// Finally, reset the time limit and continue to solve the
// best model to optimality
bestModel->getEnv().set(GRB_DoubleParam_TimeLimit, GRB_INFINITY);
bestModel->optimize();
cout << "Solved with MIPFocus: " <<
bestModel->getEnv().get(GRB_IntParam_MIPFocus) << endl;

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Error during optimization" << endl;
}

delete bestModel;
delete m;
delete env;
return 0;
}

// Simple function to determine the MIP gap
double gap(GRBModel *model) throw(GRBException)

```

```
{
  if ((model->get(GRB_IntAttr_SolCount) == 0) ||
      (fabs(model->get(GRB_DoubleAttr_ObjVal)) < 1e-6))
  {
    return GRB_INFINITY;
  }
  return fabs(model->get(GRB_DoubleAttr_ObjBound) -
             model->get(GRB_DoubleAttr_ObjVal)) /
         fabs(model->get(GRB_DoubleAttr_ObjVal));
}
```

## sensitivity\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Simple MIP sensitivity analysis example.
   For each integer variable, fix it to its lower and upper bound
   and check the impact on the objective. */

#include "gurobi_c++.h"
using namespace std;

int
main(int argc,
     char *argv[])
{
  if (argc < 2)
  {
    cout << "Usage: sensitivity_c++ filename" << endl;
    return 1;
  }

  GRBEnv* env = 0;
  GRBVar* avars = 0;
  GRBVar* bv = 0;
  try
  {
    // Read model
    env = new GRBEnv();
    GRBModel a = GRBModel(*env, argv[1]);
    a.optimize();
    a.getEnv().set(GRB_IntParam_OutputFlag, 0);

    // Extract variables from model
    avars = a.getVars();

    for (int i = 0; i < a.get(GRB_IntAttr_NumVars); ++i)
    {
      GRBVar v = avars[i];
      if (v.get(GRB_CharAttr_VType) == GRB_BINARY)
      {

        // Create clone and fix variable
        GRBModel b = GRBModel(a);
        bv = b.getVars();
        if (v.get(GRB_DoubleAttr_X) - v.get(GRB_DoubleAttr_LB) < 0.5)
        {
```

```

        bv[i].set(GRB_DoubleAttr_LB, bv[i].get(GRB_DoubleAttr_UB));
    }
    else
    {
        bv[i].set(GRB_DoubleAttr_UB, bv[i].get(GRB_DoubleAttr_LB));
    }
    delete[] bv;
    bv = 0;

    b.optimize();

    if (b.get(GRB_IntAttr_Status) == GRB_OPTIMAL)
    {
        double objchg =
            b.get(GRB_DoubleAttr_ObjVal) - a.get(GRB_DoubleAttr_ObjVal);
        if (objchg < 0)
        {
            objchg = 0;
        }
        cout << "Objective sensitivity for variable " <<
            v.get(GRB_StringAttr_VarName) << " is " << objchg << endl;
    }
    else
    {
        cout << "Objective sensitivity for variable " <<
            v.get(GRB_StringAttr_VarName) << " is infinite" << endl;
    }
}
}

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Error during optimization" << endl;
}

delete[] avars;
delete[] bv;
delete env;

```

```
    return 0;  
}
```

## qcp\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QCP model:

    maximize    x
    subject to  x + y + z = 1
                x^2 + y^2 <= z^2 (second-order cone)
                x^2 <= yz        (rotated second-order cone)
*/

#include "gurobi_c++.h"
using namespace std;

int
main(int   argc,
     char *argv[])
{
  try {
    GRBEnv env = GRBEnv();

    GRBModel model = GRBModel(env);

    // Create variables

    GRBVar x = model.addVar(0.0, GRB_INFINITY, 0.0, GRB_CONTINUOUS, "x");
    GRBVar y = model.addVar(0.0, GRB_INFINITY, 0.0, GRB_CONTINUOUS, "y");
    GRBVar z = model.addVar(0.0, GRB_INFINITY, 0.0, GRB_CONTINUOUS, "z");

    // Integrate new variables

    model.update();

    // Set objective

    GRBLinExpr obj = x;
    model.setObjective(obj, GRB_MAXIMIZE);

    // Add linear constraint: x + y + z = 1

    model.addConstr(x + y + z == 1, "c0");

    // Add second-order cone: x^2 + y^2 <= z^2

    model.addQConstr(x*x + y*y <= z*z, "qc0");
```

```

// Add rotated cone:  $x^2 \leq yz$ 

model.addQConstr(x*x <= y*z, "qc1");

// Optimize model

model.optimize();

cout << x.get(GRB_StringAttr_VarName) << " "
     << x.get(GRB_DoubleAttr_X) << endl;
cout << y.get(GRB_StringAttr_VarName) << " "
     << y.get(GRB_DoubleAttr_X) << endl;
cout << z.get(GRB_StringAttr_VarName) << " "
     << z.get(GRB_DoubleAttr_X) << endl;

cout << "Obj: " << model.get(GRB_DoubleAttr_ObjVal) << endl;

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch(...) {
    cout << "Exception during optimization" << endl;
}

return 0;
}

```

## qp\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QP model:

    minimize    x^2 + x*y + y^2 + y*z + z^2 + 2 x
    subject to  x + 2 y + 3 z >= 4
                x + y          >= 1
```

```
It solves it once as a continuous model, and once as an integer model.
*/
```

```
#include "gurobi_c++.h"
using namespace std;

int
main(int   argc,
      char *argv[])
{
  try {
    GRBEnv env = GRBEnv();

    GRBModel model = GRBModel(env);

    // Create variables

    GRBVar x = model.addVar(0.0, 1.0, 0.0, GRB_CONTINUOUS, "x");
    GRBVar y = model.addVar(0.0, 1.0, 0.0, GRB_CONTINUOUS, "y");
    GRBVar z = model.addVar(0.0, 1.0, 0.0, GRB_CONTINUOUS, "z");

    // Integrate new variables

    model.update();

    // Set objective

    GRBQuadExpr obj = x*x + x*y + y*y + y*z + z*z + 2*x;
    model.setObjective(obj);

    // Add constraint: x + 2 y + 3 z >= 4

    model.addConstr(x + 2 * y + 3 * z >= 4, "c0");

    // Add constraint: x + y >= 1
```

```

model.addConstr(x + y >= 1, "c1");

// Optimize model

model.optimize();

cout << x.get(GRB_StringAttr_VarName) << " "
    << x.get(GRB_DoubleAttr_X) << endl;
cout << y.get(GRB_StringAttr_VarName) << " "
    << y.get(GRB_DoubleAttr_X) << endl;
cout << z.get(GRB_StringAttr_VarName) << " "
    << z.get(GRB_DoubleAttr_X) << endl;

cout << "Obj: " << model.get(GRB_DoubleAttr_ObjVal) << endl;

// Change variable types to integer

x.set(GRB_CharAttr_VType, GRB_INTEGER);
y.set(GRB_CharAttr_VType, GRB_INTEGER);
z.set(GRB_CharAttr_VType, GRB_INTEGER);

// Optimize model

model.optimize();

cout << x.get(GRB_StringAttr_VarName) << " "
    << x.get(GRB_DoubleAttr_X) << endl;
cout << y.get(GRB_StringAttr_VarName) << " "
    << y.get(GRB_DoubleAttr_X) << endl;
cout << z.get(GRB_StringAttr_VarName) << " "
    << z.get(GRB_DoubleAttr_X) << endl;

cout << "Obj: " << model.get(GRB_DoubleAttr_ObjVal) << endl;

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch(...) {
    cout << "Exception during optimization" << endl;
}

return 0;
}

```

## sos\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example creates a very simple Special Ordered Set (SOS) model.
   The model consists of 3 continuous variables, no linear constraints,
   and a pair of SOS constraints of type 1. */

#include "gurobi_c++.h"
using namespace std;

int
main(int  argc,
     char *argv[])
{
  GRBEnv *env = 0;
  GRBVar *x = 0;
  try {
    env = new GRBEnv();

    GRBModel model = GRBModel(*env);

    // Create variables

    double ub[]    = {1, 1, 2};
    double obj[]   = {-2, -1, -1};
    string names[] = {"x0", "x1", "x2"};

    x = model.addVars(NULL, ub, obj, NULL, names, 3);

    // Integrate new variables

    model.update();

    // Add first SOS1: x0=0 or x1=0

    GRBVar sosv1[] = {x[0], x[1]};
    double soswt1[] = {1, 2};

    model.addSOS(sosv1, soswt1, 2, GRB_SOS_TYPE1);

    // Add second SOS1: x0=0 or x2=0 */

    GRBVar sosv2[] = {x[0], x[2]};
    double soswt2[] = {1, 2};
```

```

model.addSOS(sosv2, soswt2, 2, GRB_SOS_TYPE1);

// Optimize model

model.optimize();

for (int i = 0; i < 3; i++)
    cout << x[i].get(GRB_StringAttr_VarName) << " "
        << x[i].get(GRB_DoubleAttr_X) << endl;

cout << "Obj: " << model.get(GRB_DoubleAttr_ObjVal) << endl;

} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch(...) {
    cout << "Exception during optimization" << endl;
}

delete[] x;
delete env;
return 0;
}

```

## sudoku\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */
/*
Sudoku example.

The Sudoku board is a 9x9 grid, which is further divided into a 3x3 grid
of 3x3 grids. Each cell in the grid must take a value from 0 to 9.
No two grid cells in the same row, column, or 3x3 subgrid may take the
same value.

In the MIP formulation, binary variables  $x[i,j,v]$  indicate whether
cell  $\langle i,j \rangle$  takes value 'v'. The constraints are as follows:
1. Each cell must take exactly one value ( $\sum_v x[i,j,v] = 1$ )
2. Each value is used exactly once per row ( $\sum_i x[i,j,v] = 1$ )
3. Each value is used exactly once per column ( $\sum_j x[i,j,v] = 1$ )
4. Each value is used exactly once per 3x3 subgrid ( $\sum_{\text{grid}} x[i,j,v] = 1$ )

Input datasets for this example can be found in examples/data/sudoku*.
*/

#include "gurobi_c++.h"
#include <sstream>
using namespace std;

#define sd 3
#define n (sd*sd)

string itos(int i) {stringstream s; s << i; return s.str(); }

int
main(int argc,
     char *argv[])
{
    try {
        GRBEnv env = GRBEnv();
        GRBModel model = GRBModel(env);

        GRBVar vars[n][n][n];
        int i, j, v;

        // Create 3-D array of model variables

        for (i = 0; i < n; i++) {
            for (j = 0; j < n; j++) {
                for (v = 0; v < n; v++) {
```

```

        string s = "G_" + itos(i) + "_" + itos(j) + "_" + itos(v);
        vars[i][j][v] = model.addVar(0.0, 1.0, 0.0, GRB_BINARY, s);
    }
}

// Integrate variables into model

model.update();

// Add constraints

// Each cell must take one value

for (i = 0; i < n; i++) {
    for (j = 0; j < n; j++) {
        GRBLinExpr expr = 0;
        for (v = 0; v < n; v++)
            expr += vars[i][j][v];
        string s = "V_" + itos(i) + "_" + itos(j);
        model.addConstr(expr, GRB_EQUAL, 1.0, s);
    }
}

// Each value appears once per row

for (i = 0; i < n; i++) {
    for (v = 0; v < n; v++) {
        GRBLinExpr expr = 0;
        for (j = 0; j < n; j++)
            expr += vars[i][j][v];
        string s = "R_" + itos(i) + "_" + itos(v);
        model.addConstr(expr == 1.0, s);
    }
}

// Each value appears once per column

for (j = 0; j < n; j++) {
    for (v = 0; v < n; v++) {
        GRBLinExpr expr = 0;
        for (i = 0; i < n; i++)
            expr += vars[i][j][v];
        string s = "C_" + itos(j) + "_" + itos(v);
        model.addConstr(expr == 1.0, s);
    }
}

```

```

    }
}

// Each value appears once per sub-grid

for (v = 0; v < n; v++) {
    for (int i0 = 0; i0 < sd; i0++) {
        for (int j0 = 0; j0 < sd; j0++) {
            GRBLinExpr expr = 0;
            for (int i1 = 0; i1 < sd; i1++) {
                for (int j1 = 0; j1 < sd; j1++) {
                    expr += vars[i0*sd+i1][j0*sd+j1][v];
                }
            }

            string s = "Sub_" + itos(v) + "_" + itos(i0) + "_" + itos(j0);
            model.addConstr(expr == 1.0, s);
        }
    }
}

// Fix variables associated with pre-specified cells

char input[10];
for (i = 0; i < n; i++) {
    cin >> input;
    for (j = 0; j < n; j++) {
        int val = (int) input[j] - 48 - 1; // 0-based

        if (val >= 0)
            vars[i][j][val].set(GRB_DoubleAttr_LB, 1.0);
    }
}

// Optimize model

model.optimize();

// Write model to file

model.write("sudoku.lp");

cout << endl;
for (i = 0; i < n; i++) {
    for (j = 0; j < n; j++) {

```

```
        for (v = 0; v < n; v++) {
            if (vars[i][j][v].get(GRB_DoubleAttr_X) > 0.5)
                cout << v+1;
        }
    }
    cout << endl;
}
cout << endl;
} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during optimization" << endl;
}

return 0;
}
```

## tsp\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve a traveling salesman problem on a randomly generated set of
points using lazy constraints. The base MIP model only includes
'degree-2' constraints, requiring each node to have exactly
two incident edges. Solutions to this model may contain subtours -
tours that don't visit every node. The lazy constraint callback
adds new constraints to cut them off. */

#include "gurobi_c++.h"
#include <cstdlib>
#include <cmath>
#include <sstream>
using namespace std;

string itos(int i) {stringstream s; s << i; return s.str(); }
double distance(double* x, double* y, int i, int j);
void findsubtour(int n, double** sol, int* tourlenP, int* tour);

// Subtour elimination callback. Whenever a feasible solution is found,
// find the smallest subtour, and add a subtour elimination constraint
// if the tour doesn't visit every node.

class subtourelim: public GRBCallback
{
public:
    GRBVar** vars;
    int n;
    subtourelim(GRBVar** xvars, int xn) {
        vars = xvars;
        n = xn;
    }
protected:
    void callback() {
        try {
            if (where == GRB_CB_MIPSOL) {
                // Found an integer feasible solution - does it visit every node?
                double **x = new double*[n];
                int *tour = new int[n];
                int i, j, len;
                for (i = 0; i < n; i++)
                    x[i] = getSolution(vars[i], n);

                findsubtour(n, x, &len, tour);
            }
        }
    }
};
```

```

    if (len < n) {
        // Add subtour elimination constraint
        GRBLinExpr expr = 0;
        for (i = 0; i < len; i++)
            for (j = 0; j < len; j++)
                expr += vars[tour[i]][tour[j]];
        addLazy(expr <= len-1);
    }

    for (i = 0; i < n; i++)
        delete[] x[i];
    delete[] x;
    delete[] tour;
}
} catch (GRBException e) {
    cout << "Error number: " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during callback" << endl;
}
}
};

```

```

// Given an integer-feasible solution 'sol', find the smallest
// sub-tour. Result is returned in 'tour', and length is
// returned in 'tourlenP'.

```

```

void
findsubtour(int      n,
            double** sol,
            int*      tourlenP,
            int*      tour)
{
    bool* seen = new bool[n];
    int bestind, bestlen;
    int i, node, len, start;

    for (i = 0; i < n; i++)
        seen[i] = false;

    start = 0;
    bestlen = n+1;
    bestind = -1;
    node = 0;

```

```

while (start < n) {
    for (node = 0; node < n; node++)
        if (!seen[node])
            break;
    if (node == n)
        break;
    for (len = 0; len < n; len++) {
        tour[start+len] = node;
        seen[node] = true;
        for (i = 0; i < n; i++) {
            if (sol[node][i] > 0.5 && !seen[i]) {
                node = i;
                break;
            }
        }
        if (i == n) {
            len++;
            if (len < bestlen) {
                bestlen = len;
                bestind = start;
            }
            start += len;
            break;
        }
    }
}

for (i = 0; i < bestlen; i++)
    tour[i] = tour[bestind+i];
*tourlenP = bestlen;

delete[] seen;
}

// Euclidean distance between points 'i' and 'j'.

double
distance(double* x,
         double* y,
         int    i,
         int    j)
{
    double dx = x[i]-x[j];
    double dy = y[i]-y[j];

```

```

    return sqrt(dx*dx+dy*dy);
}

int
main(int  argc,
     char *argv[])
{
    if (argc < 2) {
        cout << "Usage: tsp_c++ size" << endl;
        return 1;
    }

    int n = atoi(argv[1]);
    double* x = new double[n];
    double* y = new double[n];

    int i;
    for (i = 0; i < n; i++) {
        x[i] = ((double) rand())/RAND_MAX;
        y[i] = ((double) rand())/RAND_MAX;
    }

    GRBEnv *env = NULL;
    GRBVar **vars = new GRBVar*[n];

    try {
        int j;

        env = new GRBEnv();
        GRBModel model = GRBModel(*env);

        // Must set LazyConstraints parameter when using lazy constraints
        model.getEnv().set(GRB_IntParam_LazyConstraints, 1);

        // Create binary decision variables

        for (i = 0; i < n; i++)
            vars[i] = model.addVars(n);
        model.update();

        for (i = 0; i < n; i++) {
            for (j = 0; j < n; j++) {
                vars[i][j].set(GRB_CharAttr_VType, GRB_BINARY);
                vars[i][j].set(GRB_DoubleAttr_Obj, distance(x, y, i, j));
            }
        }
    }
}

```

```

    vars[i][j].set(GRB_StringAttr_VarName, "x_"+itos(i)+"_"+itos(j));
}
}

// Integrate new variables

model.update();

// Degree-2 constraints

for (i = 0; i < n; i++) {
    GRBLinExpr expr = 0;
    for (j = 0; j < n; j++)
        expr += vars[i][j];
    model.addConstr(expr == 2, "deg2_"+itos(i));
}

// Forbid edge from node back to itself

for (i = 0; i < n; i++)
    vars[i][i].set(GRB_DoubleAttr_UB, 0);

// Symmetric TSP

for (i = 0; i < n; i++)
    for (j = 0; j < i; j++)
        model.addConstr(vars[i][j] == vars[j][i]);

// Set callback function

subtourelim cb = subtourelim(vars, n);
model.setCallback(&cb);

// Optimize model

model.optimize();

// Extract solution

if (model.get(GRB_IntAttr_SolCount) > 0) {
    double **sol = new double*[n];
    for (i = 0; i < n; i++)
        sol[i] = model.get(GRB_DoubleAttr_X, vars[i], n);

    int* tour = new int[n];

```

```

    int len;

    findsubtour(n, sol, &len, tour);

    cout << "Tour: ";
    for (i = 0; i < len; i++)
        cout << tour[i] << " ";
    cout << endl;

    for (i = 0; i < n; i++)
        delete[] sol[i];
    delete[] sol;
    delete[] tour;
}

} catch (GRBException e) {
    cout << "Error number: " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during optimization" << endl;
}

for (i = 0; i < n; i++)
    delete[] vars[i];
delete[] vars;
delete[] x;
delete[] y;
delete env;
return 0;
}

```

## tune\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a model from a file and tunes it.
   It then writes the best parameter settings to a file
   and solves the model using these parameters. */

#include "gurobi_c++.h"
#include <cmath>
using namespace std;

int
main(int  argc,
     char *argv[])
{
  if (argc < 2) {
    cout << "Usage: tune_c++ filename" << endl;
    return 1;
  }

  GRBEnv *env = 0;
  try {
    env = new GRBEnv();

    // Read model from file

    GRBModel model = GRBModel(*env, argv[1]);

    GRBEnv menv = model.getEnv();

    // Set the TuneResults parameter to 1

    menv.set(GRB_IntParam_TuneResults, 1);

    // Tune the model

    model.tune();

    // Get the number of tuning results

    int resultcount = model.get(GRB_IntAttr_TuneResultCount);

    if (resultcount > 0) {

      // Load the tuned parameters into the model's environment
```

```
model.getTuneResult(0);

// Write tuned parameters to a file

model.write("tune.prm");

// Solve the model using the tuned parameters

model.optimize();
}
} catch(GRBException e) {
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
} catch (...) {
    cout << "Error during tuning" << endl;
}

delete env;
return 0;
}
```

## workforce1\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, use IIS to find a set of
conflicting constraints. Note that there may be additional conflicts
besides what is reported via IIS. */

#include "gurobi_c++.h"
#include <sstream>
using namespace std;

int
main(int argc,
     char *argv[])
{
    GRBEnv* env = 0;
    GRBConstr* c = 0;
    GRBVar** x = 0;
    int xCt = 0;
    try
    {

        // Sample data
        const int nShifts = 14;
        const int nWorkers = 7;

        // Sets of days and workers
        string Shifts[] =
            { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
              "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
              "Sun14" };
        string Workers[] =
            { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

        // Number of workers required for each shift
        double shiftRequirements[] =
            { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

        // Amount each worker is paid to work one shift
        double pay[] = { 10, 12, 10, 8, 8, 9, 11 };

        // Worker availability: 0 if the worker is unavailable for a shift
        double availability[][nShifts] =
            { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
```

```

    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

// Model
env = new GRBEnv();
GRBModel model = GRBModel(*env);
model.set(GRB_StringAttr_ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
x = new GRBVar*[nWorkers];
for (int w = 0; w < nWorkers; ++w)
{
    x[w] = model.addVars(nShifts);
    xCt++;
    model.update();
    for (int s = 0; s < nShifts; ++s)
    {
        ostringstream vname;
        vname << Workers[w] << "." << Shifts[s];
        x[w][s].set(GRB_DoubleAttr_UB, availability[w][s]);
        x[w][s].set(GRB_DoubleAttr_Obj, pay[w]);
        x[w][s].set(GRB_StringAttr_VarName, vname.str());
    }
}

// The objective is to minimize the total pay costs
model.set(GRB_IntAttr_ModelSense, 1);

// Update model to integrate new variables
model.update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s)
{
    GRBLinExpr lhs = 0;
    for (int w = 0; w < nWorkers; ++w)
    {
        lhs += x[w][s];
    }
}

```

```

    }
    model.addConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Optimize
model.optimize();
int status = model.get(GRB_IntAttr_Status);
if (status == GRB_UNBOUNDED)
{
    cout << "The model cannot be solved "
        << "because it is unbounded" << endl;
    return 1;
}
if (status == GRB_OPTIMAL)
{
    cout << "The optimal objective is " <<
        model.get(GRB_DoubleAttr_ObjVal) << endl;
    return 0;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    cout << "Optimization was stopped with status " << status << endl;
    return 1;
}

// do IIS
cout << "The model is infeasible; computing IIS" << endl;
model.computeIIS();
cout << "\nThe following constraint(s) "
    << "cannot be satisfied:" << endl;
c = model.getConstrs();
for (int i = 0; i < model.get(GRB_IntAttr_NumConstrs); ++i)
{
    if (c[i].get(GRB_IntAttr_IISConstr) == 1)
    {
        cout << c[i].get(GRB_StringAttr_ConstrName) << endl;
    }
}

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}

```

```
catch (...)  
{  
    cout << "Exception during optimization" << endl;  
}  
  
delete[] c;  
for (int i = 0; i < xCt; ++i) {  
    delete[] x[i];  
}  
delete[] x;  
delete env;  
return 0;  
}
```

## workforce2\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
   particular day. If the problem cannot be solved, use IIS iteratively to
   find all conflicting constraints. */

#include "gurobi_c++.h"
#include <sstream>
#include <deque>
using namespace std;

int
main(int argc,
     char *argv[])
{
  GRBEnv* env = 0;
  GRBConstr* c = 0;
  GRBVar** x = 0;
  int xCt = 0;
  try
  {

    // Sample data
    const int nShifts = 14;
    const int nWorkers = 7;

    // Sets of days and workers
    string Shifts[] =
      { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
        "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
        "Sun14" };
    string Workers[] =
      { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

    // Number of workers required for each shift
    double shiftRequirements[] =
      { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

    // Amount each worker is paid to work one shift
    double pay[] = { 10, 12, 10, 8, 8, 9, 11 };

    // Worker availability: 0 if the worker is unavailable for a shift
    double availability[][nShifts] =
      { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
```

```

        { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
        { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
        { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
        { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
        { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
        { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

// Model
env = new GRBEnv();
GRBModel model = GRBModel(*env);
model.set(GRB_StringAttr_ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
x = new GRBVar*[nWorkers];
for (int w = 0; w < nWorkers; ++w)
{
    x[w] = model.addVars(nShifts);
    xCt++;
    model.update();
    for (int s = 0; s < nShifts; ++s)
    {
        ostringstream vname;
        vname << Workers[w] << "." << Shifts[s];
        x[w][s].set(GRB_DoubleAttr_UB, availability[w][s]);
        x[w][s].set(GRB_DoubleAttr_Obj, pay[w]);
        x[w][s].set(GRB_StringAttr_VarName, vname.str());
    }
}

// The objective is to minimize the total pay costs
model.set(GRB_IntAttr_ModelSense, 1);

// Update model to integrate new variables
model.update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s)
{
    GRBLinExpr lhs = 0;
    for (int w = 0; w < nWorkers; ++w)
    {
        lhs += x[w][s];
    }
}

```

```

    }
    model.addConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Optimize
model.optimize();
int status = model.get(GRB_IntAttr_Status);
if (status == GRB_UNBOUNDED)
{
    cout << "The model cannot be solved "
        << "because it is unbounded" << endl;
    return 1;
}
if (status == GRB_OPTIMAL)
{
    cout << "The optimal objective is " <<
        model.get(GRB_DoubleAttr_ObjVal) << endl;
    return 0;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    cout << "Optimization was stopped with status " << status << endl;
    return 1;
}

// do IIS
cout << "The model is infeasible; computing IIS" << endl;
deque<string> removed;

// Loop until we reduce to a model that can be solved
while (1)
{
    model.computeIIS();
    cout << "\nThe following constraint cannot be satisfied:" << endl;
    c = model.getConstrs();
    for (int i = 0; i < model.get(GRB_IntAttr_NumConstrs); ++i)
    {
        if (c[i].get(GRB_IntAttr_IISConstr) == 1)
        {
            cout << c[i].get(GRB_StringAttr_ConstrName) << endl;
            // Remove a single constraint from the model
            removed.push_back(c[i].get(GRB_StringAttr_ConstrName));
            model.remove(c[i]);
            break;
        }
    }
}

```

```

    }
    delete[] c;
    c = 0;

    cout << endl;
    model.optimize();
    status = model.get(GRB_IntAttr_Status);

    if (status == GRB_UNBOUNDED)
    {
        cout << "The model cannot be solved because it is unbounded" << endl;
        return 0;
    }
    if (status == GRB_OPTIMAL)
    {
        break;
    }
    if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
    {
        cout << "Optimization was stopped with status " << status << endl;
        return 1;
    }
}
cout << "\nThe following constraints were removed "
<< "to get a feasible LP:" << endl;

for (deque<string>::iterator r = removed.begin();
     r != removed.end();
     ++r)
{
    cout << *r << " ";
}
cout << endl;

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Exception during optimization" << endl;
}
}

```

```
delete[] c;
for (int i = 0; i < xCt; ++i) {
    delete[] x[i];
}
delete[] x;
delete env;
return 0;
}
```

## workforce3\_c++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, add slack variables
to determine which constraints cannot be satisfied, and how much
they need to be relaxed. */

#include "gurobi_c++.h"
#include <sstream>
#include <deque>
using namespace std;

int
main(int argc,
     char *argv[])
{
    GRBEnv* env = 0;
    GRBConstr* c = 0;
    GRBVar** x = 0;
    int xCt = 0;
    try
    {

        // Sample data
        const int nShifts = 14;
        const int nWorkers = 7;

        // Sets of days and workers
        string Shifts[] =
            { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
              "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
              "Sun14" };
        string Workers[] =
            { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

        // Number of workers required for each shift
        double shiftRequirements[] =
            { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

        // Amount each worker is paid to work one shift
        double pay[] = { 10, 12, 10, 8, 8, 9, 11 };

        // Worker availability: 0 if the worker is unavailable for a shift
        double availability[][nShifts] =
```

```

    { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
      { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
      { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
      { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
      { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

// Model
env = new GRBEnv();
GRBModel model = GRBModel(*env);
model.set(GRB_StringAttr_ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
x = new GRBVar*[nWorkers];
for (int w = 0; w < nWorkers; ++w)
{
    x[w] = model.addVars(nShifts);
    xCt++;
    model.update();
    for (int s = 0; s < nShifts; ++s)
    {
        ostringstream vname;
        vname << Workers[w] << "." << Shifts[s];
        x[w][s].set(GRB_DoubleAttr_UB, availability[w][s]);
        x[w][s].set(GRB_DoubleAttr_Obj, pay[w]);
        x[w][s].set(GRB_StringAttr_VarName, vname.str());
    }
}

// The objective is to minimize the total pay costs
model.set(GRB_IntAttr_ModelSense, 1);

// Update model to integrate new variables
model.update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s)
{
    GRBLinExpr lhs = 0;
    for (int w = 0; w < nWorkers; ++w)
    {

```

```

    lhs += x[w][s];
}
model.addConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Optimize
model.optimize();
int status = model.get(GRB_IntAttr_Status);
if (status == GRB_UNBOUNDED)
{
    cout << "The model cannot be solved "
    << "because it is unbounded" << endl;
    return 1;
}
if (status == GRB_OPTIMAL)
{
    cout << "The optimal objective is " <<
    model.get(GRB_DoubleAttr_ObjVal) << endl;
    return 0;
}
if ((status != GRB_INF_OR_UNBD) && (status != GRB_INFEASIBLE))
{
    cout << "Optimization was stopped with status " << status << endl;
    return 1;
}

// Add slack variables to make the model feasible
cout << "The model is infeasible; adding slack variables" << endl;

// Set original objective coefficients to zero
model.setObjective(GRBLinExpr(0.0));

// Add a new slack variable to each shift constraint so that the shifts
// can be satisfied
deque<GRBVar> slacks;
c = model.getConstrs();
for (int i = 0; i < model.get(GRB_IntAttr_NumConstrs); ++i)
{
    GRBColumn col;
    col.addTerm(1.0, c[i]);
    GRBVar newvar =
        model.addVar(0, GRB_INFINITY, 1.0, GRB_CONTINUOUS, col,
                    c[i].get(GRB_StringAttr_ConstrName) + "Slack");
    slacks.push_back(newvar);
}

```

```

// Solve the model with slacks
model.optimize();
status = model.get(GRB_IntAttr_Status);

if ((status == GRB_INF_OR_UNBD) || (status == GRB_INFEASIBLE) ||
    (status == GRB_UNBOUNDED))
{
    cout << "The model with slacks cannot be solved " <<
        "because it is infeasible or unbounded" << endl;
    return 1;
}
if (status != GRB_OPTIMAL)
{
    cout << "Optimization was stopped with status " << status << endl;
    return 1;
}

cout << "\nSlack values:" << endl;
for (deque<GRBVar>::iterator sv = slacks.begin();
     sv != slacks.end();
     ++sv)
{
    if (sv->get(GRB_DoubleAttr_X) > 1e-6)
    {
        cout << sv->get(GRB_StringAttr_VarName) << " = " <<
            sv->get(GRB_DoubleAttr_X) << endl;
    }
}

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Exception during optimization" << endl;
}

delete[] c;
for (int i = 0; i < xCt; ++i) {
    delete[] x[i];
}

```

```
delete[] x;  
delete env;  
return 0;  
}
```

## workforce4\_++.cpp

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. We use Pareto optimization to solve the model:
first, we minimize the linear sum of the slacks. Then, we constrain
the sum of the slacks, and we minimize a quadratic objective that
tries to balance the workload among the workers. */

#include "gurobi_c++.h"
#include <sstream>
using namespace std;

int solveAndPrint(GRBModel& model, GRBVar& totSlack,
                 int nWorkers, string* Workers,
                 GRBVar* totShifts) throw(GRBException);

int
main(int argc,
     char *argv[])
{
    GRBEnv* env = 0;
    GRBConstr* c = 0;
    GRBVar* v = 0;
    GRBVar** x = 0;
    GRBVar* slacks = 0;
    GRBVar* totShifts = 0;
    GRBVar* diffShifts = 0;
    int xCt = 0;
    try
    {

        // Sample data
        const int nShifts = 14;
        const int nWorkers = 7;

        // Sets of days and workers
        string Shifts[] =
            { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
              "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
              "Sun14" };
        string Workers[] =
            { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

        // Number of workers required for each shift
```

```

double shiftRequirements[] =
    { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

// Worker availability: 0 if the worker is unavailable for a shift
double availability[][nShifts] =
    { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
      { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
      { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
      { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
      { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
      { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

// Model
env = new GRBEnv();
GRBModel model = GRBModel(*env);
model.set(GRB_StringAttr_ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. This is no longer a pure assignment model, so we must
// use binary variables.
x = new GRBVar*[nWorkers];
int s, w;
for (w = 0; w < nWorkers; ++w)
{
    x[w] = model.addVars(nShifts);
    xCt++;
    model.update();
    for (s = 0; s < nShifts; ++s)
    {
        ostringstream vname;
        vname << Workers[w] << "." << Shifts[s];
        x[w][s].set(GRB_DoubleAttr_UB, availability[w][s]);
        x[w][s].set(GRB_CharAttr_VType, GRB_BINARY);
        x[w][s].set(GRB_StringAttr_VarName, vname.str());
    }
}

// Slack variables for each shift constraint so that the shifts can
// be satisfied
slacks = model.addVars(nShifts);
model.update();
for (s = 0; s < nShifts; ++s)
{
    ostringstream vname;

```

```

    vname << Shifts[s] << "Slack";
    slacks[s].set(GRB_StringAttr_VarName, vname.str());
}

// Variable to represent the total slack
GRBVar totSlack = model.addVar(0, GRB_INFINITY, 0, GRB_CONTINUOUS,
                               "totSlack");

// Variables to count the total shifts worked by each worker
totShifts = model.addVars(nWorkers);
model.update();
for (w = 0; w < nWorkers; ++w)
{
    ostringstream vname;
    vname << Workers[w] << "TotShifts";
    totShifts[w].set(GRB_StringAttr_VarName, vname.str());
}

// Update model to integrate new variables
model.update();

GRBLinExpr lhs;

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (s = 0; s < nShifts; ++s)
{
    lhs = 0;
    lhs += slacks[s];
    for (w = 0; w < nWorkers; ++w)
    {
        lhs += x[w][s];
    }
    model.addConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Constraint: set totSlack equal to the total slack
lhs = 0;
for (s = 0; s < nShifts; ++s)
{
    lhs += slacks[s];
}
model.addConstr(lhs == totSlack, "totSlack");

// Constraint: compute the total number of shifts for each worker

```

```

for (w = 0; w < nWorkers; ++w) {
    lhs = 0;
    for (s = 0; s < nShifts; ++s) {
        lhs += x[w][s];
    }
    ostringstream vname;
    vname << "totShifts" << Workers[w];
    model.addConstr(lhs == totShifts[w], vname.str());
}

// Objective: minimize the total slack
GRBLinExpr obj = 0;
obj += totSlack;
model.setObjective(obj);

// Optimize
int status = solveAndPrint(model, totSlack, nWorkers, Workers, totShifts);
if (status != GRB_OPTIMAL)
{
    return 1;
}

// Constrain the slack by setting its upper and lower bounds
totSlack.set(GRB_DoubleAttr_UB, totSlack.get(GRB_DoubleAttr_X));
totSlack.set(GRB_DoubleAttr_LB, totSlack.get(GRB_DoubleAttr_X));

// Variable to count the average number of shifts worked
GRBVar avgShifts =
    model.addVar(0, GRB_INFINITY, 0, GRB_CONTINUOUS, "avgShifts");

// Variables to count the difference from average for each worker;
// note that these variables can take negative values.
diffShifts = model.addVars(nWorkers);
model.update();
for (w = 0; w < nWorkers; ++w) {
    ostringstream vname;
    vname << Workers[w] << "Diff";
    diffShifts[w].set(GRB_StringAttr_VarName, vname.str());
    diffShifts[w].set(GRB_DoubleAttr_LB, -GRB_INFINITY);
}

// Update model to integrate new variables
model.update();

// Constraint: compute the average number of shifts worked

```

```

lhs = 0;
for (w = 0; w < nWorkers; ++w) {
    lhs += totShifts[w];
}
model.addConstr(lhs == nWorkers * avgShifts, "avgShifts");

// Constraint: compute the difference from the average number of shifts
for (w = 0; w < nWorkers; ++w) {
    lhs = 0;
    lhs += totShifts[w];
    lhs -= avgShifts;
    ostringstream vname;
    vname << Workers[w] << "Diff";
    model.addConstr(lhs == diffShifts[w], vname.str());
}

// Objective: minimize the sum of the square of the difference from the
// average number of shifts worked
GRBQuadExpr qobj;
for (w = 0; w < nWorkers; ++w) {
    qobj += diffShifts[w] * diffShifts[w];
}
model.setObjective(qobj);

// Optimize
status = solveAndPrint(model, totSlack, nWorkers, Workers, totShifts);
if (status != GRB_OPTIMAL)
{
    return 1;
}

}
catch (GRBException e)
{
    cout << "Error code = " << e.getErrorCode() << endl;
    cout << e.getMessage() << endl;
}
catch (...)
{
    cout << "Exception during optimization" << endl;
}

delete[] c;
delete[] v;
for (int i = 0; i < xCt; ++i) {

```

```

    delete[] x[i];
}
delete[] x;
delete[] slacks;
delete[] totShifts;
delete[] diffShifts;
delete env;
return 0;
}

int solveAndPrint(GRBModel& model, GRBVar& totSlack,
                 int nWorkers, string* Workers,
                 GRBVar* totShifts) throw(GRBException)
{
    model.optimize();
    int status = model.get(GRB_IntAttr_Status);

    if ((status == GRB_INF_OR_UNBD) || (status == GRB_INFEASIBLE) ||
        (status == GRB_UNBOUNDED))
    {
        cout << "The model cannot be solved " <<
            "because it is infeasible or unbounded" << endl;
        return status;
    }
    if (status != GRB_OPTIMAL)
    {
        cout << "Optimization was stopped with status " << status << endl;
        return status;
    }

    // Print total slack and the number of shifts worked for each worker
    cout << endl << "Total slack required: " <<
        totSlack.get(GRB_DoubleAttr_X) << endl;
    for (int w = 0; w < nWorkers; ++w) {
        cout << Workers[w] << " worked " <<
            totShifts[w].get(GRB_DoubleAttr_X) << " shifts" << endl;
    }
    cout << endl;
    return status;
}

```

### 3.3 Java Examples

This section includes source code for all of the Gurobi Java examples. The same source code can be found in the `examples/java` directory of the Gurobi distribution.

#### Callback.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP or a MIP from a file, sets a callback
   to monitor the optimization progress and to output some progress
   information to the screen and to a log file. If it is a MIP and 10%
   gap is reached, then it aborts */

import gurobi.*;

public class Callback extends GRBCallback {
    private GRBVar[] vars;
    private double lastnode;
    private double lastiter;

    public Callback(GRBVar[] xvars) {
        vars = xvars;
        lastnode = lastiter = -1;
    }

    protected void callback() {
        try {
            if (where == GRB.CB_MESSAGE) {
                // Message callback
                String st = getStringInfo(GRB.CB_MSG_STRING);
                if (st != null) System.out.print(st);
            } else if (where == GRB.CB_PRESOLVE) {
                // Presolve callback
                int cdels = getIntInfo(GRB.CB_PRE_COLDEL);
                int rdels = getIntInfo(GRB.CB_PRE_ROWDEL);
                System.out.println(cdels+" columns and "+rdels+" rows are removed");
            } else if (where == GRB.CB_SIMPLEX) {
                // Simplex callback
                double itcnt = getDoubleInfo(GRB.CB_SPX_ITRCNT);
                if (itcnt - lastiter >= 100) {
                    lastiter = itcnt;
                    double obj = getDoubleInfo(GRB.CB_SPX_OBJVAL);
                    double pinf = getDoubleInfo(GRB.CB_SPX_PRIMINF);
                    double dinf = getDoubleInfo(GRB.CB_SPX_DUALINF);
                    int ispert = getIntInfo(GRB.CB_SPX_ISPERT);
                }
            }
        }
    }
}
```

```

        char ch;
        if (ispert == 0)      ch = ' ';
        else if (ispert == 1) ch = 'S';
        else                 ch = 'P';
        System.out.println(itcnt+" "+ obj + ch + " "+pinf + " "+ dinf);
    }
} else if (where == GRB.CB_MIP) {
    // General MIP callback
    double nodecnt = getDoubleInfo(GRB.CB_MIP_NODCNT);
    if (nodecnt - lastnode >= 100) {
        lastnode = nodecnt;
        double objbst = getDoubleInfo(GRB.CB_MIP_OBJBST);
        double objbnd = getDoubleInfo(GRB.CB_MIP_OBJBND);
        if (Math.abs(objbst - objbnd) < 0.1 * (1.0 + Math.abs(objbst)))
            abort();
        int actnodes = (int) getDoubleInfo(GRB.CB_MIP_NODLFT);
        int itcnt    = (int) getDoubleInfo(GRB.CB_MIP_ITRCNT);
        int solcnt   = getIntInfo(GRB.CB_MIP_SOLCNT);
        int cutcnt   = getIntInfo(GRB.CB_MIP_CUTCNT);
        System.out.println(nodecnt + " " + actnodes + " " + itcnt + " "
            + objbst + " " + objbnd + " " + solcnt + " " + cutcnt);
    }
} else if (where == GRB.CB_MIPSOL) {
    // MIP solution callback
    double obj      = getDoubleInfo(GRB.CB_MIPSOL_OBJ);
    int nodecnt     = (int) getDoubleInfo(GRB.CB_MIPSOL_NODCNT);
    double[] x      = getSolution(vars);
    System.out.println("**** New solution at node " + nodecnt + ", obj "
        + obj + ", x[0] = " + x[0] + "****");
}
} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
    e.printStackTrace();
}
}

public static void main(String[] args) {

    if (args.length < 1) {
        System.out.println("Usage: java Callback filename");
        System.exit(1);
    }

    try {

```

```

GRBEnv    env    = new GRBEnv();
GRBModel  model = new GRBModel(env, args[0]);

model.getEnv().set(GRB.IntParam.OutputFlag, 0);

GRBVar[]  vars   = model.getVars();

// Create a callback object and associate it with the model
model.setCallback(new Callback(vars));
model.optimize();

double[]  x       = model.get(GRB.DoubleAttr.X, vars);
String[]  vnames  = model.get(GRB.StringAttr.VarName, vars);

for (int j = 0; j < vars.length; j++) {
    if (x[j] != 0.0) System.out.println(vnames[j] + " " + x[j]);
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
    e.printStackTrace();
}
}
}

```

## Dense.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */
```

```
/* This example formulates and solves the following simple QP model:
```

```
    minimize    x + y + x^2 + x*y + y^2 + y*z + z^2
    subject to  x + 2 y + 3 z >= 4
                x +   y       >= 1
```

The example illustrates the use of dense matrices to store A and Q (and dense vectors for the other relevant data). We don't recommend that you use dense matrices, but this example may be helpful if you already have your data in this format.

```
*/
```

```
import gurobi.*;
```

```
public class Dense {
```

```
    protected static boolean
```

```
        dense_optimize(GRBEnv    env,
                       int       rows,
                       int       cols,
                       double[]   c,      // linear portion of objective function
                       double[][] Q,     // quadratic portion of objective function
                       double[][] A,     // constraint matrix
                       char[]     sense, // constraint senses
                       double[]   rhs,   // RHS vector
                       double[]   lb,    // variable lower bounds
                       double[]   ub,    // variable upper bounds
                       char[]     vtype, // variable types (continuous, binary, etc.)
                       double[]   solution) {
```

```
    boolean success = false;
```

```
    try {
```

```
        GRBModel model = new GRBModel(env);
```

```
        // Add variables to the model
```

```
        GRBVar[] vars = model.addVars(lb, ub, null, vtype, null);
        model.update();
```

```
        // Populate A matrix
```

```

for (int i = 0; i < rows; i++) {
    GRBLinExpr expr = new GRBLinExpr();
    for (int j = 0; j < cols; j++)
        if (A[i][j] != 0)
            expr.addTerm(A[i][j], vars[j]);
    model.addConstr(expr, sense[i], rhs[i], "");
}

// Populate objective

GRBQuadExpr obj = new GRBQuadExpr();
if (Q != null) {
    for (int i = 0; i < cols; i++)
        for (int j = 0; j < cols; j++)
            if (Q[i][j] != 0)
                obj.addTerm(Q[i][j], vars[i], vars[j]);
    for (int j = 0; j < cols; j++)
        if (c[j] != 0)
            obj.addTerm(c[j], vars[j]);
    model.setObjective(obj);
}

// Solve model

model.optimize();

// Extract solution

if (model.get(GRB.IntAttr.Status) == GRB.OPTIMAL) {
    success = true;

    for (int j = 0; j < cols; j++)
        solution[j] = vars[j].get(GRB.DoubleAttr.X);
}

model.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
    e.printStackTrace();
}

return success;
}

```

```

public static void main(String[] args) {
    try {
        GRBEnv env = new GRBEnv();

        double c[] = new double[] {1, 1, 0};
        double Q[][] = new double[][] {{1, 1, 0}, {0, 1, 1}, {0, 0, 1}};
        double A[][] = new double[][] {{1, 2, 3}, {1, 1, 0}};
        char sense[] = new char[] {'>', '>'};
        double rhs[] = new double[] {4, 1};
        double lb[] = new double[] {0, 0, 0};
        boolean success;
        double sol[] = new double[3];

        success = dense_optimize(env, 2, 3, c, Q, A, sense, rhs,
                                lb, null, null, sol);

        if (success) {
            System.out.println("x: " + sol[0] + ", y: " + sol[1] + ", z: " + sol[2]);
        }

        // Dispose of environment
        env.dispose();

    } catch (GRBException e) {
        System.out.println("Error code: " + e.getErrorCode() + ". " +
                           e.getMessage());
        e.printStackTrace();
    }
}

```

## Diet.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve the classic diet model, showing how to add constraints
   to an existing model. */

import gurobi.*;

public class Diet {

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

            // Nutrition guidelines, based on
            // USDA Dietary Guidelines for Americans, 2005
            // http://www.health.gov/DietaryGuidelines/dga2005/
            String Categories[] =
                new String[] { "calories", "protein", "fat", "sodium" };
            int nCategories = Categories.length;
            double minNutrition[] = new double[] { 1800, 91, 0, 0 };
            double maxNutrition[] = new double[] { 2200, GRB.INFINITY, 65, 1779 };

            // Set of foods
            String Foods[] =
                new String[] { "hamburger", "chicken", "hot dog", "fries",
                    "macaroni", "pizza", "salad", "milk", "ice cream" };
            int nFoods = Foods.length;
            double cost[] =
                new double[] { 2.49, 2.89, 1.50, 1.89, 2.09, 1.99, 2.49, 0.89,
                    1.59 };

            // Nutrition values for the foods
            double nutritionValues[][] = new double[][] {
                { 410, 24, 26, 730 }, // hamburger
                { 420, 32, 10, 1190 }, // chicken
                { 560, 20, 32, 1800 }, // hot dog
                { 380, 4, 19, 270 }, // fries
                { 320, 12, 10, 930 }, // macaroni
                { 320, 15, 12, 820 }, // pizza
                { 320, 31, 12, 1230 }, // salad
                { 100, 8, 2.5, 125 }, // milk
                { 330, 8, 10, 180 } // ice cream
            };

            // 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[nCategories];
for (int i = 0; i < nCategories; ++i) {
    nutrition[i] =
        model.addVar(minNutrition[i], maxNutrition[i], 0, GRB.CONTINUOUS,
                    Categories[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, GRB.INFINITY, cost[j], GRB.CONTINUOUS, Foods[j]);
}

// The objective is to minimize the costs
model.set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.update();

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

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

System.out.println("\nAdding constraint: at most 6 servings of dairy");
GRBLinExpr lhs = new GRBLinExpr();
lhs.addTerm(1.0, buy[7]);
lhs.addTerm(1.0, buy[8]);
model.addConstr(lhs, GRB.LESS_EQUAL, 6.0, "limit_dairy");

```

```

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

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}

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");
    }
}
}
}

```

## Facility.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Facility location: a company currently ships its product from 5 plants
   to 4 warehouses. It is considering closing some plants to reduce
   costs. What plant(s) should the company close, in order to minimize
   transportation and fixed costs?

   Based on an example from Frontline Systems:
   http://www.solver.com/disfacility.htm
   Used with permission.
*/

import gurobi.*;

public class Facility {

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

            // Warehouse demand in thousands of units
            double Demand[] = new double[] { 15, 18, 14, 20 };

            // Plant capacity in thousands of units
            double Capacity[] = new double[] { 20, 22, 17, 19, 18 };

            // Fixed costs for each plant
            double FixedCosts[] =
                new double[] { 12000, 15000, 17000, 13000, 16000 };

            // Transportation costs per thousand units
            double TransCosts[][] =
                new double[][] { { 4000, 2000, 3000, 2500, 4500 },
                                { 2500, 2600, 3400, 3000, 4000 },
                                { 1200, 1800, 2600, 4100, 3000 },
                                { 2200, 2600, 3100, 3700, 3200 } };

            // Number of plants and warehouses
            int nPlants = Capacity.length;
            int nWarehouses = Demand.length;

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

```

// Plant open decision variables: open[p] == 1 if plant p is open.
GRBVar[] open = new GRBVar[nPlants];
for (int p = 0; p < nPlants; ++p) {
    open[p] = model.addVar(0, 1, FixedCosts[p], GRB.BINARY, "Open" + p);
}

// Transportation decision variables: how much to transport from
// a plant p to a warehouse w
GRBVar[][] transport = new GRBVar[nWarehouses][nPlants];
for (int w = 0; w < nWarehouses; ++w) {
    for (int p = 0; p < nPlants; ++p) {
        transport[w][p] =
            model.addVar(0, GRB.INFINITY, TransCosts[w][p], GRB.CONTINUOUS,
                "Trans" + p + "." + w);
    }
}

// The objective is to minimize the total fixed and variable costs
model.set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.update();

// Production constraints
// Note that the right-hand limit sets the production to zero if
// the plant is closed
for (int p = 0; p < nPlants; ++p) {
    GRBLinExpr ptot = new GRBLinExpr();
    for (int w = 0; w < nWarehouses; ++w) {
        ptot.addTerm(1.0, transport[w][p]);
    }
    GRBLinExpr limit = new GRBLinExpr();
    limit.addTerm(Capacity[p], open[p]);
    model.addConstr(ptot, GRB.LESS_EQUAL, limit, "Capacity" + p);
}

// Demand constraints
for (int w = 0; w < nWarehouses; ++w) {
    GRBLinExpr dtot = new GRBLinExpr();
    for (int p = 0; p < nPlants; ++p) {
        dtot.addTerm(1.0, transport[w][p]);
    }
    model.addConstr(dtot, GRB.EQUAL, Demand[w], "Demand" + w);
}

```

```

// Guess at the starting point: close the plant with the highest
// fixed costs; open all others

// First, open all plants
for (int p = 0; p < nPlants; ++p) {
    open[p].set(GRB.DoubleAttr.Start, 1.0);
}

// Now close the plant with the highest fixed cost
System.out.println("Initial guess:");
double maxFixed = -GRB.INFINITY;
for (int p = 0; p < nPlants; ++p) {
    if (FixedCosts[p] > maxFixed) {
        maxFixed = FixedCosts[p];
    }
}
for (int p = 0; p < nPlants; ++p) {
    if (FixedCosts[p] == maxFixed) {
        open[p].set(GRB.DoubleAttr.Start, 0.0);
        System.out.println("Closing plant " + p + "\n");
        break;
    }
}

// Use barrier to solve root relaxation
model.getEnv().set(GRB.IntParam.Method, GRB.METHOD_BARRIER);

// Solve
model.optimize();

// Print solution
System.out.println("\nTOTAL COSTS: " + model.get(GRB.DoubleAttr.ObjVal));
System.out.println("SOLUTION:");
for (int p = 0; p < nPlants; ++p) {
    if (open[p].get(GRB.DoubleAttr.X) == 1.0) {
        System.out.println("Plant " + p + " open:");
        for (int w = 0; w < nWarehouses; ++w) {
            if (transport[w][p].get(GRB.DoubleAttr.X) > 0.0001) {
                System.out.println("  Transport " +
                    transport[w][p].get(GRB.DoubleAttr.X) +
                    " units to warehouse " + w);
            }
        }
    } else {

```

```
        System.out.println("Plant " + p + " closed!");
    }
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
```

## Feasopt.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, adds artificial
   variables to each constraint, and then minimizes the sum of the
   artificial variables. A solution with objective zero corresponds
   to a feasible solution to the input model.
   We can also use FeasRelax feature to do it. In this example, we
   use minrelax=1, i.e. optimizing the returned model finds a solution
   that minimizes the original objective, but only from among those
   solutions that minimize the sum of the artificial variables. */

import gurobi.*;

public class Feasopt {
    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Feasopt filename");
            System.exit(1);
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel feamodel = new GRBModel(env, args[0]);

            // Create a copy to use FeasRelax feature later */
            GRBModel feamodel1 = new GRBModel(feamodel);

            // Clear objective
            feamodel.setObjective(new GRBLinExpr());

            // Add slack variables
            GRBConstr[] c = feamodel.getConstrs();
            for (int i = 0; i < c.length; ++i) {
                char sense = c[i].get(GRB.CharAttr.Sense);
                if (sense != '>>') {
                    GRBConstr[] constrs = new GRBConstr[] { c[i] };
                    double[] coeffs = new double[] { -1 };
                    feamodel.addVar(0.0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, constrs,
                                   coeffs, "ArtN_" +
                                   c[i].get(GRB.StringAttr.ConstrName));
                }
                if (sense != '<<') {
                    GRBConstr[] constrs = new GRBConstr[] { c[i] };

```

```

        double[] coeffs = new double[] { 1 };
        feasmodel.addVar(0.0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, constrs,
                        coeffs, "ArtP_" +
                        c[i].get(GRB.StringAttr.ConstrName));
    }
}
feasmodel.update();

// Optimize modified model
feasmodel.write("feasopt.lp");
feasmodel.optimize();

// use FeasRelax feature */
feasmodel1.feasRelax(GRB.FEASRELAX_LINEAR, true, false, true);
feasmodel1.write("feasopt1.lp");
feasmodel1.optimize();

// Dispose of model and environment
feasmodel1.dispose();
feasmodel.dispose();
env.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
}

```

## Fixanddive.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Implement a simple MIP heuristic. Relax the model,
sort variables based on fractionality, and fix the 25% of
the fractional variables that are closest to integer variables.
Repeat until either the relaxation is integer feasible or
linearly infeasible. */

import gurobi.*;
import java.util.*;

public class Fixanddive {
    public static void main(String[] args) {

        // Comparison class used to sort variable list based on relaxation
        // fractionality

        class FractionalCompare implements Comparator<GRBVar> {
            public int compare(GRBVar v1, GRBVar v2) {
                try {
                    double sol1 = Math.abs(v1.get(GRB.DoubleAttr.X));
                    double sol2 = Math.abs(v2.get(GRB.DoubleAttr.X));
                    double frac1 = Math.abs(sol1 - Math.floor(sol1 + 0.5));
                    double frac2 = Math.abs(sol2 - Math.floor(sol2 + 0.5));
                    if (frac1 < frac2) {
                        return -1;
                    } else if (frac1 == frac2) {
                        return 0;
                    } else {
                        return 1;
                    }
                } catch (GRBException e) {
                    System.out.println("Error code: " + e.getErrorCode() + ". " +
                        e.getMessage());
                }
                return 0;
            }
        }

        if (args.length < 1) {
            System.out.println("Usage: java Fixanddive filename");
            System.exit(1);
        }
    }
}
```

```

try {
    // Read model
    GRBEnv env = new GRBEnv();
    GRBModel model = new GRBModel(env, args[0]);

    // Collect integer variables and relax them
    ArrayList<GRBVar> intvars = new ArrayList<GRBVar>();
    for (GRBVar v : model.getVars()) {
        if (v.get(GRB.CharAttr.VType) != GRB.CONTINUOUS) {
            intvars.add(v);
            v.set(GRB.CharAttr.VType, GRB.CONTINUOUS);
        }
    }

    model.getEnv().set(GRB.IntParam.OutputFlag, 0);
    model.optimize();

    // Perform multiple iterations. In each iteration, identify the first
    // quartile of integer variables that are closest to an integer value
    // in the relaxation, fix them to the nearest integer, and repeat.

    for (int iter = 0; iter < 1000; ++iter) {

        // create a list of fractional variables, sorted in order of
        // increasing distance from the relaxation solution to the nearest
        // integer value

        ArrayList<GRBVar> fractional = new ArrayList<GRBVar>();
        for (GRBVar v : intvars) {
            double sol = Math.abs(v.get(GRB.DoubleAttr.X));
            if (Math.abs(sol - Math.floor(sol + 0.5)) > 1e-5) {
                fractional.add(v);
            }
        }

        System.out.println("Iteration " + iter + ", obj " +
            model.get(GRB.DoubleAttr.ObjVal) + ", fractional " +
            fractional.size());

        if (fractional.size() == 0) {
            System.out.println("Found feasible solution - objective " +
                model.get(GRB.DoubleAttr.ObjVal));
            break;
        }
    }
}

```

```

// Fix the first quartile to the nearest integer value

Collections.sort(fractional, new FractionalCompare());
int nfix = Math.max(fractional.size() / 4, 1);
for (int i = 0; i < nfix; ++i) {
    GRBVar v = fractional.get(i);
    double fixval = Math.floor(v.get(GRB.DoubleAttr.X) + 0.5);
    v.set(GRB.DoubleAttr.LB, fixval);
    v.set(GRB.DoubleAttr.UB, fixval);
    System.out.println("  Fix " + v.get(GRB.StringAttr.VarName) +
        " to " + fixval + " ( rel " + v.get(GRB.DoubleAttr.X) + " )");
}

model.optimize();

// Check optimization result

if (model.get(GRB.IntAttr.Status) != GRB.Status.OPTIMAL) {
    System.out.println("Relaxation is infeasible");
    break;
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}

```

## Lp.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model is infeasible or unbounded, the example turns off
   presolve and solves the model again. If the model is infeasible,
   the example computes an Irreducible Infeasible Subsystem (IIS),
   and writes it to a file */

import gurobi.*;

public class Lp {
    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Lp filename");
            System.exit(1);
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);

            model.optimize();

            int optimstatus = model.get(GRB.IntAttr.Status);

            if (optimstatus == GRB.Status.INF_OR_UNBD) {
                model.getEnv().set(GRB.IntParam.Presolve, 0);
                model.optimize();
                optimstatus = model.get(GRB.IntAttr.Status);
            }

            if (optimstatus == GRB.Status.OPTIMAL) {
                double objval = model.get(GRB.DoubleAttr.ObjVal);
                System.out.println("Optimal objective: " + objval);
            } else if (optimstatus == GRB.Status.INFEASIBLE) {
                System.out.println("Model is infeasible");

                // Compute and write out IIS
                model.computeIIS();
                model.write("model.ilp");
            } else if (optimstatus == GRB.Status.UNBOUNDED) {
                System.out.println("Model is unbounded");
            } else {
```

```
        System.out.println("Optimization was stopped with status = "
                           + optimstatus);
    }

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
                      e.getMessage());
}
}
```

## Lpmethod.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve a model with different values of the Method parameter;
   show which value gives the shortest solve time. */

import gurobi.*;

public class Lpmethod {

    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Lpmethod filename");
            System.exit(1);
        }

        try {
            // Read model
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);
            GRBEnv menv = model.getEnv();

            // Solve the model with different values of Method
            int bestMethod = -1;
            double bestTime = menv.get(GRB.DoubleParam.TimeLimit);
            for (int i = 0; i <= 2; ++i) {
                model.reset();
                menv.set(GRB.IntParam.Method, i);
                model.optimize();
                if (model.get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL) {
                    bestTime = model.get(GRB.DoubleAttr.Runtime);
                    bestMethod = i;
                    // Reduce the TimeLimit parameter to save time
                    // with other methods
                    menv.set(GRB.DoubleParam.TimeLimit, bestTime);
                }
            }

            // Report which method was fastest
            if (bestMethod == -1) {
                System.out.println("Unable to solve this model");
            } else {
                System.out.println("Solved in " + bestTime
                    + " seconds with Method: " + bestMethod);
            }
        }
    }
}
```

```
    }

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". "
        + e.getMessage());
}
}
}
```

## Lpmod.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model can be solved, then it finds the smallest positive variable,
   sets its upper bound to zero, and resolves the model two ways:
   first with an advanced start, then without an advanced start
   (i.e. 'from scratch'). */

import gurobi.*;

public class Lpmod {
    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Lpmod filename");
            System.exit(1);
        }

        try {
            // Read model and determine whether it is an LP
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);
            if (model.get(GRB.IntAttr.IsMIP) != 0) {
                System.out.println("The model is not a linear program");
                System.exit(1);
            }

            model.optimize();

            int status = model.get(GRB.IntAttr.Status);

            if (status == GRB.Status.INF_OR_UNBD ||
                status == GRB.Status.INFEASIBLE ||
                status == GRB.Status.UNBOUNDED    ) {
                System.out.println("The model cannot be solved because it is "
                    + "infeasible or unbounded");
                System.exit(1);
            }

            if (status != GRB.Status.OPTIMAL) {
                System.out.println("Optimization was stopped with status " + status);
                System.exit(0);
            }
        }
    }
}
```

```

// Find the smallest variable value
double minVal = GRB.INFINITY;
GRBVar minVar = null;
for (GRBVar v : model.getVars()) {
    double sol = v.get(GRB.DoubleAttr.X);
    if ((sol > 0.0001) && (sol < minVal) &&
        (v.get(GRB.DoubleAttr.LB) == 0.0)) {
        minVal = sol;
        minVar = v;
    }
}

System.out.println("\n*** Setting " +
    minVar.get(GRB.StringAttr.VarName) + " from " + minVal +
    " to zero ***\n");
minVar.set(GRB.DoubleAttr.UB, 0.0);

// Solve from this starting point
model.optimize();

// Save iteration & time info
double warmCount = model.get(GRB.DoubleAttr.IterCount);
double warmTime = model.get(GRB.DoubleAttr.Runtime);

// Reset the model and resolve
System.out.println("\n*** Resetting and solving "
    + "without an advanced start ***\n");
model.reset();
model.optimize();

double coldCount = model.get(GRB.DoubleAttr.IterCount);
double coldTime = model.get(GRB.DoubleAttr.Runtime);

System.out.println("\n*** Warm start: " + warmCount + " iterations, " +
    warmTime + " seconds");
System.out.println("*** Cold start: " + coldCount + " iterations, " +
    coldTime + " seconds");

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}

```

}  
}  
}

## Mip1.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple MIP model:

    maximize    x +  y + 2 z
    subject to  x + 2 y + 3 z <= 4
                x +  y          >= 1
    x, y, z binary
*/

import gurobi.*;

public class Mip1 {
    public static void main(String[] args) {
        try {
            GRBEnv env = new GRBEnv("mip1.log");
            GRBModel model = new GRBModel(env);

            // Create variables

            GRBVar x = model.addVar(0.0, 1.0, 0.0, GRB.BINARY, "x");
            GRBVar y = model.addVar(0.0, 1.0, 0.0, GRB.BINARY, "y");
            GRBVar z = model.addVar(0.0, 1.0, 0.0, GRB.BINARY, "z");

            // Integrate new variables

            model.update();

            // Set objective: maximize x + y + 2 z

            GRBLinExpr expr = new GRBLinExpr();
            expr.addTerm(1.0, x); expr.addTerm(1.0, y); expr.addTerm(2.0, z);
            model.setObjective(expr, GRB.MAXIMIZE);

            // Add constraint: x + 2 y + 3 z <= 4

            expr = new GRBLinExpr();
            expr.addTerm(1.0, x); expr.addTerm(2.0, y); expr.addTerm(3.0, z);
            model.addConstr(expr, GRB.LESS_EQUAL, 4.0, "c0");

            // Add constraint: x + y >= 1

            expr = new GRBLinExpr();
            expr.addTerm(1.0, x); expr.addTerm(1.0, y);
```

```

model.addConstr(expr, GRB.GREATER_EQUAL, 1.0, "c1");

// Optimize model

model.optimize();

System.out.println(x.get(GRB.StringAttr.VarName)
    + " " +x.get(GRB.DoubleAttr.X));
System.out.println(y.get(GRB.StringAttr.VarName)
    + " " +y.get(GRB.DoubleAttr.X));
System.out.println(z.get(GRB.StringAttr.VarName)
    + " " +z.get(GRB.DoubleAttr.X));

System.out.println("Obj: " + model.get(GRB.DoubleAttr.ObjVal));

// Dispose of model and environment

model.dispose();
env.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}

```

## Mip2.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, solves it and
   prints the objective values from all feasible solutions
   generated while solving the MIP. Then it creates the fixed
   model and solves that model. */

import gurobi.*;

public class Mip2 {
    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Mip2 filename");
            System.exit(1);
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);
            if (model.get(GRB.IntAttr.IsMIP) == 0) {
                System.out.println("Model is not a MIP");
                System.exit(1);
            }

            model.optimize();

            int optimstatus = model.get(GRB.IntAttr.Status);
            double objval = 0;
            if (optimstatus == GRB.Status.OPTIMAL) {
                objval = model.get(GRB.DoubleAttr.ObjVal);
                System.out.println("Optimal objective: " + objval);
            } else if (optimstatus == GRB.Status.INF_OR_UNBD) {
                System.out.println("Model is infeasible or unbounded");
                return;
            } else if (optimstatus == GRB.Status.INFEASIBLE) {
                System.out.println("Model is infeasible");
                return;
            } else if (optimstatus == GRB.Status.UNBOUNDED) {
                System.out.println("Model is unbounded");
                return;
            } else {
                System.out.println("Optimization was stopped with status = "
                    + optimstatus);
            }
        }
    }
}
```

```

    return;
}

/* Iterate over the solutions and compute the objectives */
GRBVar[] vars = model.getVars();
model.getEnv().set(GRB.IntParam.OutputFlag, 0);

System.out.println();
for (int k = 0; k < model.get(GRB.IntAttr.SolCount); ++k) {
    model.getEnv().set(GRB.IntParam.SolutionNumber, k);
    double objn = 0.0;

    for (int j = 0; j < vars.length; j++) {
        objn += vars[j].get(GRB.DoubleAttr.Obj)
            * vars[j].get(GRB.DoubleAttr.Xn);
    }

    System.out.println("Solution " + k + " has objective: " + objn);
}
System.out.println();
model.getEnv().set(GRB.IntParam.OutputFlag, 1);

/* Create a fixed model, turn off presolve and solve */

GRBModel fixed = model.fixedModel();

fixed.getEnv().set(GRB.IntParam.Presolve, 0);

fixed.optimize();

int foptimstatus = fixed.get(GRB.IntAttr.Status);

if (foptimstatus != GRB.Status.OPTIMAL) {
    System.err.println("Error: fixed model isn't optimal");
    return;
}

double fobjval = fixed.get(GRB.DoubleAttr.ObjVal);

if (Math.abs(fobjval - objval) > 1.0e-6 * (1.0 + Math.abs(objval))) {
    System.err.println("Error: objective values are different");
    return;
}

GRBVar[] fvars = fixed.getVars();

```

```
double[] x      = fixed.get(GRB.DoubleAttr.X, fvars);
String[] vnames = fixed.get(GRB.StringAttr.VarName, fvars);

for (int j = 0; j < fvars.length; j++) {
    if (x[j] != 0.0) {
        System.out.println(vnames[j] + " " + x[j]);
    }
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". "
        + e.getMessage());
}
}
}
```

## Params.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Use parameters that are associated with a model.

A MIP is solved for 5 seconds with different sets of parameters.
The one with the smallest MIP gap is selected, and the optimization
is resumed until the optimal solution is found.
*/

import gurobi.*;

public class Params {

    // Simple function to determine the MIP gap
    private static double gap(GRBModel model) throws GRBException {
        if ((model.get(GRB.IntAttr.SolCount) == 0) ||
            (Math.abs(model.get(GRB.DoubleAttr.ObjVal)) < 1e-6)) {
            return GRB.INFINITY;
        }
        return Math.abs(model.get(GRB.DoubleAttr.ObjBound) -
            model.get(GRB.DoubleAttr.ObjVal)) /
            Math.abs(model.get(GRB.DoubleAttr.ObjVal));
    }

    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Params filename");
            System.exit(1);
        }

        try {
            // Read model and verify that it is a MIP
            GRBEnv env = new GRBEnv();
            GRBModel base = new GRBModel(env, args[0]);
            if (base.get(GRB.IntAttr.IsMIP) == 0) {
                System.out.println("The model is not an integer program");
                System.exit(1);
            }

            // Set a 5 second time limit
            base.getEnv().set(GRB.DoubleParam.TimeLimit, 5);

            // Now solve the model with different values of MIPFocus
```

```

double bestGap = GRB.INFINITY;
GRBModel bestModel = null;
for (int i = 0; i <= 3; ++i) {
    GRBModel m = new GRBModel(base);
    m.getEnv().set(GRB.IntParam.MIPFocus, i);
    m.optimize();
    if (bestModel == null || bestGap > gap(m)) {
        bestModel = m;
        bestGap = gap(bestModel);
    }
}

// Finally, reset the time limit and continue to solve the
// best model to optimality
bestModel.getEnv().set(GRB.DoubleParam.TimeLimit, GRB.INFINITY);
bestModel.optimize();
System.out.println("Solved with MIPFocus: " +
    bestModel.getEnv().get(GRB.IntParam.MIPFocus));

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}

```

## Qcp.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QCP model:

    maximize    x
    subject to  x + y + z = 1
                x^2 + y^2 <= z^2 (second-order cone)
                x^2 <= yz        (rotated second-order cone)
*/

import gurobi.*;

public class Qcp {
    public static void main(String[] args) {
        try {
            GRBEnv env = new GRBEnv("qcp.log");
            GRBModel model = new GRBModel(env);

            // Create variables

            GRBVar x = model.addVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "x");
            GRBVar y = model.addVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "y");
            GRBVar z = model.addVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "z");

            // Integrate new variables

            model.update();

            // Set objective

            GRBLinExpr obj = new GRBLinExpr();
            obj.addTerm(1.0, x);
            model.setObjective(obj, GRB.MAXIMIZE);

            // Add linear constraint: x + y + z = 1

            GRBLinExpr expr = new GRBLinExpr();
            expr.addTerm(1.0, x); expr.addTerm(1.0, y); expr.addTerm(1.0, z);
            model.addConstr(expr, GRB.EQUAL, 1.0, "c0");

            // Add second-order cone: x^2 + y^2 <= z^2

            GRBQuadExpr qexpr = new GRBQuadExpr();
            qexpr.addTerm(1.0, x, x);
```

```

qexpr.addTerm(1.0, y, y);
qexpr.addTerm(-1.0, z, z);
model.addQConstr(qexpr, GRB.LESS_EQUAL, 0.0, "qc0");

// Add rotated cone:  $x^2 \leq yz$ 

qexpr = new GRBQuadExpr();
qexpr.addTerm(1.0, x, x);
qexpr.addTerm(-1.0, y, z);
model.addQConstr(qexpr, GRB.LESS_EQUAL, 0.0, "qc1");

// Optimize model

model.optimize();

System.out.println(x.get(GRB.StringAttr.VarName)
                    + " " +x.get(GRB.DoubleAttr.X));
System.out.println(y.get(GRB.StringAttr.VarName)
                    + " " +y.get(GRB.DoubleAttr.X));
System.out.println(z.get(GRB.StringAttr.VarName)
                    + " " +z.get(GRB.DoubleAttr.X));

System.out.println("Obj: " + model.get(GRB.DoubleAttr.ObjVal) + " " +
                    obj.getValue());
System.out.println();

// Dispose of model and environment

model.dispose();
env.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
                      e.getMessage());
}
}
}

```

## Qp.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QP model:

    minimize    x^2 + x*y + y^2 + y*z + z^2 + 2 x
    subject to  x + 2 y + 3 z >= 4
                x + y          >= 1

    It solves it once as a continuous model, and once as an integer model.
*/

import gurobi.*;

public class Qp {
    public static void main(String[] args) {
        try {
            GRBEnv env = new GRBEnv("qp.log");
            GRBModel model = new GRBModel(env);

            // Create variables

            GRBVar x = model.addVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "x");
            GRBVar y = model.addVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "y");
            GRBVar z = model.addVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "z");

            // Integrate new variables

            model.update();

            // Set objective

            GRBQuadExpr obj = new GRBQuadExpr();
            obj.addTerm(1.0, x, x);
            obj.addTerm(1.0, x, y);
            obj.addTerm(1.0, y, y);
            obj.addTerm(1.0, y, z);
            obj.addTerm(1.0, z, z);
            obj.addTerm(2.0, x);
            model.setObjective(obj);

            // Add constraint: x + 2 y + 3 z >= 4

            GRBLinExpr expr = new GRBLinExpr();
            expr.addTerm(1.0, x); expr.addTerm(2.0, y); expr.addTerm(3.0, z);
```

```

model.addConstr(expr, GRB.GREATER_EQUAL, 4.0, "c0");

// Add constraint: x + y >= 1

expr = new GRBLinExpr();
expr.addTerm(1.0, x); expr.addTerm(1.0, y);
model.addConstr(expr, GRB.GREATER_EQUAL, 1.0, "c1");

// Optimize model

model.optimize();

System.out.println(x.get(GRB.StringAttr.VarName)
    + " " +x.get(GRB.DoubleAttr.X));
System.out.println(y.get(GRB.StringAttr.VarName)
    + " " +y.get(GRB.DoubleAttr.X));
System.out.println(z.get(GRB.StringAttr.VarName)
    + " " +z.get(GRB.DoubleAttr.X));

System.out.println("Obj: " + model.get(GRB.DoubleAttr.ObjVal) + " " +
    obj.getValue());
System.out.println();

// Change variable types to integer

x.set(GRB.CharAttr.VType, GRB.INTEGER);
y.set(GRB.CharAttr.VType, GRB.INTEGER);
z.set(GRB.CharAttr.VType, GRB.INTEGER);

// Optimize again

model.optimize();

System.out.println(x.get(GRB.StringAttr.VarName)
    + " " +x.get(GRB.DoubleAttr.X));
System.out.println(y.get(GRB.StringAttr.VarName)
    + " " +y.get(GRB.DoubleAttr.X));
System.out.println(z.get(GRB.StringAttr.VarName)
    + " " +z.get(GRB.DoubleAttr.X));

System.out.println("Obj: " + model.get(GRB.DoubleAttr.ObjVal) + " " +
    obj.getValue());

// Dispose of model and environment

```

```
    model.dispose();
    env.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
```

## Sensitivity.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Simple MIP sensitivity analysis example.
   For each integer variable, fix it to its lower and upper bound
   and check the impact on the objective. */

import gurobi.*;

public class Sensitivity {

    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Sensitivity filename");
            System.exit(1);
        }

        try {
            // Read model
            GRBEnv env = new GRBEnv();
            GRBModel a = new GRBModel(env, args[0]);
            a.optimize();
            a.getEnv().set(GRB.IntParam.OutputFlag, 0);

            // Extract variables from model
            GRBVar[] avars = a.getVars();

            for (int i = 0; i < avars.length; ++i) {
                GRBVar v = avars[i];
                if (v.get(GRB.CharAttr.VType) == GRB.BINARY) {

                    // Create clone and fix variable
                    GRBModel b = new GRBModel(a);
                    GRBVar bv = b.getVars()[i];
                    if (v.get(GRB.DoubleAttr.X) - v.get(GRB.DoubleAttr.LB) < 0.5) {
                        bv.set(GRB.DoubleAttr.LB, bv.get(GRB.DoubleAttr.UB));
                    } else {
                        bv.set(GRB.DoubleAttr.UB, bv.get(GRB.DoubleAttr.LB));
                    }

                    b.optimize();

                    if (b.get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL) {
                        double objchg =
```

```

        b.get(GRB.DoubleAttr.ObjVal) - a.get(GRB.DoubleAttr.ObjVal);
    if (objchg < 0) {
        objchg = 0;
    }
    System.out.println("Objective sensitivity for variable " +
        v.get(GRB.StringAttr.VarName) + " is " + objchg);
} else {
    System.out.println("Objective sensitivity for variable " +
        v.get(GRB.StringAttr.VarName) + " is infinite");
}

    // Dispose of model
    b.dispose();
}
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
}

```

## Sos.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example creates a very simple Special Ordered Set (SOS) model.
   The model consists of 3 continuous variables, no linear constraints,
   and a pair of SOS constraints of type 1. */

import gurobi.*;

public class Sos {
    public static void main(String[] args) {
        try {
            GRBEnv env = new GRBEnv();

            GRBModel model = new GRBModel(env);

            // Create variables

            double ub[]    = {1, 1, 2};
            double obj[]   = {-2, -1, -1};
            String names[] = {"x0", "x1", "x2"};

            GRBVar[] x = model.addVars(null, ub, obj, null, names);

            // Integrate new variables

            model.update();

            // Add first SOS1: x0=0 or x1=0

            GRBVar sosv1[] = {x[0], x[1]};
            double soswt1[] = {1, 2};

            model.addSOS(sosv1, soswt1, GRB.SOS_TYPE1);

            // Add second SOS1: x0=0 or x2=0

            GRBVar sosv2[] = {x[0], x[2]};
            double soswt2[] = {1, 2};

            model.addSOS(sosv2, soswt2, GRB.SOS_TYPE1);

            // Optimize model

            model.optimize();
        }
    }
}
```

```
for (int i = 0; i < 3; i++)
    System.out.println(x[i].get(GRB.StringAttr.VarName) + " "
        + x[i].get(GRB.DoubleAttr.X));

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
```

## Sudoku.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */
/*
Sudoku example.

The Sudoku board is a 9x9 grid, which is further divided into a 3x3 grid
of 3x3 grids. Each cell in the grid must take a value from 0 to 9.
No two grid cells in the same row, column, or 3x3 subgrid may take the
same value.

In the MIP formulation, binary variables  $x[i,j,v]$  indicate whether
cell  $\langle i,j \rangle$  takes value 'v'. The constraints are as follows:
1. Each cell must take exactly one value ( $\sum_v x[i,j,v] = 1$ )
2. Each value is used exactly once per row ( $\sum_i x[i,j,v] = 1$ )
3. Each value is used exactly once per column ( $\sum_j x[i,j,v] = 1$ )
4. Each value is used exactly once per 3x3 subgrid ( $\sum_{\text{grid}} x[i,j,v] = 1$ )

Input datasets for this example can be found in examples/data/sudoku*.
*/

import gurobi.*;
import java.io.*;

public class Sudoku {
    public static void main(String[] args) {
        int n = 9;
        int s = 3;

        if (args.length < 1) {
            System.out.println("Usage: java Sudoku filename");
            System.exit(1);
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env);

            // Create 3-D array of model variables

            GRBVar[][][] vars = new GRBVar[n][n][n];

            for (int i = 0; i < n; i++) {
                for (int j = 0; j < n; j++) {
                    for (int v = 0; v < n; v++) {
                        String st = "G_" + String.valueOf(i) + "_" + String.valueOf(j)

```

```

        + "_" + String.valueOf(v);
    vars[i][j][v] = model.addVar(0.0, 1.0, 0.0, GRB.BINARY, st);
    }
}

// Integrate variables into model

model.update();

// Add constraints

GRBLinExpr expr;

// Each cell must take one value

for (int i = 0; i < n; i++) {
    for (int j = 0; j < n; j++) {
        expr = new GRBLinExpr();
        expr.addTerms(null, vars[i][j]);
        String st = "V_" + String.valueOf(i) + "_" + String.valueOf(j);
        model.addConstr(expr, GRB.EQUAL, 1.0, st);
    }
}

// Each value appears once per row

for (int i = 0; i < n; i++) {
    for (int v = 0; v < n; v++) {
        expr = new GRBLinExpr();
        for (int j = 0; j < n; j++)
            expr.addTerm(1.0, vars[i][j][v]);
        String st = "R_" + String.valueOf(i) + "_" + String.valueOf(v);
        model.addConstr(expr, GRB.EQUAL, 1.0, st);
    }
}

// Each value appears once per column

for (int j = 0; j < n; j++) {
    for (int v = 0; v < n; v++) {
        expr = new GRBLinExpr();
        for (int i = 0; i < n; i++)
            expr.addTerm(1.0, vars[i][j][v]);
        String st = "C_" + String.valueOf(j) + "_" + String.valueOf(v);

```

```

    model.addConstr(expr, GRB.EQUAL, 1.0, st);
}
}

// Each value appears once per sub-grid

for (int v = 0; v < n; v++) {
    for (int i0 = 0; i0 < s; i0++) {
        for (int j0 = 0; j0 < s; j0++) {
            expr = new GRBLinExpr();
            for (int i1 = 0; i1 < s; i1++) {
                for (int j1 = 0; j1 < s; j1++) {
                    expr.addTerm(1.0, vars[i0*s+i1][j0*s+j1][v]);
                }
            }
            String st = "Sub_" + String.valueOf(v) + "_" + String.valueOf(i0)
                + "_" + String.valueOf(j0);
            model.addConstr(expr, GRB.EQUAL, 1.0, st);
        }
    }
}

// Update model

model.update();

// Fix variables associated with pre-specified cells

File file = new File(args[0]);
FileInputStream fis = new FileInputStream(file);
byte[] input = new byte[n];

for (int i = 0; i < n; i++) {
    fis.read(input);
    for (int j = 0; j < n; j++) {
        int val = (int) input[j] - 48 - 1; // 0-based

        if (val >= 0)
            vars[i][j][val].set(GRB.DoubleAttr.LB, 1.0);
    }
    // read the newline byte
    fis.read();
}

// Optimize model

```

```

model.optimize();

// Write model to file
model.write("sudoku.lp");

double[][][] x = model.get(GRB.DoubleAttr.X, vars);

System.out.println();
for (int i = 0; i < n; i++) {
    for (int j = 0; j < n; j++) {
        for (int v = 0; v < n; v++) {
            if (x[i][j][v] > 0.5) {
                System.out.print(v+1);
            }
        }
    }
    System.out.println();
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
} catch (IOException e) {
    System.out.println("IO Error");
}
}
}

```

## Tsp.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

// Solve a traveling salesman problem on a randomly generated set of
// points using lazy constraints. The base MIP model only includes
// 'degree-2' constraints, requiring each node to have exactly
// two incident edges. Solutions to this model may contain subtours -
// tours that don't visit every node. The lazy constraint callback
// adds new constraints to cut them off.

import gurobi.*;

public class Tsp extends GRBCallback {
    private GRBVar[][] vars;

    public Tsp(GRBVar[][] xvars) {
        vars = xvars;
    }

    // Subtour elimination callback. Whenever a feasible solution is found,
    // find the subtour that contains node 0, and add a subtour elimination
    // constraint if the tour doesn't visit every node.

    protected void callback() {
        try {
            if (where == GRB.CB_MIPSOL) {
                // Found an integer feasible solution - does it visit every node?
                int n = vars.length;
                int[] tour = findsubtour(getSolution(vars));

                if (tour.length < n) {
                    // Add subtour elimination constraint
                    GRBLinExpr expr = new GRBLinExpr();
                    for (int i = 0; i < tour.length; i++)
                        for (int j = i+1; j < tour.length; j++)
                            expr.addTerm(1.0, vars[tour[i]][tour[j]]);
                    addLazy(expr, GRB.LESS_EQUAL, tour.length-1);
                }
            }
        } catch (GRBException e) {
            System.out.println("Error code: " + e.getErrorCode() + ". " +
                e.getMessage());
            e.printStackTrace();
        }
    }
}
```

```
// Given an integer-feasible solution 'sol', return the smallest
// sub-tour (as a list of node indices).
```

```
protected static int[] findsubtour(double[][] sol)
{
    int n = sol.length;
    boolean[] seen = new boolean[n];
    int[] tour = new int[n];
    int bestind, bestlen;
    int i, node, len, start;

    for (i = 0; i < n; i++)
        seen[i] = false;

    start = 0;
    bestlen = n+1;
    bestind = -1;
    node = 0;
    while (start < n) {
        for (node = 0; node < n; node++)
            if (!seen[node])
                break;
        if (node == n)
            break;
        for (len = 0; len < n; len++) {
            tour[start+len] = node;
            seen[node] = true;
            for (i = 0; i < n; i++) {
                if (sol[node][i] > 0.5 && !seen[i]) {
                    node = i;
                    break;
                }
            }
            if (i == n) {
                len++;
                if (len < bestlen) {
                    bestlen = len;
                    bestind = start;
                }
                start += len;
                break;
            }
        }
    }
}
```

```

    int result[] = new int[bestlen];
    for (i = 0; i < bestlen; i++)
        result[i] = tour[bestind+i];
    return result;
}

// Euclidean distance between points 'i' and 'j'

protected static double distance(double[] x,
                                  double[] y,
                                  int i,
                                  int j) {

    double dx = x[i]-x[j];
    double dy = y[i]-y[j];
    return Math.sqrt(dx*dx+dy*dy);
}

public static void main(String[] args) {

    if (args.length < 1) {
        System.out.println("Usage: java Tsp ncities");
        System.exit(1);
    }

    int n = Integer.parseInt(args[0]);

    try {
        GRBEnv env = new GRBEnv();
        GRBModel model = new GRBModel(env);

        // Must set LazyConstraints parameter when using lazy constraints

        model.getEnv().set(GRB.IntParam.LazyConstraints, 1);

        double[] x = new double[n];
        double[] y = new double[n];

        for (int i = 0; i < n; i++) {
            x[i] = Math.random();
            y[i] = Math.random();
        }

        // Create variables

```

```

GRBVar[] [] vars = new GRBVar[n][n];

for (int i = 0; i < n; i++)
    for (int j = 0; j < n; j++)
        vars[i][j] = model.addVar(0.0, 1.0, distance(x, y, i, j),
                                   GRB.BINARY,
                                   "x"+String.valueOf(i)+"_"+String.valueOf(j));

// Integrate variables

model.update();

// Degree-2 constraints

for (int i = 0; i < n; i++) {
    GRBLinExpr expr = new GRBLinExpr();
    for (int j = 0; j < n; j++)
        expr.addTerm(1.0, vars[i][j]);
    model.addConstr(expr, GRB.EQUAL, 2.0, "deg2_"+String.valueOf(i));
}

// Forbid edge from node back to itself

for (int i = 0; i < n; i++)
    vars[i][i].set(GRB.DoubleAttr.UB, 0.0);

// Symmetric TSP

for (int i = 0; i < n; i++)
    for (int j = 0; j < i; j++)
        model.addConstr(vars[i][j], GRB.EQUAL, vars[j][i], "");

model.setCallback(new Tsp(vars));
model.optimize();

if (model.get(GRB.IntAttr.SolCount) > 0) {
    int[] tour = findsubtour(model.get(GRB.DoubleAttr.X, vars));

    System.out.print("Tour: ");
    for (int i = 0; i < tour.length; i++)
        System.out.print(String.valueOf(tour[i]) + " ");
    System.out.println();
}

// Dispose of model and environment

```

```
    model.dispose();
    env.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
    e.printStackTrace();
}
}
}
```

## Tune.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a model from a file and tunes it.
   It then writes the best parameter settings to a file
   and solves the model using these parameters. */

import gurobi.*;

public class Tune {
    public static void main(String[] args) {

        if (args.length < 1) {
            System.out.println("Usage: java Tune filename");
            System.exit(1);
        }

        try {
            GRBEnv env = new GRBEnv();

            // Read model from file
            GRBModel model = new GRBModel(env, args[0]);

            // Set the TuneResults parameter to 1
            model.getEnv().set(GRB.IntParam.TuneResults, 1);

            // Tune the model
            model.tune();

            // Get the number of tuning results
            int resultcount = model.get(GRB.IntAttr.TuneResultCount);

            if (resultcount > 0) {

                // Load the tuned parameters into the model's environment
                model.getTuneResult(0);

                // Write the tuned parameters to a file
                model.write("tune.prm");

                // Solve the model using the tuned parameters
                model.optimize();
            }

            // Dispose of model and environment
        }
    }
}
```

```
    model.dispose();
    env.dispose();

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". "
        + e.getMessage());
}
}
}
```

## Workforce1.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, use IIS to find a set of
conflicting constraints. Note that there may be additional conflicts
besides what is reported via IIS. */

import gurobi.*;

public class Workforce1 {

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

            // Sample data
            // Sets of days and workers
            String Shifts[] =
                new String[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            String Workers[] =
                new String[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.length;
            int nWorkers = Workers.length;

            // Number of workers required for each shift
            double shiftRequirements[] =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Amount each worker is paid to work one shift
            double pay[] = new double[] { 10, 12, 10, 8, 8, 9, 11 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double availability[][] =
                new double[][] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

            // Model
```

```

GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
GRBVar[] [] x = new GRBVar[nWorkers][nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w][s] =
            model.addVar(0, availability[w][s], pay[w], GRB.CONTINUOUS,
                Workers[w] + "." + Shifts[s]);
    }
}

// The objective is to minimize the total pay costs
model.set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s) {
    GRBLinExpr lhs = new GRBLinExpr();
    for (int w = 0; w < nWorkers; ++w) {
        lhs.addTerm(1.0, x[w][s]);
    }
    model.addConstr(lhs, GRB.EQUAL, shiftRequirements[s], Shifts[s]);
}

// Optimize
model.optimize();
int status = model.get(GRB.IntAttr.Status);
if (status == GRB.Status.UNBOUNDED) {
    System.out.println("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {
    System.out.println("The optimal objective is " +
        model.get(GRB.DoubleAttr.ObjVal));
    return;
}

```

```

if (status != GRB.Status.INF_OR_UNBD &&
    status != GRB.Status.INFEASIBLE ){
    System.out.println("Optimization was stopped with status " + status);
    return;
}

// Compute IIS
System.out.println("The model is infeasible; computing IIS");
model.computeIIS();
System.out.println("\nThe following constraint(s) "
    + "cannot be satisfied:");
for (GRBConstr c : model.getConstrs()) {
    if (c.get(GRB.IntAttr.IISConstr) == 1) {
        System.out.println(c.get(GRB.StringAttr.ConstrName));
    }
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}

```

## Workforce2.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, use IIS iteratively to
find all conflicting constraints. */

import gurobi.*;
import java.util.*;

public class Workforce2 {

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

            // Sample data
            // Sets of days and workers
            String Shifts[] =
                new String[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            String Workers[] =
                new String[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.length;
            int nWorkers = Workers.length;

            // Number of workers required for each shift
            double shiftRequirements[] =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Amount each worker is paid to work one shift
            double pay[] = new double[] { 10, 12, 10, 8, 8, 9, 11 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double availability[][] =
                new double[][] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

            // Model
```

```

GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
GRBVar[] [] x = new GRBVar[nWorkers][nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w][s] =
            model.addVar(0, availability[w][s], pay[w], GRB.CONTINUOUS,
                Workers[w] + "." + Shifts[s]);
    }
}

// The objective is to minimize the total pay costs
model.set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s) {
    GRBLinExpr lhs = new GRBLinExpr();
    for (int w = 0; w < nWorkers; ++w) {
        lhs.addTerm(1.0, x[w][s]);
    }
    model.addConstr(lhs, GRB.EQUAL, shiftRequirements[s], Shifts[s]);
}

// Optimize
model.optimize();
int status = model.get(GRB.IntAttr.Status);
if (status == GRB.Status.UNBOUNDED) {
    System.out.println("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {
    System.out.println("The optimal objective is " +
        model.get(GRB.DoubleAttr.ObjVal));
    return;
}

```

```

if (status != GRB.Status.INF_OR_UNBD &&
    status != GRB.Status.INFEASIBLE    ) {
    System.out.println("Optimization was stopped with status " + status);
    return;
}

// Do IIS
System.out.println("The model is infeasible; computing IIS");
LinkedList<String> removed = new LinkedList<String>();

// Loop until we reduce to a model that can be solved
while (true) {
    model.computeIIS();
    System.out.println("\nThe following constraint cannot be satisfied:");
    for (GRBConstr c : model.getConstrs()) {
        if (c.get(GRB.IntAttr.IISConstr) == 1) {
            System.out.println(c.get(GRB.StringAttr.ConstrName));
            // Remove a single constraint from the model
            removed.add(c.get(GRB.StringAttr.ConstrName));
            model.remove(c);
            break;
        }
    }
}

System.out.println();
model.optimize();
status = model.get(GRB.IntAttr.Status);

if (status == GRB.Status.UNBOUNDED) {
    System.out.println("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {
    break;
}
if (status != GRB.Status.INF_OR_UNBD &&
    status != GRB.Status.INFEASIBLE    ) {
    System.out.println("Optimization was stopped with status " +
        status);
    return;
}
}

System.out.println("\nThe following constraints were removed "

```

```
        + "to get a feasible LP:");
for (String s : removed) {
    System.out.print(s + " ");
}
System.out.println();

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
```

## Workforce3.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, add slack variables
to determine which constraints cannot be satisfied, and how much
they need to be relaxed. */

import gurobi.*;
import java.util.*;

public class Workforce3 {

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

            // Sample data
            // Sets of days and workers
            String Shifts[] =
                new String[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            String Workers[] =
                new String[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.length;
            int nWorkers = Workers.length;

            // Number of workers required for each shift
            double shiftRequirements[] =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Amount each worker is paid to work one shift
            double pay[] = new double[] { 10, 12, 10, 8, 8, 9, 11 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double availability[][] =
                new double[][] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };
        }
    }
}
```

```

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

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
GRBVar[] [] x = new GRBVar[nWorkers][nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w][s] =
            model.addVar(0, availability[w][s], pay[w], GRB.CONTINUOUS,
                Workers[w] + "." + Shifts[s]);
    }
}

// The objective is to minimize the total pay costs
model.set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
LinkedList<GRBConstr> reqCts = new LinkedList<GRBConstr>();
for (int s = 0; s < nShifts; ++s) {
    GRBLinExpr lhs = new GRBLinExpr();
    for (int w = 0; w < nWorkers; ++w) {
        lhs.addTerm(1.0, x[w][s]);
    }
    GRBConstr newCt =
        model.addConstr(lhs, GRB.EQUAL, shiftRequirements[s], Shifts[s]);
    reqCts.add(newCt);
}

// Optimize
model.optimize();
int status = model.get(GRB.IntAttr.Status);
if (status == GRB.Status.UNBOUNDED) {
    System.out.println("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {

```

```

    System.out.println("The optimal objective is " +
        model.get(GRB.DoubleAttr.ObjVal));
    return;
}
if (status != GRB.Status.INF_OR_UNBD &&
    status != GRB.Status.INFEASIBLE    ) {
    System.out.println("Optimization was stopped with status " + status);
    return;
}

// Add slack variables to make the model feasible
System.out.println("The model is infeasible; adding slack variables");

// Set original objective coefficients to zero
model.setObjective(new GRBLinExpr());

// Add a new slack variable to each shift constraint so that the shifts
// can be satisfied
LinkedList<GRBVar> slacks = new LinkedList<GRBVar>();
for (GRBConstr c : reqCts) {
    GRBColumn col = new GRBColumn();
    col.addTerm(1.0, c);
    GRBVar newvar =
        model.addVar(0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, col,
            c.get(GRB.StringAttr.ConstrName) + "Slack");
    slacks.add(newvar);
}

// Solve the model with slacks
model.optimize();
status = model.get(GRB.IntAttr.Status);
if (status == GRB.Status.INF_OR_UNBD ||
    status == GRB.Status.INFEASIBLE ||
    status == GRB.Status.UNBOUNDED    ) {
    System.out.println("The model with slacks cannot be solved "
        + "because it is infeasible or unbounded");
    return;
}
if (status != GRB.Status.OPTIMAL) {
    System.out.println("Optimization was stopped with status " + status);
    return;
}

System.out.println("\nSlack values:");
for (GRBVar sv : slacks) {

```

```
    if (sv.get(GRB.DoubleAttr.X) > 1e-6) {
        System.out.println(sv.get(GRB.StringAttr.VarName) + " = " +
            sv.get(GRB.DoubleAttr.X));
    }
}

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

} catch (GRBException e) {
    System.out.println("Error code: " + e.getErrorCode() + ". " +
        e.getMessage());
}
}
}
```

## Workforce4.java

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. We use Pareto optimization to solve the model:
first, we minimize the linear sum of the slacks. Then, we constrain
the sum of the slacks, and we minimize a quadratic objective that
tries to balance the workload among the workers. */

import gurobi.*;

public class Workforce4 {

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

            // Sample data
            // Sets of days and workers
            String Shifts[] =
                new String[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            String Workers[] =
                new String[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.length;
            int nWorkers = Workers.length;

            // Number of workers required for each shift
            double shiftRequirements[] =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double availability[][] =
                new double[][] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

            // Model
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env);
```

```

model.set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. This is no longer a pure assignment model, so we must
// use binary variables.
GRBVar[][] x = new GRBVar[nWorkers][nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w][s] =
            model.addVar(0, availability[w][s], 0, GRB.BINARY,
                Workers[w] + "." + Shifts[s]);
    }
}

// Slack variables for each shift constraint so that the shifts can
// be satisfied
GRBVar[] slacks = new GRBVar[nShifts];
for (int s = 0; s < nShifts; ++s) {
    slacks[s] =
        model.addVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS,
            Shifts[s] + "Slack");
}

// Variable to represent the total slack
GRBVar totSlack = model.addVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS,
    "totSlack");

// Variables to count the total shifts worked by each worker
GRBVar[] totShifts = new GRBVar[nWorkers];
for (int w = 0; w < nWorkers; ++w) {
    totShifts[w] = model.addVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS,
        Workers[w] + "TotShifts");
}

// Update model to integrate new variables
model.update();

GRBLinExpr lhs;

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s, plus the slack
for (int s = 0; s < nShifts; ++s) {
    lhs = new GRBLinExpr();
    lhs.addTerm(1.0, slacks[s]);
    for (int w = 0; w < nWorkers; ++w) {

```

```

    lhs.addTerm(1.0, x[w][s]);
}
model.addConstr(lhs, GRB.EQUAL, shiftRequirements[s], Shifts[s]);
}

// Constraint: set totSlack equal to the total slack
lhs = new GRBLinExpr();
lhs.addTerm(-1.0, totSlack);
for (int s = 0; s < nShifts; ++s) {
    lhs.addTerm(1.0, slacks[s]);
}
model.addConstr(lhs, GRB.EQUAL, 0, "totSlack");

// Constraint: compute the total number of shifts for each worker
for (int w = 0; w < nWorkers; ++w) {
    lhs = new GRBLinExpr();
    lhs.addTerm(-1.0, totShifts[w]);
    for (int s = 0; s < nShifts; ++s) {
        lhs.addTerm(1.0, x[w][s]);
    }
    model.addConstr(lhs, GRB.EQUAL, 0, "totShifts" + Workers[w]);
}

// Objective: minimize the total slack
GRBLinExpr obj = new GRBLinExpr();
obj.addTerm(1.0, totSlack);
model.setObjective(obj);

// Optimize
int status =
    solveAndPrint(model, totSlack, nWorkers, Workers, totShifts);
if (status != GRB.Status.OPTIMAL ) {
    return;
}

// Constrain the slack by setting its upper and lower bounds
totSlack.set(GRB.DoubleAttr.UB, totSlack.get(GRB.DoubleAttr.X));
totSlack.set(GRB.DoubleAttr.LB, totSlack.get(GRB.DoubleAttr.X));

// Variable to count the average number of shifts worked
GRBVar avgShifts =
    model.addVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS, "avgShifts");

// Variables to count the difference from average for each worker;
// note that these variables can take negative values.

```

```

GRBVar[] diffShifts = new GRBVar[nWorkers];
for (int w = 0; w < nWorkers; ++w) {
    diffShifts[w] = model.addVar(-GRB.INFINITY, GRB.INFINITY, 0,
                                GRB.CONTINUOUS, Workers[w] + "Diff");
}

// Update model to integrate new variables
model.update();

// Constraint: compute the average number of shifts worked
lhs = new GRBLinExpr();
lhs.addTerm(-nWorkers, avgShifts);
for (int w = 0; w < nWorkers; ++w) {
    lhs.addTerm(1.0, totShifts[w]);
}
model.addConstr(lhs, GRB.EQUAL, 0, "avgShifts");

// Constraint: compute the difference from the average number of shifts
for (int w = 0; w < nWorkers; ++w) {
    lhs = new GRBLinExpr();
    lhs.addTerm(-1, diffShifts[w]);
    lhs.addTerm(-1, avgShifts);
    lhs.addTerm( 1, totShifts[w]);
    model.addConstr(lhs, GRB.EQUAL, 0, Workers[w] + "Diff");
}

// Objective: minimize the sum of the square of the difference from the
// average number of shifts worked
GRBQuadExpr qobj = new GRBQuadExpr();
for (int w = 0; w < nWorkers; ++w) {
    qobj.addTerm(1.0, diffShifts[w], diffShifts[w]);
}
model.setObjective(qobj);

// Optimize
status =
    solveAndPrint(model, totSlack, nWorkers, Workers, totShifts);
if (status != GRB.Status.OPTIMAL ) {
    return;
}

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

```

```

    } catch (GRBException e) {
        System.out.println("Error code: " + e.getErrorCode() + ". " +
            e.getMessage());
    }
}

private static int solveAndPrint(GRBModel model, GRBVar totSlack,
                                int nWorkers, String[] Workers,
                                GRBVar[] totShifts) throws GRBException {

    model.optimize();
    int status = model.get(GRB.IntAttr.Status);
    if (status == GRB.Status.INF_OR_UNBD ||
        status == GRB.Status.INFEASIBLE ||
        status == GRB.Status.UNBOUNDED ) {
        System.out.println("The model cannot be solved "
            + "because it is infeasible or unbounded");
        return status;
    }
    if (status != GRB.Status.OPTIMAL ) {
        System.out.println("Optimization was stopped with status " + status);
        return status;
    }

    // Print total slack and the number of shifts worked for each worker
    System.out.println("\nTotal slack required: " +
        totSlack.get(GRB.DoubleAttr.X));
    for (int w = 0; w < nWorkers; ++w) {
        System.out.println(Workers[w] + " worked " +
            totShifts[w].get(GRB.DoubleAttr.X) + " shifts");
    }
    System.out.println("\n");
    return status;
}
}

```

## 3.4 C# Examples

This section includes source code for all of the Gurobi C# examples. The same source code can be found in the `examples/c#` directory of the Gurobi distribution.

### callback\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP or a MIP from a file, sets a callback
   to monitor the optimization progress and to output some progress
   information to the screen and to a log file. If it is a MIP and 10%
   gap is reached, then it aborts. */

using System;
using Gurobi;

class callback_cs : GRBCallback
{
    private GRBVar[] vars;
    private double lastnode;
    private double lastiter;

    public callback_cs(GRBVar[] xvars)
    {
        vars = xvars;
        lastnode = lastiter = -1;
    }

    protected override void Callback()
    {
        try {
            if (where == GRB.Callback.MESSAGE) {
                // Message callback
                string st = GetStringInfo(GRB.Callback.MSG_STRING);
                if (st != null) Console.Write(st);
            } else if (where == GRB.Callback.PRESOLVE) {
                // Presolve callback
                int cdels = GetIntInfo(GRB.Callback.PRE_COLDEL);
                int rdels = GetIntInfo(GRB.Callback.PRE_ROWDEL);
                Console.WriteLine(cdels+" columns and "+rdels+" rows are removed");
            } else if (where == GRB.Callback.SIMPLEX) {
                // Simplex callback
                double itcnt = GetDoubleInfo(GRB.Callback.SPX_ITRCNT);
                if (itcnt - lastiter >= 100) {
                    lastiter = itcnt;
                }
            }
        }
    }
}
```

```

        double obj = GetDoubleInfo(GRB.Callback.SPX_OBJVAL);
        double pinf = GetDoubleInfo(GRB.Callback.SPX_PRIMINF);
        double dinf = GetDoubleInfo(GRB.Callback.SPX_DUALINF);
        int ispert = GetIntInfo(GRB.Callback.SPX_ISPERT);
        char ch;
        if (ispert == 0) ch = ' ';
        else if (ispert == 1) ch = 'S';
        else ch = 'P';
        Console.WriteLine(itcnt+" "+obj + ch + " "+pinf + " "+dinf);
    }
} else if (where == GRB.Callback.MIP) {
    // General MIP callback
    double nodecnt = GetDoubleInfo(GRB.Callback.MIP_NODCNT);
    if (nodecnt - lastnode >= 100) {
        lastnode = nodecnt;
        double objbst = GetDoubleInfo(GRB.Callback.MIP_OBJBST);
        double objbnd = GetDoubleInfo(GRB.Callback.MIP_OBJBND);
        if (Math.Abs(objbst - objbnd) < 0.1 * (1.0 + Math.Abs(objbst)))
            Abort();
        int actnodes = (int) GetDoubleInfo(GRB.Callback.MIP_NODLFT);
        int itcnt = (int) GetDoubleInfo(GRB.Callback.MIP_ITRCNT);
        int solcnt = GetIntInfo(GRB.Callback.MIP_SOLCNT);
        int cutcnt = GetIntInfo(GRB.Callback.MIP_CUTCNT);
        Console.WriteLine(nodecnt + " " + actnodes + " " + itcnt + " "
            + objbst + " " + objbnd + " " + solcnt + " " + cutcnt);
    }
} else if (where == GRB.Callback.MIPSOL) {
    // MIP solution callback
    double obj = GetDoubleInfo(GRB.Callback.MIPSOL_OBJ);
    int nodecnt = (int) GetDoubleInfo(GRB.Callback.MIPSOL_NODCNT);
    double[] x = GetSolution(vars);
    Console.WriteLine("**** New solution at node " + nodecnt + ", obj "
        + obj + ", x[0] = " + x[0] + "****");
}
} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
    Console.WriteLine(e.StackTrace);
}
}

static void Main(string[] args)
{
    if (args.Length < 1) {
        Console.Out.WriteLine("Usage: callback_cs filename");
        return;
    }
}

```

```

}

try {
    GRBEnv env = new GRBEnv();
    GRBModel model = new GRBModel(env, args[0]);

    GRBVar[] vars = model.GetVars();

    // Create a callback object and associate it with the model
    model.SetCallback(new callback_cs(vars));
    model.Optimize();

    double[] x = model.Get(GRB.DoubleAttr.X, vars);
    string[] vnames = model.Get(GRB.StringAttr.VarName, vars);

    for (int j = 0; j < vars.Length; j++) {
        if (x[j] != 0.0) Console.WriteLine(vnames[j] + " " + x[j]);
    }

    // Dispose of model and env
    model.Dispose();
    env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
    Console.WriteLine(e.StackTrace);
}
}
}

```

## dense\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */
```

```
/* This example formulates and solves the following simple QP model:
```

```
    minimize    x + y + x^2 + x*y + y^2 + y*z + z^2
    subject to  x + 2 y + 3 z >= 4
                x +   y       >= 1
```

The example illustrates the use of dense matrices to store A and Q (and dense vectors for the other relevant data). We don't recommend that you use dense matrices, but this example may be helpful if you already have your data in this format.

```
*/
```

```
using System;
```

```
using Gurobi;
```

```
class dense_cs {
```

```
    protected static bool
```

```
        dense_optimize(GRBEnv    env,
                       int       rows,
                       int       cols,
                       double[]  c,    // linear portion of objective function
                       double[,] Q,    // quadratic portion of objective function
                       double[,] A,    // constraint matrix
                       char[]    sense, // constraint senses
                       double[]  rhs,  // RHS vector
                       double[]  lb,   // variable lower bounds
                       double[]  ub,   // variable upper bounds
                       char[]    vtype, // variable types (continuous, binary, etc.)
                       double[]  solution) {
```

```
    bool success = false;
```

```
    try {
```

```
        GRBModel model = new GRBModel(env);
```

```
        // Add variables to the model
```

```
        GRBVar[] vars = model.AddVars(lb, ub, null, vtype, null);
        model.Update();
```

```
        // Populate A matrix
```

```

for (int i = 0; i < rows; i++) {
    GRBLinExpr expr = new GRBLinExpr();
    for (int j = 0; j < cols; j++)
        if (A[i,j] != 0)
            expr.AddTerm(A[i,j], vars[j]); // Note: '+=' would be much slower
    model.AddConstr(expr, sense[i], rhs[i], "");
}

// Populate objective

GRBQuadExpr obj = new GRBQuadExpr();
if (Q != null) {
    for (int i = 0; i < cols; i++)
        for (int j = 0; j < cols; j++)
            if (Q[i,j] != 0)
                obj.AddTerm(Q[i,j], vars[i], vars[j]); // Note: '+=' would be much slower
    for (int j = 0; j < cols; j++)
        if (c[j] != 0)
            obj.AddTerm(c[j], vars[j]); // Note: '+=' would be much slower
    model.SetObjective(obj);
}

// Solve model

model.Optimize();

// Extract solution

if (model.Get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL) {
    success = true;

    for (int j = 0; j < cols; j++)
        solution[j] = vars[j].Get(GRB.DoubleAttr.X);
}

model.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}

return success;
}

```

```

public static void Main(String[] args) {
    try {
        GRBEnv env = new GRBEnv();

        double[] c = new double[] {1, 1, 0};
        double[,] Q = new double[,] {{1, 1, 0}, {0, 1, 1}, {0, 0, 1}};
        double[,] A = new double[,] {{1, 2, 3}, {1, 1, 0}};
        char[] sense = new char[] {'>', '>'};
        double[] rhs = new double[] {4, 1};
        double[] lb = new double[] {0, 0, 0};
        bool success;
        double[] sol = new double[3];

        success = dense_optimize(env, 2, 3, c, Q, A, sense, rhs,
                                lb, null, null, sol);

        if (success) {
            Console.WriteLine("x: " + sol[0] + ", y: " + sol[1] + ", z: " + sol[2]);
        }

        // Dispose of environment
        env.Dispose();

    } catch (GRBException e) {
        Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
    }
}
}

```

## diet\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve the classic diet model, showing how to add constraints
   to an existing model. */

using System;
using Gurobi;

class diet_cs
{
    static void Main()
    {
        try {

            // Nutrition guidelines, based on
            // USDA Dietary Guidelines for Americans, 2005
            // http://www.health.gov/DietaryGuidelines/dga2005/
            string[] Categories =
                new string[] { "calories", "protein", "fat", "sodium" };
            int nCategories = Categories.Length;
            double[] minNutrition = new double[] { 1800, 91, 0, 0 };
            double[] maxNutrition = new double[] { 2200, GRB.INFINITY, 65, 1779 };

            // Set of foods
            string[] Foods =
                new string[] { "hamburger", "chicken", "hot dog", "fries",
                    "macaroni", "pizza", "salad", "milk", "ice cream" };
            int nFoods = Foods.Length;
            double[] cost =
                new double[] { 2.49, 2.89, 1.50, 1.89, 2.09, 1.99, 2.49, 0.89,
                    1.59 };

            // Nutrition values for the foods
            double[,] nutritionValues = new double[,] {
                { 410, 24, 26, 730 }, // hamburger
                { 420, 32, 10, 1190 }, // chicken
                { 560, 20, 32, 1800 }, // hot dog
                { 380, 4, 19, 270 }, // fries
                { 320, 12, 10, 930 }, // macaroni
                { 320, 15, 12, 820 }, // pizza
                { 320, 31, 12, 1230 }, // salad
                { 100, 8, 2.5, 125 }, // milk
                { 330, 8, 10, 180 } // ice cream
            };
        }
    }
}
```

```

// 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[nCategories];
for (int i = 0; i < nCategories; ++i) {
    nutrition[i] =
        model.AddVar(minNutrition[i], maxNutrition[i], 0, GRB.CONTINUOUS,
            Categories[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, GRB.INFINITY, cost[j], GRB.CONTINUOUS, Foods[j]);
}

// The objective is to minimize the costs
model.Set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.Update();

// Nutrition constraints
for (int i = 0; i < nCategories; ++i) {
    GRBLinExpr ntot = 0.0;
    for (int j = 0; j < nFoods; ++j)
        ntot.AddTerm(nutritionValues[j,i], buy[j]);
    model.AddConstr(ntot == nutrition[i], Categories[i]);
}

// Solve
model.Optimize();
PrintSolution(model, buy, nutrition);

Console.WriteLine("\nAdding constraint: at most 6 servings of dairy");
model.AddConstr(buy[7] + buy[8] <= 6.0, "limit_dairy");

// Solve
model.Optimize();

```

```

PrintSolution(model, buy, nutrition);

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}

private static void PrintSolution(GRBModel model, GRBVar[] buy,
    GRBVar[] nutrition) {
    if (model.Get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL) {
        Console.WriteLine("\nCost: " + model.Get(GRB.DoubleAttr.ObjVal));
        Console.WriteLine("\nBuy:");
        for (int j = 0; j < buy.Length; ++j) {
            if (buy[j].Get(GRB.DoubleAttr.X) > 0.0001) {
                Console.WriteLine(buy[j].Get(GRB.StringAttr.VarName) + " " +
                    buy[j].Get(GRB.DoubleAttr.X));
            }
        }
        Console.WriteLine("\nNutrition:");
        for (int i = 0; i < nutrition.Length; ++i) {
            Console.WriteLine(nutrition[i].Get(GRB.StringAttr.VarName) + " " +
                nutrition[i].Get(GRB.DoubleAttr.X));
        }
    } else {
        Console.WriteLine("No solution");
    }
}
}
}

```

## facility\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Facility location: a company currently ships its product from 5 plants
   to 4 warehouses. It is considering closing some plants to reduce
   costs. What plant(s) should the company close, in order to minimize
   transportation and fixed costs?

   Based on an example from Frontline Systems:
   http://www.solver.com/disfacility.htm
   Used with permission.
*/

using System;
using Gurobi;

class facility_cs
{
    static void Main()
    {
        try {

            // Warehouse demand in thousands of units
            double[] Demand = new double[] { 15, 18, 14, 20 };

            // Plant capacity in thousands of units
            double[] Capacity = new double[] { 20, 22, 17, 19, 18 };

            // Fixed costs for each plant
            double[] FixedCosts =
                new double[] { 12000, 15000, 17000, 13000, 16000 };

            // Transportation costs per thousand units
            double[,] TransCosts =
                new double[,] { { 4000, 2000, 3000, 2500, 4500 },
                                { 2500, 2600, 3400, 3000, 4000 },
                                { 1200, 1800, 2600, 4100, 3000 },
                                { 2200, 2600, 3100, 3700, 3200 } };

            // Number of plants and warehouses
            int nPlants = Capacity.Length;
            int nWarehouses = Demand.Length;

            // Model
            GRBEnv env = new GRBEnv();
```

```

GRBModel model = new GRBModel(env);
model.Set(GRB.StringAttr.ModelName, "facility");

// Plant open decision variables: open[p] == 1 if plant p is open.
GRBVar[] open = new GRBVar[nPlants];
for (int p = 0; p < nPlants; ++p) {
    open[p] = model.AddVar(0, 1, FixedCosts[p], GRB.BINARY, "Open" + p);
}

// Transportation decision variables: how much to transport from
// a plant p to a warehouse w
GRBVar[,] transport = new GRBVar[nWarehouses,nPlants];
for (int w = 0; w < nWarehouses; ++w) {
    for (int p = 0; p < nPlants; ++p) {
        transport[w,p] =
            model.AddVar(0, GRB.INFINITY, TransCosts[w,p], GRB.CONTINUOUS,
                "Trans" + p + "." + w);
    }
}

// The objective is to minimize the total fixed and variable costs
model.Set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.Update();

// Production constraints
// Note that the right-hand limit sets the production to zero if
// the plant is closed
for (int p = 0; p < nPlants; ++p) {
    GRBLinExpr ptot = 0.0;
    for (int w = 0; w < nWarehouses; ++w)
        ptot.AddTerm(1.0, transport[w,p]);
    model.AddConstr(ptot <= Capacity[p] * open[p], "Capacity" + p);
}

// Demand constraints
for (int w = 0; w < nWarehouses; ++w) {
    GRBLinExpr dtot = 0.0;
    for (int p = 0; p < nPlants; ++p)
        dtot.AddTerm(1.0, transport[w,p]);
    model.AddConstr(dtot == Demand[w], "Demand" + w);
}

// Guess at the starting point: close the plant with the highest

```

```

// fixed costs; open all others

// First, open all plants
for (int p = 0; p < nPlants; ++p) {
    open[p].Set(GRB.DoubleAttr.Start, 1.0);
}

// Now close the plant with the highest fixed cost
Console.WriteLine("Initial guess:");
double maxFixed = -GRB.INFINITY;
for (int p = 0; p < nPlants; ++p) {
    if (FixedCosts[p] > maxFixed) {
        maxFixed = FixedCosts[p];
    }
}
for (int p = 0; p < nPlants; ++p) {
    if (FixedCosts[p] == maxFixed) {
        open[p].Set(GRB.DoubleAttr.Start, 0.0);
        Console.WriteLine("Closing plant " + p + "\n");
        break;
    }
}

// Use barrier to solve root relaxation
model.GetEnv().Set(GRB.IntParam.Method, GRB.METHOD_BARRIER);

// Solve
model.Optimize();

// Print solution
Console.WriteLine("\nTOTAL COSTS: " + model.Get(GRB.DoubleAttr.ObjVal));
Console.WriteLine("SOLUTION:");
for (int p = 0; p < nPlants; ++p) {
    if (open[p].Get(GRB.DoubleAttr.X) == 1.0) {
        Console.WriteLine("Plant " + p + " open:");
        for (int w = 0; w < nWarehouses; ++w) {
            if (transport[w,p].Get(GRB.DoubleAttr.X) > 0.0001) {
                Console.WriteLine("  Transport " +
                    transport[w,p].Get(GRB.DoubleAttr.X) +
                    " units to warehouse " + w);
            }
        }
    } else {
        Console.WriteLine("Plant " + p + " closed!");
    }
}

```

```
    }

    // Dispose of model and env
    model.Dispose();
    env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## feasopt\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, adds artificial
   variables to each constraint, and then minimizes the sum of the
   artificial variables. A solution with objective zero corresponds
   to a feasible solution to the input model.
   We can also use FeasRelax feature to do it. In this example, we
   use minrelax=1, i.e. optimizing the returned model finds a solution
   that minimizes the original objective, but only from among those
   solutions that minimize the sum of the artificial variables. */

using Gurobi;
using System;

class feasopt_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: feasopt_cs filename");
            return;
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel feamodel = new GRBModel(env, args[0]);

            // Create a copy to use FeasRelax feature later */
            GRBModel feamodel1 = new GRBModel(feamodel);

            // Clear objective
            feamodel.SetObjective(new GRBLinExpr());

            // Add slack variables
            GRBConstr[] c = feamodel.GetConstrs();
            for (int i = 0; i < c.Length; ++i) {
                char sense = c[i].Get(GRB.CharAttr.Sense);
                if (sense != '>') {
                    GRBConstr[] constrs = new GRBConstr[] { c[i] };
                    double[] coeffs = new double[] { -1 };
                    feamodel.AddVar(0.0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, constrs,
                                    coeffs, "ArtN_" + c[i].Get(GRB.StringAttr.ConstrName));
                }
                if (sense != '<') {

```

```

        GRBConstr[] constrs = new GRBConstr[] { c[i] };
        double[] coeffs = new double[] { 1 };
        feasmodel.AddVar(0.0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, constrs,
            coeffs, "ArtP_" +
                c[i].Get(GRB.StringAttr.ConstrName));
    }
}
feasmodel.Update();

// Optimize modified model
feasmodel.Write("feasopt.lp");
feasmodel.Optimize();

// Use FeasRelax feature */
feasmodel1.FeasRelax(GRB.FEASRELAX_LINEAR, true, false, true);
feasmodel1.Write("feasopt1.lp");
feasmodel1.Optimize();

// Dispose of model and env
feasmodel1.Dispose();
feasmodel.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
}

```

## fixanddive\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Implement a simple MIP heuristic. Relax the model,
   sort variables based on fractionality, and fix the 25% of
   the fractional variables that are closest to integer variables.
   Repeat until either the relaxation is integer feasible or
   linearly infeasible. */

using System;
using System.Collections.Generic;
using Gurobi;

class fixanddive_cs
{
    // Comparison class used to sort variable list based on relaxation
    // fractionality

    class FractionalCompare : IComparer<GRBVar>
    {
        public int Compare(GRBVar v1, GRBVar v2)
        {
            try {
                double sol1 = Math.Abs(v1.Get(GRB.DoubleAttr.X));
                double sol2 = Math.Abs(v2.Get(GRB.DoubleAttr.X));
                double frac1 = Math.Abs(sol1 - Math.Floor(sol1 + 0.5));
                double frac2 = Math.Abs(sol2 - Math.Floor(sol2 + 0.5));
                if (frac1 < frac2) {
                    return -1;
                } else if (frac1 > frac2) {
                    return 1;
                } else {
                    return 0;
                }
            } catch (GRBException e) {
                Console.WriteLine("Error code: " + e.ErrorCode + ". " +
                    e.Message);
            }
            return 0;
        }
    }

    static void Main(string[] args)
    {
        if (args.Length < 1) {
```

```

    Console.Out.WriteLine("Usage: fixanddive_cs filename");
    return;
}

try {
    // Read model
    GRBEnv env = new GRBEnv();
    GRBModel model = new GRBModel(env, args[0]);

    // Collect integer variables and relax them
    List<GRBVar> intvars = new List<GRBVar>();
    foreach (GRBVar v in model.GetVars()) {
        if (v.Get(GRB.CharAttr.VType) != GRB.CONTINUOUS) {
            intvars.Add(v);
            v.Set(GRB.CharAttr.VType, GRB.CONTINUOUS);
        }
    }
}

model.GetEnv().Set(GRB.IntParam.OutputFlag, 0);
model.Optimize();

// Perform multiple iterations. In each iteration, identify the first
// quartile of integer variables that are closest to an integer value
// in the relaxation, fix them to the nearest integer, and repeat.

for (int iter = 0; iter < 1000; ++iter) {

    // create a list of fractional variables, sorted in order of
    // increasing distance from the relaxation solution to the nearest
    // integer value

    List<GRBVar> fractional = new List<GRBVar>();
    foreach (GRBVar v in intvars) {
        double sol = Math.Abs(v.Get(GRB.DoubleAttr.X));
        if (Math.Abs(sol - Math.Floor(sol + 0.5)) > 1e-5) {
            fractional.Add(v);
        }
    }

    Console.WriteLine("Iteration " + iter + ", obj " +
        model.Get(GRB.DoubleAttr.ObjVal) + ", fractional " +
        fractional.Count);

    if (fractional.Count == 0) {
        Console.WriteLine("Found feasible solution - objective " +

```

```

        model.Get(GRB.DoubleAttr.ObjVal));
    break;
}

// Fix the first quartile to the nearest integer value

fractional.Sort(new FractionalCompare());
int nfix = Math.Max(fractional.Count / 4, 1);
for (int i = 0; i < nfix; ++i) {
    GRBVar v = fractional[i];
    double fixval = Math.Floor(v.Get(GRB.DoubleAttr.X) + 0.5);
    v.Set(GRB.DoubleAttr.LB, fixval);
    v.Set(GRB.DoubleAttr.UB, fixval);
    Console.WriteLine(" Fix " + v.Get(GRB.StringAttr.VarName) +
        " to " + fixval + " ( rel " + v.Get(GRB.DoubleAttr.X) + " )");
}

model.Optimize();

// Check optimization result

if (model.Get(GRB.IntAttr.Status) != GRB.Status.OPTIMAL) {
    Console.WriteLine("Relaxation is infeasible");
    break;
}
}

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}
}

```

## lp\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model is infeasible or unbounded, the example turns off
   presolve and solves the model again. If the model is infeasible,
   the example computes an Irreducible Infeasible Subsystem (IIS),
   and writes it to a file. */

using System;
using Gurobi;

class lp_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.WriteLine("Usage: lp_cs filename");
            return;
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);

            model.Optimize();

            int optimstatus = model.Get(GRB.IntAttr.Status);

            if (optimstatus == GRB.Status.INF_OR_UNBD) {
                model.GetEnv().Set(GRB.IntParam.Presolve, 0);
                model.Optimize();
                optimstatus = model.Get(GRB.IntAttr.Status);
            }

            if (optimstatus == GRB.Status.OPTIMAL) {
                double objval = model.Get(GRB.DoubleAttr.ObjVal);
                Console.WriteLine("Optimal objective: " + objval);
            } else if (optimstatus == GRB.Status.INFEASIBLE) {
                Console.WriteLine("Model is infeasible");

                // compute and write out IIS

                model.ComputeIIS();
                model.Write("model.ilp");
            }
        }
    }
}
```

```
} else if (optimstatus == GRB.Status.UNBOUNDED) {
    Console.WriteLine("Model is unbounded");
} else {
    Console.WriteLine("Optimization was stopped with status = "
        + optimstatus);
}

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## lpmethod\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Solve a model with different values of the Method parameter;
   show which value gives the shortest solve time. */

using System;
using Gurobi;

class lpmethod_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: lpmethod_cs filename");
            return;
        }

        try {
            // Read model
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);
            GRBEnv menv = model.GetEnv();

            // Solve the model with different values of Method
            int bestMethod = -1;
            double bestTime = menv.Get(GRB.DoubleParam.TimeLimit);
            for (int i = 0; i <= 2; ++i)
            {
                model.Reset();
                menv.Set(GRB.IntParam.Method, i);
                model.Optimize();
                if (model.Get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL)
                {
                    bestTime = model.Get(GRB.DoubleAttr.Runtime);
                    bestMethod = i;
                    // Reduce the TimeLimit parameter to save time
                    // with other methods
                    menv.Set(GRB.DoubleParam.TimeLimit, bestTime);
                }
            }

            // Report which method was fastest
            if (bestMethod == -1) {
                Console.WriteLine("Unable to solve this model");
            }
        }
    }
}
```

```
} else {
    Console.WriteLine("Solved in " + bestTime
        + " seconds with Method: " + bestMethod);
}

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## lpmod\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads an LP model from a file and solves it.
   If the model can be solved, then it finds the smallest positive variable,
   sets its upper bound to zero, and resolves the model two ways:
   first with an advanced start, then without an advanced start
   (i.e. 'from scratch'). */

using System;
using Gurobi;

class lpmod_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.WriteLine("Usage: lpmod_cs filename");
            return;
        }

        try {
            // Read model and determine whether it is an LP
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);
            if (model.Get(GRB.IntAttr.IsMIP) != 0) {
                Console.WriteLine("The model is not a linear program");
                Environment.Exit(1);
            }

            model.Optimize();

            int status = model.Get(GRB.IntAttr.Status);

            if ((status == GRB.Status.INF_OR_UNBD) ||
                (status == GRB.Status.INFEASIBLE) ||
                (status == GRB.Status.UNBOUNDED)) {
                Console.WriteLine("The model cannot be solved because it is "
                    + "infeasible or unbounded");
                Environment.Exit(1);
            }

            if (status != GRB.Status.OPTIMAL) {
                Console.WriteLine("Optimization was stopped with status " + status);
                Environment.Exit(0);
            }
        }
    }
}
```

```

}

// Find the smallest variable value
double minVal = GRB.INFINITY;
GRBVar minVar = null;
foreach (GRBVar v in model.GetVars()) {
    double sol = v.Get(GRB.DoubleAttr.X);
    if ((sol > 0.0001) && (sol < minVal) &&
        (v.Get(GRB.DoubleAttr.LB) == 0.0)) {
        minVal = sol;
        minVar = v;
    }
}

Console.WriteLine("\n*** Setting " +
    minVar.Get(GRB.StringAttr.VarName) + " from " + minVal +
    " to zero ***\n");
minVar.Set(GRB.DoubleAttr.UB, 0.0);

// Solve from this starting point
model.Optimize();

// Save iteration & time info
double warmCount = model.Get(GRB.DoubleAttr.IterCount);
double warmTime = model.Get(GRB.DoubleAttr.Runtime);

// Reset the model and resolve
Console.WriteLine("\n*** Resetting and solving "
    + "without an advanced start ***\n");
model.Reset();
model.Optimize();

double coldCount = model.Get(GRB.DoubleAttr.IterCount);
double coldTime = model.Get(GRB.DoubleAttr.Runtime);

Console.WriteLine("\n*** Warm start: " + warmCount + " iterations, " +
    warmTime + " seconds");
Console.WriteLine("*** Cold start: " + coldCount + " iterations, " +
    coldTime + " seconds");

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {

```

```
        Console.WriteLine("Error code: " + e.ErrorCode + ". " +  
            e.Message);  
    }  
}  
}
```

## mip1\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple MIP model:

    maximize    x +  y + 2 z
    subject to  x + 2 y + 3 z <= 4
                x +  y          >= 1
    x, y, z binary
*/

using System;
using Gurobi;

class mip1_cs
{
    static void Main()
    {
        try {
            GRBEnv env = new GRBEnv("mip1.log");
            GRBModel model = new GRBModel(env);

            // Create variables

            GRBVar x = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, "x");
            GRBVar y = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, "y");
            GRBVar z = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, "z");

            // Integrate new variables

            model.Update();

            // Set objective: maximize x + y + 2 z

            model.SetObjective(x + y + 2 * z, GRB.MAXIMIZE);

            // Add constraint: x + 2 y + 3 z <= 4

            model.AddConstr(x + 2 * y + 3 * z <= 4.0, "c0");

            // Add constraint: x + y >= 1

            model.AddConstr(x + y >= 1.0, "c1");

            // Optimize model
```

```
model.Optimize();

Console.WriteLine(x.Get(GRB.StringAttr.VarName)
    + " " + x.Get(GRB.DoubleAttr.X));
Console.WriteLine(y.Get(GRB.StringAttr.VarName)
    + " " + y.Get(GRB.DoubleAttr.X));
Console.WriteLine(z.Get(GRB.StringAttr.VarName)
    + " " + z.Get(GRB.DoubleAttr.X));

Console.WriteLine("Obj: " + model.Get(GRB.DoubleAttr.ObjVal));

// Dispose of model and env

model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## mip2\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a MIP model from a file, solves it and
   prints the objective values from all feasible solutions
   generated while solving the MIP. Then it creates the fixed
   model and solves that model. */

using System;
using Gurobi;

class mip2_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: mip2_cs filename");
            return;
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env, args[0]);
            if (model.Get(GRB.IntAttr.IsMIP) == 0) {
                Console.WriteLine("Model is not a MIP");
                return;
            }

            model.Optimize();

            int optimstatus = model.Get(GRB.IntAttr.Status);
            double objval = 0;
            if (optimstatus == GRB.Status.OPTIMAL) {
                objval = model.Get(GRB.DoubleAttr.ObjVal);
                Console.WriteLine("Optimal objective: " + objval);
            } else if (optimstatus == GRB.Status.INF_OR_UNBD) {
                Console.WriteLine("Model is infeasible or unbounded");
                return;
            } else if (optimstatus == GRB.Status.INFEASIBLE) {
                Console.WriteLine("Model is infeasible");
                return;
            } else if (optimstatus == GRB.Status.UNBOUNDED) {
                Console.WriteLine("Model is unbounded");
                return;
            } else {
```

```

    Console.WriteLine("Optimization was stopped with status = "
        + optimstatus);
    return;
}

/* Iterate over the solutions and compute the objectives */

GRBVar[] vars = model.GetVars();
model.GetEnv().Set(GRB.IntParam.OutputFlag, 0);

Console.WriteLine();
for (int k = 0; k < model.Get(GRB.IntAttr.SolCount); ++k) {
    model.GetEnv().Set(GRB.IntParam.SolutionNumber, k);
    double objn = 0.0;

    for (int j = 0; j < vars.Length; j++) {
        objn += vars[j].Get(GRB.DoubleAttr.Obj)
            * vars[j].Get(GRB.DoubleAttr.Xn);
    }

    Console.WriteLine("Solution " + k + " has objective: " + objn);
}
Console.WriteLine();
model.GetEnv().Set(GRB.IntParam.OutputFlag, 1);

/* Create a fixed model, turn off presolve and solve */

GRBModel fixedmodel = model.FixedModel();

fixedmodel.GetEnv().Set(GRB.IntParam.Presolve, 0);

fixedmodel.Optimize();

int foptimstatus = fixedmodel.Get(GRB.IntAttr.Status);

if (foptimstatus != GRB.Status.OPTIMAL) {
    Console.WriteLine("Error: fixed model isn't optimal");
    return;
}

double fobjval = fixedmodel.Get(GRB.DoubleAttr.ObjVal);

if (Math.Abs(fobjval - objval) > 1.0e-6 * (1.0 + Math.Abs(objval))) {
    Console.WriteLine("Error: objective values are different");
    return;
}

```

```
}

GRBVar[] fvars = fixedmodel.GetVars();
double[] x     = fixedmodel.Get(GRB.DoubleAttr.X, fvars);
string[] vnames = fixedmodel.Get(GRB.StringAttr.VarName, fvars);

for (int j = 0; j < fvars.Length; j++) {
    if (x[j] != 0.0) Console.WriteLine(vnames[j] + " " + x[j]);
}

// Dispose of models and env
fixedmodel.Dispose();
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## params\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Use parameters that are associated with a model.

A MIP is solved for 5 seconds with different sets of parameters.
The one with the smallest MIP gap is selected, and the optimization
is resumed until the optimal solution is found.
*/

using System;
using Gurobi;

class params_cs
{
    // Simple function to determine the MIP gap
    private static double Gap(GRBModel model) {
        if ((model.Get(GRB.IntAttr.SolCount) == 0) ||
            (Math.Abs(model.Get(GRB.DoubleAttr.ObjVal)) < 1e-6)) {
            return GRB.INFINITY;
        }
        return Math.Abs(model.Get(GRB.DoubleAttr.ObjBound) -
            model.Get(GRB.DoubleAttr.ObjVal)) /
            Math.Abs(model.Get(GRB.DoubleAttr.ObjVal));
    }

    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: params_cs filename");
            return;
        }

        try {
            // Read model and verify that it is a MIP
            GRBEnv env = new GRBEnv();
            GRBModel basemodel = new GRBModel(env, args[0]);
            if (basemodel.Get(GRB.IntAttr.IsMIP) == 0) {
                Console.WriteLine("The model is not an integer program");
                Environment.Exit(1);
            }

            // Set a 5 second time limit
            basemodel.GetEnv().Set(GRB.DoubleParam.TimeLimit, 5);
        }
    }
}
```

```

// Now solve the model with different values of MIPFocus
double bestGap = GRB.INFINITY;
GRBModel bestModel = null;
for (int i = 0; i <= 3; ++i) {
    GRBModel m = new GRBModel(basemodel);
    m.GetEnv().Set(GRB.IntParam.MIPFocus, i);
    m.Optimize();
    if (bestModel == null || bestGap > Gap(m)) {
        bestModel = m;
        bestGap = Gap(bestModel);
    }
}

// Finally, reset the time limit and continue to solve the
// best model to optimality
bestModel.GetEnv().Set(GRB.DoubleParam.TimeLimit, GRB.INFINITY);
bestModel.Optimize();
Console.WriteLine("Solved with MIPFocus: " +
    bestModel.GetEnv().Get(GRB.IntParam.MIPFocus));

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}
}

```

## qcp\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example formulates and solves the following simple QCP model:

    maximize    x
    subject to  x + y + z = 1
                x^2 + y^2 <= z^2 (second-order cone)
                x^2 <= yz        (rotated second-order cone)
*/

using System;
using Gurobi;

class qcp_cs
{
    static void Main()
    {
        try {
            GRBEnv env = new GRBEnv("qcp.log");
            GRBModel model = new GRBModel(env);

            // Create variables

            GRBVar x = model.AddVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "x");
            GRBVar y = model.AddVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "y");
            GRBVar z = model.AddVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "z");

            // Integrate new variables

            model.Update();

            // Set objective

            GRBLinExpr obj = x;
            model.SetObjective(obj, GRB.MAXIMIZE);

            // Add linear constraint: x + y + z = 1

            model.AddConstr(x + y + z == 1.0, "c0");

            // Add second-order cone: x^2 + y^2 <= z^2

            model.AddQConstr(x*x + y*y <= z*z, "qc0");
        }
    }
}
```

```

// Add rotated cone:  $x^2 \leq yz$ 
model.AddQConstr(x*x <= y*z, "qc1");

// Optimize model
model.Optimize();

Console.WriteLine(x.Get(GRB.StringAttr.VarName)
    + " " + x.Get(GRB.DoubleAttr.X));
Console.WriteLine(y.Get(GRB.StringAttr.VarName)
    + " " + y.Get(GRB.DoubleAttr.X));
Console.WriteLine(z.Get(GRB.StringAttr.VarName)
    + " " + z.Get(GRB.DoubleAttr.X));

Console.WriteLine("Obj: " + model.Get(GRB.DoubleAttr.ObjVal) + " " +
    obj.Value);

// Dispose of model and env

model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}

```

## qp\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */  
  
/* This example formulates and solves the following simple QP model:
```

```
    minimize    x^2 + x*y + y^2 + y*z + z^2 + 2 x  
    subject to  x + 2 y + 3 z >= 4  
                x +   y       >= 1
```

```
    It solves it once as a continuous model, and once as an integer model.  
*/
```

```
using System;  
using Gurobi;
```

```
class qp_cs  
{  
    static void Main()  
    {  
        try {  
            GRBEnv env = new GRBEnv("qp.log");  
            GRBModel model = new GRBModel(env);  
  
            // Create variables  
  
            GRBVar x = model.AddVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "x");  
            GRBVar y = model.AddVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "y");  
            GRBVar z = model.AddVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "z");  
  
            // Integrate new variables  
  
            model.Update();  
  
            // Set objective  
  
            GRBQuadExpr obj = x*x + x*y + y*y + y*z + z*z + 2*x;  
            model.SetObjective(obj);  
  
            // Add constraint: x + 2 y + 3 z >= 4  
  
            model.AddConstr(x + 2 * y + 3 * z >= 4.0, "c0");  
  
            // Add constraint: x + y >= 1  
  
            model.AddConstr(x + y >= 1.0, "c1");
```

```

// Optimize model

model.Optimize();

Console.WriteLine(x.Get(GRB.StringAttr.VarName)
    + " " + x.Get(GRB.DoubleAttr.X));
Console.WriteLine(y.Get(GRB.StringAttr.VarName)
    + " " + y.Get(GRB.DoubleAttr.X));
Console.WriteLine(z.Get(GRB.StringAttr.VarName)
    + " " + z.Get(GRB.DoubleAttr.X));

Console.WriteLine("Obj: " + model.Get(GRB.DoubleAttr.ObjVal) + " " +
    obj.Value);

// Change variable types to integer

x.Set(GRB.CharAttr.VType, GRB.INTEGER);
y.Set(GRB.CharAttr.VType, GRB.INTEGER);
z.Set(GRB.CharAttr.VType, GRB.INTEGER);

// Optimize model

model.Optimize();

Console.WriteLine(x.Get(GRB.StringAttr.VarName)
    + " " + x.Get(GRB.DoubleAttr.X));
Console.WriteLine(y.Get(GRB.StringAttr.VarName)
    + " " + y.Get(GRB.DoubleAttr.X));
Console.WriteLine(z.Get(GRB.StringAttr.VarName)
    + " " + z.Get(GRB.DoubleAttr.X));

Console.WriteLine("Obj: " + model.Get(GRB.DoubleAttr.ObjVal) + " " +
    obj.Value);

// Dispose of model and env

model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}

```

}  
}

## sensitivity\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Simple MIP sensitivity analysis example.
   For each integer variable, fix it to its lower and upper bound
   and check the impact on the objective. */

using System;
using Gurobi;

class sensitivity_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: sensitivity_cs filename");
            return;
        }

        try {
            // Read model
            GRBEnv env = new GRBEnv();
            GRBModel a = new GRBModel(env, args[0]);
            a.Optimize();
            a.GetEnv().Set(GRB.IntParam.OutputFlag, 0);

            // Extract variables from model
            GRBVar[] avars = a.GetVars();

            for (int i = 0; i < avars.Length; ++i) {
                GRBVar v = avars[i];
                if (v.Get(GRB.CharAttr.VType) == GRB.BINARY) {

                    // Create clone and fix variable
                    GRBModel b = new GRBModel(a);
                    GRBVar bv = b.GetVars()[i];
                    if (v.Get(GRB.DoubleAttr.X) - v.Get(GRB.DoubleAttr.LB) < 0.5) {
                        bv.Set(GRB.DoubleAttr.LB, bv.Get(GRB.DoubleAttr.UB));
                    } else {
                        bv.Set(GRB.DoubleAttr.UB, bv.Get(GRB.DoubleAttr.LB));
                    }

                    b.Optimize();

                    if (b.Get(GRB.IntAttr.Status) == GRB.Status.OPTIMAL) {
```

```

        double objchg =
            b.Get(GRB.DoubleAttr.ObjVal) - a.Get(GRB.DoubleAttr.ObjVal);
        if (objchg < 0) {
            objchg = 0;
        }
        Console.WriteLine("Objective sensitivity for variable " +
            v.Get(GRB.StringAttr.VarName) + " is " + objchg);
    } else {
        Console.WriteLine("Objective sensitivity for variable " +
            v.Get(GRB.StringAttr.VarName) + " is infinite");
    }

    // Dispose of model
    b.Dispose();
}

// Dispose of model and env
a.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}
}

```

## SOS\_CS.CS

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example creates a very simple Special Ordered Set (SOS) model.
   The model consists of 3 continuous variables, no linear constraints,
   and a pair of SOS constraints of type 1. */

using System;
using Gurobi;

class sos_cs
{
    static void Main()
    {
        try {
            GRBEnv env = new GRBEnv();

            GRBModel model = new GRBModel(env);

            // Create variables

            double[] ub    = {1, 1, 2};
            double[] obj    = {-2, -1, -1};
            string[] names = {"x0", "x1", "x2"};

            GRBVar[] x = model.AddVars(null, ub, obj, null, names);

            // Integrate new variables

            model.Update();

            // Add first SOS1: x0=0 or x1=0

            GRBVar[] sosv1 = {x[0], x[1]};
            double[] soswt1 = {1, 2};

            model.AddSOS(sosv1, soswt1, GRB.SOS_TYPE1);

            // Add second SOS1: x0=0 or x2=0

            GRBVar[] sosv2 = {x[0], x[2]};
            double[] soswt2 = {1, 2};

            model.AddSOS(sosv2, soswt2, GRB.SOS_TYPE1);
```

```
// Optimize model

model.Optimize();

for (int i = 0; i < 3; i++)
    Console.WriteLine(x[i].Get(GRB.StringAttr.VarName) + " "
        + x[i].Get(GRB.DoubleAttr.X));

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## sudoku\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/*
Sudoku example.

The Sudoku board is a 9x9 grid, which is further divided into a 3x3 grid
of 3x3 grids. Each cell in the grid must take a value from 0 to 9.
No two grid cells in the same row, column, or 3x3 subgrid may take the
same value.

In the MIP formulation, binary variables  $x[i,j,v]$  indicate whether
cell  $\langle i,j \rangle$  takes value 'v'. The constraints are as follows:
1. Each cell must take exactly one value ( $\sum_v x[i,j,v] = 1$ )
2. Each value is used exactly once per row ( $\sum_i x[i,j,v] = 1$ )
3. Each value is used exactly once per column ( $\sum_j x[i,j,v] = 1$ )
4. Each value is used exactly once per 3x3 subgrid ( $\sum_{\text{grid}} x[i,j,v] = 1$ )

Input datasets for this example can be found in examples/data/sudoku*.
*/

using System;
using System.IO;
using Gurobi;

class sudoku_cs
{
    static void Main(string[] args)
    {
        int n = 9;
        int s = 3;

        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: sudoku_cs filename");
            return;
        }

        try {
            GRBEnv env = new GRBEnv();
            GRBModel model = new GRBModel(env);

            // Create 3-D array of model variables

            GRBVar[, ,] vars = new GRBVar[n,n,n];
```

```

for (int i = 0; i < n; i++) {
    for (int j = 0; j < n; j++) {
        for (int v = 0; v < n; v++) {
            string st = "G_" + i.ToString() + "_" + j.ToString()
                + "_" + v.ToString();
            vars[i,j,v] = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, st);
        }
    }
}

// Integrate variables into model

model.Update();

// Add constraints

GRBLinExpr expr;

// Each cell must take one value

for (int i = 0; i < n; i++) {
    for (int j = 0; j < n; j++) {
        expr = 0.0;
        for (int v = 0; v < n; v++)
            expr.AddTerm(1.0, vars[i,j,v]);
        string st = "V_" + i.ToString() + "_" + j.ToString();
        model.AddConstr(expr == 1.0, st);
    }
}

// Each value appears once per row

for (int i = 0; i < n; i++) {
    for (int v = 0; v < n; v++) {
        expr = 0.0;
        for (int j = 0; j < n; j++)
            expr.AddTerm(1.0, vars[i,j,v]);
        string st = "R_" + i.ToString() + "_" + v.ToString();
        model.AddConstr(expr == 1.0, st);
    }
}

// Each value appears once per column

for (int j = 0; j < n; j++) {

```

```

    for (int v = 0; v < n; v++) {
        expr = 0.0;
        for (int i = 0; i < n; i++)
            expr.AddTerm(1.0, vars[i,j,v]);
        string st = "C_" + j.ToString() + "_" + v.ToString();
        model.AddConstr(expr == 1.0, st);
    }
}

// Each value appears once per sub-grid

for (int v = 0; v < n; v++) {
    for (int i0 = 0; i0 < s; i0++) {
        for (int j0 = 0; j0 < s; j0++) {
            expr = 0.0;
            for (int i1 = 0; i1 < s; i1++) {
                for (int j1 = 0; j1 < s; j1++) {
                    expr.AddTerm(1.0, vars[i0*s+i1,j0*s+j1,v]);
                }
            }
            string st = "Sub_" + v.ToString() + "_" + i0.ToString()
                + "_" + j0.ToString();
            model.AddConstr(expr == 1.0, st);
        }
    }
}

// Update model

model.Update();

// Fix variables associated with pre-specified cells

StreamReader sr = File.OpenText(args[0]);

for (int i = 0; i < n; i++) {
    string input = sr.ReadLine();
    for (int j = 0; j < n; j++) {
        int val = (int) input[j] - 48 - 1; // 0-based

        if (val >= 0)
            vars[i,j,val].Set(GRB.DoubleAttr.LB, 1.0);
    }
}

```

```

// Optimize model

model.Optimize();

// Write model to file
model.Write("sudoku.lp");

double[, ,] x = model.Get(GRB.DoubleAttr.X, vars);

Console.WriteLine();
for (int i = 0; i < n; i++) {
    for (int j = 0; j < n; j++) {
        for (int v = 0; v < n; v++) {
            if (x[i,j,v] > 0.5) {
                Console.Write(v+1);
            }
        }
    }
    Console.WriteLine();
}

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}

```

## tsp\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

// Solve a traveling salesman problem on a randomly generated set of
// points using lazy constraints. The base MIP model only includes
// 'degree-2' constraints, requiring each node to have exactly
// two incident edges. Solutions to this model may contain subtours -
// tours that don't visit every node. The lazy constraint callback
// adds new constraints to cut them off.

using System;
using Gurobi;

class tsp_cs : GRBCallback {
    private GRBVar[,] vars;

    public tsp_cs(GRBVar[,] xvars) {
        vars = xvars;
    }

    // Subtour elimination callback. Whenever a feasible solution is found,
    // find the smallest subtour, and add a subtour elimination
    // constraint if the tour doesn't visit every node.

    protected override void Callback() {
        try {
            if (where == GRB.Callback.MIPSOL) {
                // Found an integer feasible solution - does it visit every node?

                int n = vars.GetLength(0);
                int[] tour = findsubtour(GetSolution(vars));

                if (tour.Length < n) {
                    // Add subtour elimination constraint
                    GRBLinExpr expr = 0;
                    for (int i = 0; i < tour.Length; i++)
                        for (int j = i+1; j < tour.Length; j++)
                            expr.AddTerm(1.0, vars[tour[i], tour[j]]);
                    AddLazy(expr <= tour.Length-1);
                }
            }
        } catch (GRBException e) {
            Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
            Console.WriteLine(e.StackTrace);
        }
    }
}
```

```

}

// Given an integer-feasible solution 'sol', return the smallest
// sub-tour (as a list of node indices).

protected static int[] findsubtour(double[,] sol)
{
    int n = sol.GetLength(0);
    bool[] seen = new bool[n];
    int[] tour = new int[n];
    int bestind, bestlen;
    int i, node, len, start;

    for (i = 0; i < n; i++)
        seen[i] = false;

    start = 0;
    bestlen = n+1;
    bestind = -1;
    node = 0;
    while (start < n) {
        for (node = 0; node < n; node++)
            if (!seen[node])
                break;
        if (node == n)
            break;
        for (len = 0; len < n; len++) {
            tour[start+len] = node;
            seen[node] = true;
            for (i = 0; i < n; i++) {
                if (sol[node, i] > 0.5 && !seen[i]) {
                    node = i;
                    break;
                }
            }
        }
        if (i == n) {
            len++;
            if (len < bestlen) {
                bestlen = len;
                bestind = start;
            }
            start += len;
            break;
        }
    }
}

```

```

    }

    for (i = 0; i < bestlen; i++)
        tour[i] = tour[bestind+i];
    System.Array.Resize(ref tour, bestlen);

    return tour;
}

// Euclidean distance between points 'i' and 'j'

protected static double distance(double[] x,
                                  double[] y,
                                  int i,
                                  int j) {

    double dx = x[i]-x[j];
    double dy = y[i]-y[j];
    return Math.Sqrt(dx*dx+dy*dy);
}

public static void Main(String[] args) {

    if (args.Length < 1) {
        Console.WriteLine("Usage: tsp_cs nnodes");
        return;
    }

    int n = Convert.ToInt32(args[0]);

    try {
        GRBEnv env = new GRBEnv();
        GRBModel model = new GRBModel(env);

        // Must set LazyConstraints parameter when using lazy constraints

        model.GetEnv().Set(GRB.IntParam.LazyConstraints, 1);

        double[] x = new double[n];
        double[] y = new double[n];

        Random r = new Random();
        for (int i = 0; i < n; i++) {
            x[i] = r.NextDouble();
            y[i] = r.NextDouble();
        }
    }
}

```

```

// Create variables

GRBVar[,] vars = new GRBVar[n, n];

for (int i = 0; i < n; i++)
    for (int j = 0; j < n; j++)
        vars[i, j] = model.AddVar(0.0, 1.0, distance(x, y, i, j),
                                   GRB.BINARY, "x"+i+"_"+j);

// Integrate variables

model.Update();

// Degree-2 constraints

for (int i = 0; i < n; i++) {
    GRBLinExpr expr = 0;
    for (int j = 0; j < n; j++)
        expr.AddTerm(1.0, vars[i, j]);
    model.AddConstr(expr == 2.0, "deg2_"+i);
}

// Forbid edge from node back to itself

for (int i = 0; i < n; i++)
    vars[i, i].Set(GRB.DoubleAttr.UB, 0.0);

// Symmetric TSP

for (int i = 0; i < n; i++)
    for (int j = 0; j < i; j++)
        model.AddConstr(vars[i, j] == vars[j, i], "");

model.SetCallback(new tsp_cs(vars));
model.Optimize();

if (model.Get(GRB.IntAttr.SolCount) > 0) {
    int[] tour = findsubtour(model.Get(GRB.DoubleAttr.X, vars));

    Console.WriteLine("Tour: ");
    for (int i = 0; i < tour.Length; i++)
        Console.Write(tour[i] + " ");
    Console.WriteLine();
}

```

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

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
    Console.WriteLine(e.StackTrace);
}
}
}
```

## tune\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* This example reads a model from a file and tunes it.
   It then writes the best parameter settings to a file
   and solves the model using these parameters. */

using System;
using Gurobi;

class tune_cs
{
    static void Main(string[] args)
    {
        if (args.Length < 1) {
            Console.Out.WriteLine("Usage: tune_cs filename");
            return;
        }

        try {
            GRBEnv env = new GRBEnv();

            // Read model from file
            GRBModel model = new GRBModel(env, args[0]);

            // Set the TuneResults parameter to 1
            model.GetEnv().Set(GRB.IntParam.TuneResults, 1);

            // Tune the model
            model.Tune();

            // Get the number of tuning results
            int resultcount = model.Get(GRB.IntAttr.TuneResultCount);

            if (resultcount > 0) {

                // Load the tuned parameters into the model's environment
                model.GetTuneResult(0);

                // Write the tuned parameters to a file
                model.Write("tune.prm");

                // Solve the model using the tuned parameters
                model.Optimize();
            }
        }
    }
}
```

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

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " + e.Message);
}
}
}
```

## workforce1\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, use IIS to find a set of
conflicting constraints. Note that there may be additional conflicts
besides what is reported via IIS. */

using System;
using Gurobi;

class workforce1_cs
{
    static void Main()
    {
        try {

            // Sample data
            // Sets of days and workers
            string[] Shifts =
                new string[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            string[] Workers =
                new string[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.Length;
            int nWorkers = Workers.Length;

            // Number of workers required for each shift
            double[] shiftRequirements =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Amount each worker is paid to work one shift
            double[] pay = new double[] { 10, 12, 10, 8, 8, 9, 11 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double[,] availability =
                new double[,] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };
        }
    }
}
```

```

// Model
GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.Set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
GRBVar[,] x = new GRBVar[nWorkers,nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w,s] =
            model.AddVar(0, availability[w,s], pay[w], GRB.CONTINUOUS,
                Workers[w] + "." + Shifts[s]);
    }
}

// The objective is to minimize the total pay costs
model.Set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.Update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s) {
    GRBLinExpr lhs = 0.0;
    for (int w = 0; w < nWorkers; ++w)
        lhs.AddTerm(1.0, x[w, s]);
    model.AddConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Optimize
model.Optimize();
int status = model.Get(GRB.IntAttr.Status);
if (status == GRB.Status.UNBOUNDED) {
    Console.WriteLine("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {
    Console.WriteLine("The optimal objective is " +
        model.Get(GRB.DoubleAttr.ObjVal));
    return;
}

```

```

    }
    if ((status != GRB.Status.INF_OR_UNBD) &&
        (status != GRB.Status.INFEASIBLE)) {
        Console.WriteLine("Optimization was stopped with status " + status);
        return;
    }

    // Do IIS
    Console.WriteLine("The model is infeasible; computing IIS");
    model.ComputeIIS();
    Console.WriteLine("\nThe following constraint(s) "
        + "cannot be satisfied:");
    foreach (GRBConstr c in model.GetConstrs()) {
        if (c.Get(GRB.IntAttr.IISConstr) == 1) {
            Console.WriteLine(c.Get(GRB.StringAttr.ConstrName));
        }
    }

    // Dispose of model and env
    model.Dispose();
    env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}
}

```

## workforce2\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, use IIS iteratively to
find all conflicting constraints. */

using System;
using System.Collections.Generic;
using Gurobi;

class workforce2_cs
{
    static void Main()
    {
        try {

            // Sample data
            // Sets of days and workers
            string[] Shifts =
                new string[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            string[] Workers =
                new string[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.Length;
            int nWorkers = Workers.Length;

            // Number of workers required for each shift
            double[] shiftRequirements =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Amount each worker is paid to work one shift
            double[] pay = new double[] { 10, 12, 10, 8, 8, 9, 11 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double[,] availability =
                new double[,] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };
        }
    }
}
```

```

// Model
GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.Set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
GRBVar[,] x = new GRBVar[nWorkers,nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w,s] =
            model.AddVar(0, availability[w,s], pay[w], GRB.CONTINUOUS,
                Workers[w] + "." + Shifts[s]);
    }
}

// The objective is to minimize the total pay costs
model.Set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.Update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
for (int s = 0; s < nShifts; ++s) {
    GRBLinExpr lhs = 0.0;
    for (int w = 0; w < nWorkers; ++w)
        lhs.AddTerm(1.0, x[w, s]);
    model.AddConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Optimize
model.Optimize();
int status = model.Get(GRB.IntAttr.Status);
if (status == GRB.Status.UNBOUNDED) {
    Console.WriteLine("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {
    Console.WriteLine("The optimal objective is " +
        model.Get(GRB.DoubleAttr.ObjVal));
    return;
}

```

```

}
if ((status != GRB.Status.INF_OR_UNBD) &&
    (status != GRB.Status.INFEASIBLE)) {
    Console.WriteLine("Optimization was stopped with status " + status);
    return;
}

// Do IIS
Console.WriteLine("The model is infeasible; computing IIS");
LinkedList<string> removed = new LinkedList<string>();

// Loop until we reduce to a model that can be solved
while (true) {
    model.ComputeIIS();
    Console.WriteLine("\nThe following constraint cannot be satisfied:");
    foreach (GRBConstr c in model.GetConstrs()) {
        if (c.Get(GRB.IntAttr.IISConstr) == 1) {
            Console.WriteLine(c.Get(GRB.StringAttr.ConstrName));
            // Remove a single constraint from the model
            removed.AddFirst(c.Get(GRB.StringAttr.ConstrName));
            model.Remove(c);
            break;
        }
    }
}

Console.WriteLine();
model.Optimize();
status = model.Get(GRB.IntAttr.Status);

if (status == GRB.Status.UNBOUNDED) {
    Console.WriteLine("The model cannot be solved "
        + "because it is unbounded");
    return;
}
if (status == GRB.Status.OPTIMAL) {
    break;
}
if ((status != GRB.Status.INF_OR_UNBD) &&
    (status != GRB.Status.INFEASIBLE)) {
    Console.WriteLine("Optimization was stopped with status " +
        status);
    return;
}
}

```

```
Console.WriteLine("\nThe following constraints were removed "
    + "to get a feasible LP:");
foreach (string s in removed) {
    Console.Write(s + " ");
}
Console.WriteLine();

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}
}
```

## workforce3\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. If the problem cannot be solved, add slack variables
to determine which constraints cannot be satisfied, and how much
they need to be relaxed. */

using System;
using System.Collections.Generic;
using Gurobi;

class workforce3_cs
{
    static void Main()
    {
        try {

            // Sample data
            // Sets of days and workers
            string[] Shifts =
                new string[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            string[] Workers =
                new string[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.Length;
            int nWorkers = Workers.Length;

            // Number of workers required for each shift
            double[] shiftRequirements =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Amount each worker is paid to work one shift
            double[] pay = new double[] { 10, 12, 10, 8, 8, 9, 11 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double[,] availability =
                new double[,] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 } };
        }
    }
}
```

```

        { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

// Model
GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.Set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. Since an assignment model always produces integer
// solutions, we use continuous variables and solve as an LP.
GRBVar[,] x = new GRBVar[nWorkers,nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w,s] =
            model.AddVar(0, availability[w,s], pay[w], GRB.CONTINUOUS,
                Workers[w] + "." + Shifts[s]);
    }
}

// The objective is to minimize the total pay costs
model.Set(GRB.IntAttr.ModelSense, 1);

// Update model to integrate new variables
model.Update();

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s
LinkedList<GRBConstr> reqCts = new LinkedList<GRBConstr>();
for (int s = 0; s < nShifts; ++s) {
    GRBLinExpr lhs = 0.0;
    for (int w = 0; w < nWorkers; ++w)
        lhs.AddTerm(1.0, x[w,s]);
    GRBConstr newCt =
        model.AddConstr(lhs == shiftRequirements[s], Shifts[s]);
    reqCts.AddFirst(newCt);
}

// Optimize
model.Optimize();
int status = model.Get(GRB.IntAttr.Status);
if (status == GRB.Status.UNBOUNDED) {
    Console.WriteLine("The model cannot be solved "
        + "because it is unbounded");
    return;
}
}

```

```

if (status == GRB.Status.OPTIMAL) {
    Console.WriteLine("The optimal objective is " +
        model.Get(GRB.DoubleAttr.ObjVal));
    return;
}
if ((status != GRB.Status.INF_OR_UNBD) &&
    (status != GRB.Status.INFEASIBLE)) {
    Console.WriteLine("Optimization was stopped with status " + status);
    return;
}

// Add slack variables to make the model feasible
Console.WriteLine("The model is infeasible; adding slack variables");

// Set original objective coefficients to zero
model.SetObjective(new GRBLinExpr());

// Add a new slack variable to each shift constraint so that the shifts
// can be satisfied
LinkedList<GRBVar> slacks = new LinkedList<GRBVar>();
foreach (GRBConstr c in reqCts) {
    GRBColumn col = new GRBColumn();
    col.AddTerm(1.0, c);
    GRBVar newvar =
        model.AddVar(0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, col,
            c.Get(GRB.StringAttr.ConstrName) + "Slack");
    slacks.AddFirst(newvar);
}

// Solve the model with slacks
model.Optimize();
status = model.Get(GRB.IntAttr.Status);
if ((status == GRB.Status.INF_OR_UNBD) ||
    (status == GRB.Status.INFEASIBLE) ||
    (status == GRB.Status.UNBOUNDED)) {
    Console.WriteLine("The model with slacks cannot be solved "
        + "because it is infeasible or unbounded");
    return;
}
if (status != GRB.Status.OPTIMAL) {
    Console.WriteLine("Optimization was stopped with status " + status);
    return;
}

Console.WriteLine("\nSlack values:");

```

```
foreach (GRBVar sv in slacks) {
    if (sv.Get(GRB.DoubleAttr.X) > 1e-6) {
        Console.WriteLine(sv.Get(GRB.StringAttr.VarName) + " = " +
            sv.Get(GRB.DoubleAttr.X));
    }
}

// Dispose of model and env
model.Dispose();
env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}
}
```

## workforce4\_cs.cs

```
/* Copyright 2013, Gurobi Optimization, Inc. */

/* Assign workers to shifts; each worker may or may not be available on a
particular day. We use Pareto optimization to solve the model:
first, we minimize the linear sum of the slacks. Then, we constrain
the sum of the slacks, and we minimize a quadratic objective that
tries to balance the workload among the workers. */

using System;
using Gurobi;

class workforce4_cs
{
    static void Main()
    {
        try {

            // Sample data
            // Sets of days and workers
            string[] Shifts =
                new string[] { "Mon1", "Tue2", "Wed3", "Thu4", "Fri5", "Sat6",
                    "Sun7", "Mon8", "Tue9", "Wed10", "Thu11", "Fri12", "Sat13",
                    "Sun14" };
            string[] Workers =
                new string[] { "Amy", "Bob", "Cathy", "Dan", "Ed", "Fred", "Gu" };

            int nShifts = Shifts.Length;
            int nWorkers = Workers.Length;

            // Number of workers required for each shift
            double[] shiftRequirements =
                new double[] { 3, 2, 4, 4, 5, 6, 5, 2, 2, 3, 4, 6, 7, 5 };

            // Worker availability: 0 if the worker is unavailable for a shift
            double[,] availability =
                new double[,] { { 0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0 },
                    { 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1 },
                    { 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1 },
                    { 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1 },
                    { 1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1 },
                    { 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 } };

            // Model
```

```

GRBEnv env = new GRBEnv();
GRBModel model = new GRBModel(env);
model.Set(GRB.StringAttr.ModelName, "assignment");

// Assignment variables: x[w][s] == 1 if worker w is assigned
// to shift s. This is no longer a pure assignment model, so we must
// use binary variables.
GRBVar[,] x = new GRBVar[nWorkers, nShifts];
for (int w = 0; w < nWorkers; ++w) {
    for (int s = 0; s < nShifts; ++s) {
        x[w,s] =
            model.AddVar(0, availability[w,s], 0, GRB.BINARY,
                Workers[w] + "." + Shifts[s]);
    }
}

// Slack variables for each shift constraint so that the shifts can
// be satisfied
GRBVar[] slacks = new GRBVar[nShifts];
for (int s = 0; s < nShifts; ++s) {
    slacks[s] =
        model.AddVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS,
            Shifts[s] + "Slack");
}

// Variable to represent the total slack
GRBVar totSlack = model.AddVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS,
    "totSlack");

// Variables to count the total shifts worked by each worker
GRBVar[] totShifts = new GRBVar[nWorkers];
for (int w = 0; w < nWorkers; ++w) {
    totShifts[w] = model.AddVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS,
        Workers[w] + "TotShifts");
}

// Update model to integrate new variables
model.Update();

GRBLinExpr lhs;

// Constraint: assign exactly shiftRequirements[s] workers
// to each shift s, plus the slack
for (int s = 0; s < nShifts; ++s) {
    lhs = new GRBLinExpr();

```

```

    lhs.AddTerm(1.0, slacks[s]);
    for (int w = 0; w < nWorkers; ++w) {
        lhs.AddTerm(1.0, x[w, s]);
    }
    model.AddConstr(lhs == shiftRequirements[s], Shifts[s]);
}

// Constraint: set totSlack equal to the total slack
lhs = new GRBLinExpr();
for (int s = 0; s < nShifts; ++s) {
    lhs.AddTerm(1.0, slacks[s]);
}
model.AddConstr(lhs == totSlack, "totSlack");

// Constraint: compute the total number of shifts for each worker
for (int w = 0; w < nWorkers; ++w) {
    lhs = new GRBLinExpr();
    for (int s = 0; s < nShifts; ++s) {
        lhs.AddTerm(1.0, x[w, s]);
    }
    model.AddConstr(lhs == totShifts[w], "totShifts" + Workers[w]);
}

// Objective: minimize the total slack
model.SetObjective(1.0*totSlack);

// Optimize
int status = solveAndPrint(model, totSlack, nWorkers, Workers, totShifts);
if (status != GRB.Status.OPTIMAL) {
    return;
}

// Constrain the slack by setting its upper and lower bounds
totSlack.Set(GRB.DoubleAttr.UB, totSlack.Get(GRB.DoubleAttr.X));
totSlack.Set(GRB.DoubleAttr.LB, totSlack.Get(GRB.DoubleAttr.X));

// Variable to count the average number of shifts worked
GRBVar avgShifts =
    model.AddVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS, "avgShifts");

// Variables to count the difference from average for each worker;
// note that these variables can take negative values.
GRBVar[] diffShifts = new GRBVar[nWorkers];
for (int w = 0; w < nWorkers; ++w) {
    diffShifts[w] = model.AddVar(-GRB.INFINITY, GRB.INFINITY, 0,

```

```

        GRB.CONTINUOUS, Workers[w] + "Diff");
    }

    // Update model to integrate new variables
    model.Update();

    // Constraint: compute the average number of shifts worked
    lhs = new GRBLinExpr();
    for (int w = 0; w < nWorkers; ++w) {
        lhs.AddTerm(1.0, totShifts[w]);
    }
    model.AddConstr(lhs == nWorkers * avgShifts, "avgShifts");

    // Constraint: compute the difference from the average number of shifts
    for (int w = 0; w < nWorkers; ++w) {
        model.AddConstr(totShifts[w] - avgShifts == diffShifts[w],
            Workers[w] + "Diff");
    }

    // Objective: minimize the sum of the square of the difference from the
    // average number of shifts worked
    GRBQuadExpr qobj = new GRBQuadExpr();
    for (int w = 0; w < nWorkers; ++w) {
        qobj.AddTerm(1.0, diffShifts[w], diffShifts[w]);
    }
    model.SetObjective(qobj);

    // Optimize
    status = solveAndPrint(model, totSlack, nWorkers, Workers, totShifts);
    if (status != GRB.Status.OPTIMAL) {
        return;
    }

    // Dispose of model and env
    model.Dispose();
    env.Dispose();

} catch (GRBException e) {
    Console.WriteLine("Error code: " + e.ErrorCode + ". " +
        e.Message);
}
}

private static int solveAndPrint(GRBModel model, GRBVar totSlack,
    int nWorkers, String[] Workers,

```

```

                                GRBVar[] totShifts)
{
    model.Optimize();
    int status = model.Get(GRB.IntAttr.Status);
    if ((status == GRB.Status.INF_OR_UNBD) ||
        (status == GRB.Status.INFEASIBLE) ||
        (status == GRB.Status.UNBOUNDED)) {
        Console.WriteLine("The model cannot be solved "
            + "because it is infeasible or unbounded");
        return status;
    }
    if (status != GRB.Status.OPTIMAL) {
        Console.WriteLine("Optimization was stopped with status " + status);
        return status;
    }

    // Print total slack and the number of shifts worked for each worker
    Console.WriteLine("\nTotal slack required: " +
        totSlack.Get(GRB.DoubleAttr.X));
    for (int w = 0; w < nWorkers; ++w) {
        Console.WriteLine(Workers[w] + " worked " +
            totShifts[w].Get(GRB.DoubleAttr.X) + " shifts");
    }
    Console.WriteLine("\n");
    return status;
}
}

```

## 3.5 Visual Basic Examples

This section includes source code for all of the Gurobi Visual Basic examples. The same source code can be found in the `examples/vb` directory of the Gurobi distribution.

### callback\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example reads an LP or a MIP from a file, sets a callback
' to monitor the optimization progress and to output some progress
' information to the screen and to a log file. If it is a MIP and 10%
' gap is reached, then it aborts.

Imports System
Imports Gurobi

Class callback_vb
    Inherits GRBCallback
    Private vars As GRBVar()
    Private lastnode As Double
    Private lasttiter As Double

    Public Sub New(ByVal xvars As GRBVar())
        vars = xvars
        lastnode = lasttiter = -1
    End Sub

    Protected Overloads Overrides Sub Callback()
        Try
            If where = GRB.Callback.PRESOLVE Then
                ' Presolve callback
                Dim cdels As Integer = GetIntInfo(GRB.Callback.PRE_COLDEL)
                Dim rdels As Integer = GetIntInfo(GRB.Callback.PRE_ROWDEL)
                Console.WriteLine(cdels & " columns and " & rdels & " rows are removed")
            ElseIf where = GRB.Callback.SIMPLEX Then
                ' Simplex callback
                Dim itcnt As Double = GetDoubleInfo(GRB.Callback.SPX_ITRCNT)
                If itcnt Mod - lasttiter >= 100 Then
                    lasttiter = itcnt
                    Dim obj As Double = GetDoubleInfo(GRB.Callback.SPX_OBJVAL)
                    Dim pinf As Double = GetDoubleInfo(GRB.Callback.SPX_PRIMINF)
                    Dim dinf As Double = GetDoubleInfo(GRB.Callback.SPX_DUALINF)
                    Dim ispert As Integer = GetIntInfo(GRB.Callback.SPX_ISPERT)
                    Dim ch As Char
                    If ispert = 0 Then
```

```

        ch = " "c
    ElseIf ispert = 1 Then
        ch = "S"c
    Else
        ch = "P"c
    End If
    Console.WriteLine(itcnt & " " & obj & ch & " " & pinf & " " & dinf)
End If
ElseIf where = GRB.Callback.MIP Then
    ' General MIP callback
    Dim nodecnt As Double = GetDoubleInfo(GRB.Callback.MIP_NODCNT)
    If nodecnt - lastnode >= 100 Then
        lastnode = nodecnt
        Dim objbst As Double = GetDoubleInfo(GRB.Callback.MIP_OBJBST)
        Dim objbnd As Double = GetDoubleInfo(GRB.Callback.MIP_OBJBND)
        If Math.Abs(objbst - objbnd) < 0.1 * (1.0R + Math.Abs(objbst)) Then
            Abort()
        End If
        Dim actnodes As Integer = CInt(GetDoubleInfo(GRB.Callback.MIP_NODLFT))
        Dim itcnt As Integer = CInt(GetDoubleInfo(GRB.Callback.MIP_ITRCNT))
        Dim solcnt As Integer = GetIntInfo(GRB.Callback.MIP_SOLCNT)
        Dim cutcnt As Integer = GetIntInfo(GRB.Callback.MIP_CUTCNT)
        Console.WriteLine(nodecnt & " " & actnodes & " " & itcnt & " " & _
            objbst & " " & objbnd & " " & solcnt & " " & cutcnt)
    End If
ElseIf where = GRB.Callback.MIPSOL Then
    ' MIP solution callback
    Dim obj As Double = GetDoubleInfo(GRB.Callback.MIPSOL_OBJ)
    Dim nodecnt As Integer = CInt(GetDoubleInfo(GRB.Callback.MIPSOL_NODCNT))
    Dim x As Double() = GetSolution(vars)
    Console.WriteLine("**** New solution at node " & nodecnt & ", obj " & _
        obj & ", x(0) = " & x(0) & "****")
End If
Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
    Console.WriteLine(e.StackTrace)
End Try
End Sub

Shared Sub Main(ByVal args As String())

    If args.Length < 1 Then
        Console.WriteLine("Usage: callback_vb filename")
        Return
    End If

```

```

Try
  Dim env As New GRBEnv()
  Dim model As New GRBModel(env, args(0))

  Dim vars As GRBVar() = model.GetVars()

  ' Create a callback object and associate it with the model
  model.SetCallback(New callback_vb(vars))
  model.Optimize()

  Dim x As Double() = model.Get(GRB.DoubleAttr.X, vars)
  Dim vnames As String() = model.Get(GRB.StringAttr.VarName, vars)

  For j As Integer = 0 To vars.Length - 1
    If x(j) <> 0.0R Then
      Console.WriteLine(vnames(j) & " " & x(j))
    End If
  Next

  ' Dispose of model and env
  model.Dispose()
  env.Dispose()

Catch e As GRBException
  Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
  Console.WriteLine(e.StackTrace)
End Try
End Sub
End Class

```

## dense\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example formulates and solves the following simple QP model:
',
' minimize    x + y + x^2 + x*y + y^2 + y*z + z^2
' subject to  x + 2 y + 3 z >= 4
'             x +   y       >= 1
',
' The example illustrates the use of dense matrices to store A and Q
' (and dense vectors for the other relevant data). We don't recommend
' that you use dense matrices, but this example may be helpful if you
' already have your data in this format.
```

```
Imports Gurobi
```

```
Class dense_vb
```

```
Protected Shared Function _
```

```
    dense_optimize(env As GRBEnv, _
                    rows As Integer, _
                    cols As Integer, _
                    c As Double(), _
                    Q As Double(), _
                    A As Double(), _
                    sense As Char(), _
                    rhs As Double(), _
                    lb As Double(), _
                    ub As Double(), _
                    vtype As Char(), _
                    solution As Double()) As Boolean
```

```
Dim success As Boolean = False
```

```
Try
```

```
    Dim model As New GRBModel(env)
```

```
    ' Add variables to the model
```

```
    Dim vars As GRBVar() = model.AddVars(lb, ub, Nothing, vtype, Nothing)
    model.Update()
```

```
    ' Populate A matrix
```

```
    For i As Integer = 0 To rows - 1
```

```

    Dim expr As New GRBLinExpr()
    For j As Integer = 0 To cols - 1
        If A(i, j) <> 0 Then
            expr.AddTerm(A(i, j), vars(j))
        End If
    Next
    model.AddConstr(expr, sense(i), rhs(i), "")
Next

' Populate objective

Dim obj As New GRBQuadExpr()
If Q IsNot Nothing Then
    For i As Integer = 0 To cols - 1
        For j As Integer = 0 To cols - 1
            If Q(i, j) <> 0 Then
                obj.AddTerm(Q(i, j), vars(i), vars(j))
            End If
        Next
    Next
    For j As Integer = 0 To cols - 1
        If c(j) <> 0 Then
            obj.AddTerm(c(j), vars(j))
        End If
    Next
    model.SetObjective(obj)
End If

' Solve model

model.Optimize()

' Extract solution

If model.Get(GRB.IntAttr.Status) = GRB.Status.OPTIMAL Then
    success = True

    For j As Integer = 0 To cols - 1
        solution(j) = vars(j).Get(GRB.DoubleAttr.X)
    Next
End If

model.Dispose()

Catch e As GRBException

```

```

        Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
    End Try

    Return success
End Function

Public Shared Sub Main(args As String())
    Try
        Dim env As New GRBEnv()

        Dim c As Double() = New Double() {1, 1, 0}
        Dim Q As Double(,) = New Double(,) {{1, 1, 0}, {0, 1, 1}, {0, 0, 1}}
        Dim A As Double(,) = New Double(,) {{1, 2, 3}, {1, 1, 0}}
        Dim sense As Char() = New Char() {">"C, ">"C}
        Dim rhs As Double() = New Double() {4, 1}
        Dim lb As Double() = New Double() {0, 0, 0}
        Dim success As Boolean
        Dim sol As Double() = New Double(2) {}

        success = dense_optimize(env, 2, 3, c, Q, A, sense, rhs, lb, Nothing, _
                                Nothing, sol)

        If success Then
            Console.WriteLine("x: " & sol(0) & ", y: " & sol(1) & ", z: " & sol(2))
        End If

        ' Dispose of environment

        env.Dispose()

        Catch e As GRBException
            Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
        End Try

    End Sub
End Class

```

## diet\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.

' Solve the classic diet model, showing how to add constraints
' to an existing model.

Imports System
Imports Gurobi

Class diet_vb
    Shared Sub Main()
        Try

            ' Nutrition guidelines, based on
            ' USDA Dietary Guidelines for Americans, 2005
            ' http://www.health.gov/DietaryGuidelines/dga2005/
            Dim Categories As String() = New String() {"calories", "protein", "fat", _
                "sodium"}

            Dim nCategories As Integer = Categories.Length
            Dim minNutrition As Double() = New Double() {1800, 91, 0, 0}
            Dim maxNutrition As Double() = New Double() {2200, GRB.INFINITY, 65, 1779}

            ' Set of foods
            Dim Foods As String() = New String() {"hamburger", "chicken", "hot dog", _
                "fries", "macaroni", "pizza", _
                "salad", "milk", "ice cream"}

            Dim nFoods As Integer = Foods.Length
            Dim cost As Double() = New Double() {2.49, 2.89, 1.5R, 1.89, 2.09, 1.99, _
                2.49, 0.89, 1.59}

            ' Nutrition values for the foods
            ' hamburger
            ' chicken
            ' hot dog
            ' fries
            ' macaroni
            ' pizza
            ' salad
            ' milk
            ' ice cream
            Dim nutritionValues As Double(,) = New Double(,) {{410, 24, 26, 730}, _
                {420, 32, 10, 1190}, _
                {560, 20, 32, 1800}, _
                {380, 4, 19, 270}, _
                {320, 12, 10, 930}, _
```

```

{320, 15, 12, 820}, _
{320, 31, 12, 1230}, _
{100, 8, 2.5, 125}, _
{330, 8, 10, 180}}

' Model
Dim env As New GRBEnv()
Dim model As New GRBModel(env)
model.Set(GRB.StringAttr.ModelName, "diet")

' Create decision variables for the nutrition information,
' which we limit via bounds
Dim nutrition As GRBVar() = New GRBVar(nCategories - 1) {}
For i As Integer = 0 To nCategories - 1
    nutrition(i) = model.AddVar(minNutrition(i), maxNutrition(i), 0, _
        GRB.CONTINUOUS, Categories(i))
Next

' Create decision variables for the foods to buy
Dim buy As GRBVar() = New GRBVar(nFoods - 1) {}
For j As Integer = 0 To nFoods - 1
    buy(j) = model.AddVar(0, GRB.INFINITY, cost(j), GRB.CONTINUOUS, _
        Foods(j))
Next

' The objective is to minimize the costs
model.Set(GRB.IntAttr.ModelSense, 1)

' Update model to integrate new variables
model.Update()

' Nutrition constraints
For i As Integer = 0 To nCategories - 1
    Dim ntot As GRBLinExpr = 0
    For j As Integer = 0 To nFoods - 1
        ntot.AddTerm(nutritionValues(j, i), buy(j))
    Next
    model.AddConstr(ntot = nutrition(i), Categories(i))
Next

' Solve
model.Optimize()
PrintSolution(model, buy, nutrition)

Console.WriteLine(vbLf & "Adding constraint: at most 6 servings of dairy")

```

```

model.AddConstr(buy(7) + buy(8) <= 6, "limit_dairy")

' Solve
model.Optimize()

PrintSolution(model, buy, nutrition)

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub

Private Shared Sub PrintSolution(ByVal model As GRBModel, ByVal buy As GRBVar(), _
                                ByVal nutrition As GRBVar())
    If model.Get(GRB.IntAttr.Status) = GRB.Status.OPTIMAL Then
        Console.WriteLine(vbLf & "Cost: " & model.Get(GRB.DoubleAttr.ObjVal))
        Console.WriteLine(vbLf & "Buy:")
        For j As Integer = 0 To buy.Length - 1
            If buy(j).Get(GRB.DoubleAttr.X) > 0.0001 Then
                Console.WriteLine(buy(j).Get(GRB.StringAttr.VarName) & " " & _
                                   buy(j).Get(GRB.DoubleAttr.X))
            End If
        Next
        Console.WriteLine(vbLf & "Nutrition:")
        For i As Integer = 0 To nutrition.Length - 1
            Console.WriteLine(nutrition(i).Get(GRB.StringAttr.VarName) & " " & _
                               nutrition(i).Get(GRB.DoubleAttr.X))
        Next
    Else
        Console.WriteLine("No solution")
    End If
End Sub
End Class

```

## facility\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' Facility location: a company currently ships its product from 5 plants
' to 4 warehouses. It is considering closing some plants to reduce
' costs. What plant(s) should the company close, in order to minimize
' transportation and fixed costs?
',
' Based on an example from Frontline Systems:
' http://www.solver.com/disfacility.htm
' Used with permission.

Imports System
Imports Gurobi

Class facility_vb
    Shared Sub Main()
        Try

            ' Warehouse demand in thousands of units
            Dim Demand As Double() = New Double() {15, 18, 14, 20}

            ' Plant capacity in thousands of units
            Dim Capacity As Double() = New Double() {20, 22, 17, 19, 18}

            ' Fixed costs for each plant
            Dim FixedCosts As Double() = New Double() {12000, 15000, 17000, 13000, _
                16000}

            ' Transportation costs per thousand units
            Dim TransCosts As Double(,) = New Double(,) {{4000, 2000, 3000, 2500, 4500}, _
                {2500, 2600, 3400, 3000, 4000}, _
                {1200, 1800, 2600, 4100, 3000}, _
                {2200, 2600, 3100, 3700, 3200}}

            ' Number of plants and warehouses
            Dim nPlants As Integer = Capacity.Length
            Dim nWarehouses As Integer = Demand.Length

            ' Model
            Dim env As New GRBEnv()
            Dim model As New GRBModel(env)
            model.Set(GRB.StringAttr.ModelName, "facility")

            ' Plant open decision variables: open(p) == 1 if plant p is open.
```

```

Dim open As GRBVar() = New GRBVar(nPlants - 1) {}
For p As Integer = 0 To nPlants - 1
    open(p) = model.AddVar(0, 1, FixedCosts(p), GRB.BINARY, "Open" & p)
Next

' Transportation decision variables: how much to transport from
' a plant p to a warehouse w
Dim transport As GRBVar(,) = New GRBVar(nWarehouses - 1, nPlants - 1) {}
For w As Integer = 0 To nWarehouses - 1
    For p As Integer = 0 To nPlants - 1
        transport(w, p) = model.AddVar(0, GRB.INFINITY, _
            TransCosts(w, p), GRB.CONTINUOUS, _
            "Trans" & p & "." & w)
    Next
Next

' The objective is to minimize the total fixed and variable costs
model.Set(GRB.IntAttr.ModelSense, 1)

' Update model to integrate new variables
model.Update()

' Production constraints
' Note that the right-hand limit sets the production to zero if
' the plant is closed
For p As Integer = 0 To nPlants - 1
    Dim ptot As GRBLinExpr = 0
    For w As Integer = 0 To nWarehouses - 1
        ptot.AddTerm(1.0, transport(w, p))
    Next
    model.AddConstr(ptot <= Capacity(p) * open(p), "Capacity" & p)
Next

' Demand constraints
For w As Integer = 0 To nWarehouses - 1
    Dim dtot As GRBLinExpr = 0
    For p As Integer = 0 To nPlants - 1
        dtot.AddTerm(1.0, transport(w, p))
    Next
    model.AddConstr(dtot = Demand(w), "Demand" & w)
Next

' Guess at the starting point: close the plant with the highest
' fixed costs; open all others

```

```

' First, open all plants
For p As Integer = 0 To nPlants - 1
    open(p).Set(GRB.DoubleAttr.Start, 1.0)
Next

' Now close the plant with the highest fixed cost
Console.WriteLine("Initial guess:")
Dim maxFixed As Double = -GRB.INFINITY
For p As Integer = 0 To nPlants - 1
    If FixedCosts(p) > maxFixed Then
        maxFixed = FixedCosts(p)
    End If
Next

For p As Integer = 0 To nPlants - 1
    If FixedCosts(p) = maxFixed Then
        open(p).Set(GRB.DoubleAttr.Start, 0.0)
        Console.WriteLine("Closing plant " & p & vbLf)
        Exit For
    End If
Next

' Use barrier to solve root relaxation
model.GetEnv().Set(GRB.IntParam.Method, GRB.METHOD_BARRIER)

' Solve
model.Optimize()

' Print solution
Console.WriteLine(vbLf & "TOTAL COSTS: " & model.Get(GRB.DoubleAttr.ObjVal))
Console.WriteLine("SOLUTION:")
For p As Integer = 0 To nPlants - 1
    If open(p).Get(GRB.DoubleAttr.X) = 1.0 Then
        Console.WriteLine("Plant " & p & " open:")
        For w As Integer = 0 To nWarehouses - 1
            If transport(w, p).Get(GRB.DoubleAttr.X) > 0.0001 Then
                Console.WriteLine("  Transport " & _
                    transport(w, p).Get(GRB.DoubleAttr.X) & _
                    " units to warehouse " & w)
            End If
        Next
    Else
        Console.WriteLine("Plant " & p & " closed!")
    End If
Next

Next

```

```
        ' Dispose of model and env
        model.Dispose()
        env.Dispose()

    Catch e As GRBException
        Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
    End Try
End Sub
End Class
```

## feasopt\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example reads a MIP model from a file, adds artificial
' variables to each constraint, and then minimizes the sum of the
' artificial variables. A solution with objective zero corresponds
' to a feasible solution to the input model.
' We can also use FeasRelax feature to do it. In this example, we
' use minrelax=1, i.e. optimizing the returned model finds a solution
' that minimizes the original objective, but only from among those
' solutions that minimize the sum of the artificial variables.

Imports Gurobi
Imports System

Class feaso_t_vb
    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: feaso_t_vb filename")
            Return
        End If

        Try
            Dim env As New GRBEnv()
            Dim feasmodel As New GRBModel(env, args(0))

            'Create a copy to use FeasRelax feature later
            Dim feasmodel1 As New GRBModel(feasmodel)

            ' Clear objective
            feasmodel.SetObjective(New GRBLinExpr())

            ' Add slack variables
            Dim c As GRBConstr() = feasmodel.GetConstrs()
            For i As Integer = 0 To c.Length - 1
                Dim sense As Char = c(i).Get(GRB.CharAttr.Sense)
                If sense <> ">"c Then
                    Dim constrs As GRBConstr() = New GRBConstr() {c(i)}
                    Dim coeffs As Double() = New Double() {-1}
                    feasmodel.AddVar(0.0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, _
                                    constrs, coeffs, _
                                    "ArtN_" & c(i).Get(GRB.StringAttr.ConstrName))
                End If
                If sense <> "<"c Then
```

```

        Dim constrs As GRBConstr() = New GRBConstr() {c(i)}
        Dim coeffs As Double() = New Double() {1}
        feamodel.AddVar(0.0, GRB.INFINITY, 1.0, GRB.CONTINUOUS, _
                        constrs, coeffs, _
                        "ArtP_" & c(i).Get(GRB.StringAttr.ConstrName))
    End If
Next
feamodel.Update()

' Optimize modified model
feamodel.Write("feasopt.lp")
feamodel.Optimize()

' Use FeasRelax feature */
feamodel1.FeasRelax(GRB.FEASRELAX_LINEAR, true, false, true)
feamodel1.Write("feasopt1.lp")
feamodel1.Optimize()

' Dispose of model and env
feamodel1.Dispose()
feamodel.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## fixanddive\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
,
' Implement a simple MIP heuristic. Relax the model,
' sort variables based on fractionality, and fix the 25% of
' the fractional variables that are closest to integer variables.
' Repeat until either the relaxation is integer feasible or
' linearly infeasible.

Imports System
Imports System.Collections.Generic
Imports Gurobi

Class fixanddive_vb
    ' Comparison class used to sort variable list based on relaxation
    ' fractionality

    Private Class FractionalCompare : Implements IComparer(Of GRBVar)
        Public Function Compare(ByVal v1 As GRBVar, ByVal v2 As GRBVar) As Integer _
            Implements IComparer(Of Gurobi.GRBVar).Compare
            Try
                Dim sol1 As Double = Math.Abs(v1.Get(GRB.DoubleAttr.X))
                Dim sol2 As Double = Math.Abs(v2.Get(GRB.DoubleAttr.X))
                Dim frac1 As Double = Math.Abs(sol1 - Math.Floor(sol1 + 0.5))
                Dim frac2 As Double = Math.Abs(sol2 - Math.Floor(sol2 + 0.5))
                If frac1 < frac2 Then
                    Return -1
                ElseIf frac1 > frac2 Then
                    Return 1
                Else
                    Return 0
                End If
            Catch e As GRBException
                Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
            End Try
            Return 0
        End Function
    End Class

End Class

Shared Sub Main(ByVal args As String())

    If args.Length < 1 Then
        Console.WriteLine("Usage: fixanddive_vb filename")
        Return
    End If
```

```

Try
    ' Read model
    Dim env As New GRBEnv()
    Dim model As New GRBModel(env, args(0))

    ' Collect integer variables and relax them
    Dim intvars As New List(Of GRBVar)()
    For Each v As GRBVar In model.GetVars()
        If v.Get(GRB.CharAttr.VType) <> GRB.CONTINUOUS Then
            intvars.Add(v)
            v.Set(GRB.CharAttr.VType, GRB.CONTINUOUS)
        End If
    Next

    model.GetEnv().Set(GRB.IntParam.OutputFlag, 0)
    model.Optimize()

    ' Perform multiple iterations. In each iteration, identify the first
    ' quartile of integer variables that are closest to an integer value
    ' in the relaxation, fix them to the nearest integer, and repeat.

    For iter As Integer = 0 To 999

        ' create a list of fractional variables, sorted in order of
        ' increasing distance from the relaxation solution to the nearest
        ' integer value

        Dim fractional As New List(Of GRBVar)()
        For Each v As GRBVar In intvars
            Dim sol As Double = Math.Abs(v.Get(GRB.DoubleAttr.X))
            If Math.Abs(sol - Math.Floor(sol + 0.5)) > 0.00001 Then
                fractional.Add(v)
            End If
        Next

        Console.WriteLine("Iteration " & iter & ", obj " & _
            model.Get(GRB.DoubleAttr.ObjVal) & _
            ", fractional " & fractional.Count)

        If fractional.Count = 0 Then
            Console.WriteLine("Found feasible solution - objective " & _
                model.Get(GRB.DoubleAttr.ObjVal))

            Exit For
        End If
    Next

```

```

' Fix the first quartile to the nearest integer value

fractional.Sort(New FractionalCompare())
Dim nfix As Integer = Math.Max(fractional.Count / 4, 1)
For i As Integer = 0 To nfix - 1
    Dim v As GRBVar = fractional(i)
    Dim fixval As Double = Math.Floor(v.Get(GRB.DoubleAttr.X) + 0.5)
    v.Set(GRB.DoubleAttr.LB, fixval)
    v.Set(GRB.DoubleAttr.UB, fixval)
    Console.WriteLine("  Fix " & v.Get(GRB.StringAttr.VarName) & _
        " to " & fixval & _
        " ( rel " & v.Get(GRB.DoubleAttr.X) & " )")
Next

model.Optimize()

' Check optimization result

If model.Get(GRB.IntAttr.Status) <> GRB.Status.OPTIMAL Then
    Console.WriteLine("Relaxation is infeasible")
    Exit For
End If
Next

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " + e.Message)
End Try
End Sub
End Class

```

## lp\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example reads an LP model from a file and solves it.
' If the model is infeasible or unbounded, the example turns off
' presolve and solves the model again. If the model is infeasible,
' the example computes an Irreducible Infeasible Subsystem (IIS),
' and writes it to a file.

Imports System
Imports Gurobi

Class lp_vb
    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: lp_vb filename")
            Return
        End If

        Try
            Dim env As GRBEnv = New GRBEnv("lp1.log")
            Dim model As GRBModel = New GRBModel(env, args(0))

            model.Optimize()

            Dim optimstatus As Integer = model.Get(GRB.IntAttr.Status)

            If optimstatus = GRB.Status.INF_OR_UNBD Then
                model.GetEnv().Set(GRB.IntParam.Presolve, 0)
                model.Optimize()
                optimstatus = model.Get(GRB.IntAttr.Status)
            End If

            If optimstatus = GRB.Status.OPTIMAL Then
                Dim objval As Double = model.Get(GRB.DoubleAttr.ObjVal)
                Console.WriteLine("Optimal objective: " & objval)
            ElseIf optimstatus = GRB.Status.INFEASIBLE Then
                Console.WriteLine("Model is infeasible")
                model.ComputeIIS()
                model.Write("model.ilp")
            ElseIf optimstatus = GRB.Status.UNBOUNDED Then
                Console.WriteLine("Model is unbounded")
            Else
                Console.WriteLine("Optimization was stopped with status = " & _
```

```
                                optimstatus)
End If

    ' Dispose of model and env
    model.Dispose()
    env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class
```

## lpmethod\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' Solve a model with different values of the Method parameter;
' show which value gives the shortest solve time.

Imports System
Imports Gurobi

Class lpmethod_vb

    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: lpmethod_vb filename")
            Return
        End If

        Try
            ' Read model and verify that it is a MIP
            Dim env As New GRBEnv()
            Dim model As New GRBModel(env, args(0))
            Dim menv As GRBEnv = model.GetEnv()

            ' Solve the model with different values of Method
            Dim bestMethod As Integer = -1
            Dim bestTime As Double = menv.get(GRB.DoubleParam.TimeLimit)
            For i As Integer = 0 To 2
                model.Reset()
                menv.Set(GRB.IntParam.Method, i)
                model.Optimize()
                If model.Get(GRB.IntAttr.Status) = GRB.Status.OPTIMAL Then
                    bestTime = model.Get(GRB.DoubleAttr.Runtime)
                    bestMethod = i
                    ' Reduce the TimeLimit parameter to save time
                    ' with other methods
                    menv.Set(GRB.DoubleParam.TimeLimit, bestTime)
                End If
            Next

            ' Report which method was fastest
            If bestMethod = -1 Then
                Console.WriteLine("Unable to solve this model")
            Else
                Console.WriteLine("Solved in " & bestTime & _
```

```
                " seconds with Method: " & bestMethod)
    End If

    ' Dispose of model and env
    model.Dispose()
    env.Dispose()

    Catch e As GRBException
        Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
    End Try
End Sub
End Class
```

## lpmod\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example reads an LP model from a file and solves it.
' If the model can be solved, then it finds the smallest positive variable,
' sets its upper bound to zero, and resolves the model two ways:
' first with an advanced start, then without an advanced start
' (i.e. from scratch).

Imports System
Imports Gurobi

Class lpmod_vb
    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: lpmod_vb filename")
            Return
        End If

        Try
            ' Read model and determine whether it is an LP
            Dim env As New GRBEnv()
            Dim model As New GRBModel(env, args(0))
            If model.Get(GRB.IntAttr.IsMIP) <> 0 Then
                Console.WriteLine("The model is not a linear program")
                Environment.Exit(1)
            End If

            model.Optimize()

            Dim status As Integer = model.Get(GRB.IntAttr.Status)

            If (status = GRB.Status.INF_OR_UNBD) OrElse _
                (status = GRB.Status.INFEASIBLE) OrElse _
                (status = GRB.Status.UNBOUNDED) Then
                Console.WriteLine("The model cannot be solved because it is " & _
                    "infeasible or unbounded")
                Environment.Exit(1)
            End If

            If status <> GRB.Status.OPTIMAL Then
                Console.WriteLine("Optimization was stopped with status " & status)
                Environment.Exit(0)
            End If
        End Try
    End Sub
End Class
```

```

' Find the smallest variable value
Dim minVal As Double = GRB.INFINITY
Dim minVar As GRBVar = Nothing
For Each v As GRBVar In model.GetVars()
    Dim sol As Double = v.Get(GRB.DoubleAttr.X)
    If (sol > 0.0001) AndAlso _
        (sol < minVal) AndAlso _
        (v.Get(GRB.DoubleAttr.LB) = 0.0) Then
        minVal = sol
        minVar = v
    End If
Next

Console.WriteLine(vbLf & "*** Setting " & _
    minVar.Get(GRB.StringAttr.VarName) & _
    " from " & minVal & " to zero ***" & vbLf)
minVar.Set(GRB.DoubleAttr.UB, 0)

' Solve from this starting point
model.Optimize()

' Save iteration & time info
Dim warmCount As Double = model.Get(GRB.DoubleAttr.IterCount)
Dim warmTime As Double = model.Get(GRB.DoubleAttr.Runtime)

' Reset the model and resolve
Console.WriteLine(vbLf & "*** Resetting and solving " & _
    "without an advanced start ***" & vbLf)
model.Reset()
model.Optimize()

Dim coldCount As Double = model.Get(GRB.DoubleAttr.IterCount)
Dim coldTime As Double = model.Get(GRB.DoubleAttr.Runtime)

Console.WriteLine(vbLf & "*** Warm start: " & warmCount & _
    " iterations, " & warmTime & " seconds")

Console.WriteLine("*** Cold start: " & coldCount & " iterations, " & _
    coldTime & " seconds")

' Dispose of model and env
model.Dispose()
env.Dispose()

```

```
        Catch e As GRBException
            Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
        End Try
    End Sub
End Class
```

## mip1\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example formulates and solves the following simple MIP model:
',
'   maximize    x +   y + 2 z
'   subject to  x + 2 y + 3 z <= 4
'               x +   y       >= 1
'   x, y, z binary

Imports System
Imports Gurobi

Class mip1_vb
    Shared Sub Main()
        Try
            Dim env As GRBEnv = New GRBEnv("mip1.log")
            Dim model As GRBModel = New GRBModel(env)

            ' Create variables

            Dim x As GRBVar = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, "x")
            Dim y As GRBVar = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, "y")
            Dim z As GRBVar = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, "z")

            ' Integrate new variables

            model.Update()

            ' Set objective: maximize x + y + 2 z

            model.SetObjective(x + y + 2 * z, GRB.MAXIMIZE)

            ' Add constraint: x + 2 y + 3 z <= 4

            model.AddConstr(x + 2 * y + 3 * z <= 4.0, "c0")

            ' Add constraint: x + y >= 1

            model.AddConstr(x + 2 * y + 3 * z <= 4.0, "c1")

            ' Optimize model

            model.Optimize()
```

```
Console.WriteLine(x.Get(GRB.StringAttr.VarName) & " " & _
                  x.Get(GRB.DoubleAttr.X))
Console.WriteLine(y.Get(GRB.StringAttr.VarName) & " " & _
                  y.Get(GRB.DoubleAttr.X))
Console.WriteLine(z.Get(GRB.StringAttr.VarName) & " " & _
                  z.Get(GRB.DoubleAttr.X))

Console.WriteLine("Obj: " & model.Get(GRB.DoubleAttr.ObjVal))

' Dispose of model and env

model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class
```

## mip2\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' This example reads a MIP model from a file, solves it and
' prints the objective values from all feasible solutions
' generated while solving the MIP. Then it creates the fixed
' model and solves that model.

Imports System
Imports Gurobi

Class mip2_vb
    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: mip2_vb filename")
            Return
        End If

        Try
            Dim env As GRBEnv = New GRBEnv("lp1.log")
            Dim model As GRBModel = New GRBModel(env, args(0))

            If model.Get(GRB.IntAttr.IsMIP) = 0 Then
                Console.WriteLine("Model is not a MIP")
                Return
            End If

            model.Optimize()

            Dim optimstatus As Integer = model.Get(GRB.IntAttr.Status)

            If optimstatus = GRB.Status.INF_OR_UNBD Then
                model.GetEnv().Set(GRB.IntParam.Presolve, 0)
                model.Optimize()
                optimstatus = model.Get(GRB.IntAttr.Status)
            End If

            Dim objval As Double

            If optimstatus = GRB.Status.OPTIMAL Then
                objval = model.Get(GRB.DoubleAttr.ObjVal)
                Console.WriteLine("Optimal objective: " & objval)
            ElseIf optimstatus = GRB.Status.INFEASIBLE Then
```

```

        Console.WriteLine("Model is infeasible")
        model.ComputeIIS()
        model.Write("model.ilp")
        Return
    ElseIf optimstatus = GRB.Status.UNBOUNDED Then
        Console.WriteLine("Model is unbounded")
        Return
    Else
        Console.WriteLine("Optimization was stopped with status = " & _
            optimstatus)
        Return
    End If

    ' Iterate over the solutions and compute the objectives
    Dim vars() As GRBVar = model.GetVars()
    model.GetEnv().Set(GRB.IntParam.OutputFlag, 0)

    Console.WriteLine()
    For k As Integer = 0 To model.Get(GRB.IntAttr.SolCount) - 1
        model.GetEnv().Set(GRB.IntParam.SolutionNumber, k)
        Dim objn As Double = 0.0

        For j As Integer = 0 To vars.Length - 1
            objn += vars(j).Get(GRB.DoubleAttr.Obj) * _
                vars(j).Get(GRB.DoubleAttr.Xn)
        Next

        Console.WriteLine("Solution " & k & " has objective: " & objn)
    Next
    Console.WriteLine()
    model.GetEnv().Set(GRB.IntParam.OutputFlag, 1)

    ' Solve fixed model
    Dim fixedmodel As GRBModel = model.FixedModel()
    fixedmodel.GetEnv().Set(GRB.IntParam.Presolve, 0)
    fixedmodel.Optimize()

    Dim foptimstatus As Integer = fixedmodel.Get(GRB.IntAttr.Status)
    If foptimstatus <> GRB.Status.OPTIMAL Then
        Console.WriteLine("Error: fixed model isn't optimal")
        Return
    End If

    Dim fobjval As Double = fixedmodel.Get(GRB.DoubleAttr.ObjVal)

```

```

If Math.Abs(fobjval - objval) > 0.000001 * (1.0 + Math.Abs(objval)) Then
End If

Dim fvars() As GRBVar = fixedmodel.GetVars()
Dim x() As Double = fixedmodel.Get(GRB.DoubleAttr.X, fvars)
Dim vnames() As String = fixedmodel.Get(GRB.StringAttr.VarName, fvars)

For j As Integer = 0 To fvars.Length - 1
    If x(j) <> 0 Then
        Console.WriteLine(vnames(j) & " " & x(j))
    End If
Next

' Dispose of models and env
fixedmodel.Dispose()
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## params\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' Use parameters that are associated with a model.

' A MIP is solved for 5 seconds with different sets of parameters.
' The one with the smallest MIP gap is selected, and the optimization
' is resumed until the optimal solution is found.

Imports System
Imports Gurobi

Class params_vb
    ' Simple function to determine the MIP gap
    Private Shared Function Gap(ByVal model As GRBModel) As Double
        If (model.Get(GRB.IntAttr.SolCount) = 0) OrElse _
            (Math.Abs(model.Get(GRB.DoubleAttr.ObjVal)) < 0.000001) Then
            Return GRB.INFINITY
        End If
        Return Math.Abs(model.Get(GRB.DoubleAttr.ObjBound) - _
            model.Get(GRB.DoubleAttr.ObjVal)) / _
            Math.Abs(model.Get(GRB.DoubleAttr.ObjVal))
    End Function

    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: params_vb filename")
            Return
        End If

        Try
            ' Read model and verify that it is a MIP
            Dim env As New GRBEnv()
            Dim basemodel As New GRBModel(env, args(0))
            If basemodel.Get(GRB.IntAttr.IsMIP) = 0 Then
                Console.WriteLine("The model is not an integer program")
                Environment.Exit(1)
            End If

            ' Set a 5 second time limit
            basemodel.GetEnv().Set(GRB.DoubleParam.TimeLimit, 5)

            ' Now solve the model with different values of MIPFocus
            Dim bestGap As Double = GRB.INFINITY
```

```

Dim bestModel As GRBModel = Nothing
For i As Integer = 0 To 3
    Dim m As New GRBModel(basemodel)
    m.GetEnv().Set(GRB.IntParam.MIPFocus, i)
    m.Optimize()
    If bestModel Is Nothing OrElse bestGap > Gap(m) Then
        bestModel = m
        bestGap = Gap(bestModel)
    End If
Next

' Finally, reset the time limit and continue to solve the
' best model to optimality
bestModel.GetEnv().Set(GRB.DoubleParam.TimeLimit, GRB.INFINITY)
bestModel.Optimize()

Console.WriteLine("Solved with MIPFocus: " & _
    bestModel.GetEnv().Get(GRB.IntParam.MIPFocus))
Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## qcp\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.

' This example formulates and solves the following simple QCP model:
,
'      maximize    x
'      subject to  x + y + z = 1
'                  x^2 + y^2 <= z^2 (second-order cone)
'                  x^2 <= yz        (rotated second-order cone)

Imports Gurobi

Class qcp_cs
  Shared Sub Main()
    Try
      Dim env As New GRBEnv("qcp.log")
      Dim model As New GRBModel(env)

      ' Create variables

      Dim x As GRBVar = model.AddVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "x")
      Dim y As GRBVar = model.AddVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "y")
      Dim z As GRBVar = model.AddVar(0.0, GRB.INFINITY, 0.0, GRB.CONTINUOUS, "z")

      ' Integrate new variables

      model.Update()

      ' Set objective

      Dim obj As GRBLinExpr = x
      model.SetObjective(obj, GRB.MAXIMIZE)

      ' Add linear constraint: x + y + z = 1

      model.AddConstr(x + y + z = 1.0, "c0")

      ' Add second-order cone: x^2 + y^2 <= z^2

      model.AddQConstr(x * x + y * y <= z * z, "qc0")

      ' Add rotated cone: x^2 <= yz

      model.AddQConstr(x * x <= y * z, "qc1")
```

```

    ' Optimize model

model.Optimize()

Console.WriteLine(x.Get(GRB.StringAttr.VarName) & " " & _
                  x.Get(GRB.DoubleAttr.X))
Console.WriteLine(y.Get(GRB.StringAttr.VarName) & " " & _
                  y.Get(GRB.DoubleAttr.X))
Console.WriteLine(z.Get(GRB.StringAttr.VarName) & " " & _
                  z.Get(GRB.DoubleAttr.X))

Console.WriteLine("Obj: " & model.Get(GRB.DoubleAttr.ObjVal) & " " & _
                  obj.Value)

' Dispose of model and env

model.Dispose()

env.Dispose()
Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## qp\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.

' This example formulates and solves the following simple QP model:
,
'      minimize    x^2 + x*y + y^2 + y*z + z^2 + 2 x
'      subject to  x + 2 y + 3 z >= 4
'                  x +   y           >= 1
,
' It solves it once as a continuous model, and once as an integer model.
,
```

Imports Gurobi

Class qp\_vb

Shared Sub Main()

Try

Dim env As New GRBEnv("qp.log")

Dim model As New GRBModel(env)

' Create variables

Dim x As GRBVar = model.AddVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "x")

Dim y As GRBVar = model.AddVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "y")

Dim z As GRBVar = model.AddVar(0.0, 1.0, 0.0, GRB.CONTINUOUS, "z")

' Integrate new variables

model.Update()

' Set objective

Dim obj As New GRBQuadExpr()

obj = x\*x + x\*y + y\*y + y\*z + z\*z + 2\*x

model.SetObjective(obj)

' Add constraint: x + 2 y + 3 z >= 4

model.AddConstr(x + 2 \* y + 3 \* z >= 4.0, "c0")

' Add constraint: x + y >= 1

model.AddConstr(x + y >= 1.0, "c1")

' Optimize model

```

model.Optimize()

Console.WriteLine(x.Get(GRB.StringAttr.VarName) & " " & _
                  x.Get(GRB.DoubleAttr.X))
Console.WriteLine(y.Get(GRB.StringAttr.VarName) & " " & _
                  y.Get(GRB.DoubleAttr.X))
Console.WriteLine(z.Get(GRB.StringAttr.VarName) & " " & _
                  z.Get(GRB.DoubleAttr.X))

Console.WriteLine("Obj: " & model.Get(GRB.DoubleAttr.ObjVal) & _
                  " " & obj.Value)

' Change variable types to integer

x.Set(GRB.CharAttr.VType, GRB.INTEGER)
y.Set(GRB.CharAttr.VType, GRB.INTEGER)
z.Set(GRB.CharAttr.VType, GRB.INTEGER)

' Optimize model

model.Optimize()

Console.WriteLine(x.Get(GRB.StringAttr.VarName) & " " & _
                  x.Get(GRB.DoubleAttr.X))
Console.WriteLine(y.Get(GRB.StringAttr.VarName) & " " & _
                  y.Get(GRB.DoubleAttr.X))
Console.WriteLine(z.Get(GRB.StringAttr.VarName) & " " & _
                  z.Get(GRB.DoubleAttr.X))

Console.WriteLine("Obj: " & model.Get(GRB.DoubleAttr.ObjVal) & _
                  " " & obj.Value)

' Dispose of model and env

model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## sensitivity\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' Simple MIP sensitivity analysis example.
' For each integer variable, fix it to its lower and upper bound
' and check the impact on the objective.

Imports System
Imports Gurobi

Class sensitivity_vb
    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.WriteLine("Usage: sensitivity_vb filename")
            Return
        End If

        Try
            ' Read model
            Dim env As New GRBEnv()
            Dim a As New GRBModel(env, args(0))
            a.Optimize()
            a.GetEnv().Set(GRB.IntParam.OutputFlag, 0)

            ' Extract variables from model
            Dim avars As GRBVar() = a.GetVars()

            For i As Integer = 0 To avars.Length - 1
                Dim v As GRBVar = avars(i)
                If v.Get(GRB.CharAttr.VType) = GRB.BINARY Then

                    ' Create clone and fix variable
                    Dim b As New GRBModel(a)
                    Dim bv As GRBVar = b.GetVars()(i)
                    If v.Get(GRB.DoubleAttr.X) - v.Get(GRB.DoubleAttr.LB) < 0.5 Then
                        bv.Set(GRB.DoubleAttr.LB, bv.Get(GRB.DoubleAttr.UB))
                    Else
                        bv.Set(GRB.DoubleAttr.UB, bv.Get(GRB.DoubleAttr.LB))
                    End If

                    b.Optimize()

                    If b.Get(GRB.IntAttr.Status) = GRB.Status.OPTIMAL Then
                        Dim objchg As Double = b.Get(GRB.DoubleAttr.ObjVal) - _
```

```

                                a.Get(GRB.DoubleAttr.ObjVal)
    If objchg < 0 Then
        objchg = 0
    End If
    Console.WriteLine("Objective sensitivity for variable " & _
                      v.Get(GRB.StringAttr.VarName) & _
                      " is " & objchg)
Else
    Console.WriteLine("Objective sensitivity for variable " & _
                      v.Get(GRB.StringAttr.VarName) & _
                      " is infinite")
End If

    ' Dispose of model
    b.Dispose()
End If
Next

    ' Dispose of model and env
    a.Dispose()
    env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " + e.Message)
End Try
End Sub
End Class

```

## sos\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
,
' This example creates a very simple Special Ordered Set (SOS) model.
' The model consists of 3 continuous variables, no linear constraints,
' and a pair of SOS constraints of type 1.

Imports System
Imports Gurobi

Class sos_vb
    Shared Sub Main()
        Try
            Dim env As New GRBEnv()
            Dim model As New GRBModel(env)

            ' Create variables

            Dim ub As Double() = {1, 1, 2}
            Dim obj As Double() = {-2, -1, -1}
            Dim names As String() = {"x0", "x1", "x2"}

            Dim x As GRBVar() = model.AddVars(Nothing, ub, obj, Nothing, names)

            ' Integrate new variables

            model.Update()

            ' Add first SOS1: x0=0 or x1=0

            Dim sosv1 As GRBVar() = {x(0), x(1)}
            Dim soswt1 As Double() = {1, 2}

            model.AddSOS(sosv1, soswt1, GRB.SOS_TYPE1)

            ' Add second SOS1: x0=0 or x2=0

            Dim sosv2 As GRBVar() = {x(0), x(2)}
            Dim soswt2 As Double() = {1, 2}

            model.AddSOS(sosv2, soswt2, GRB.SOS_TYPE1)

            ' Optimize model

            model.Optimize()
```

```
For i As Integer = 0 To 2
    Console.WriteLine(x(i).Get(GRB.StringAttr.VarName) & " " & _
        x(i).Get(GRB.DoubleAttr.X))
Next

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class
```

## sudoku\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' Sudoku example.
',
' The Sudoku board is a 9x9 grid, which is further divided into a 3x3 grid
' of 3x3 grids. Each cell in the grid must take a value from 0 to 9.
' No two grid cells in the same row, column, or 3x3 subgrid may take the
' same value.

' In the MIP formulation, binary variables x(i,j,v) indicate whether
' cell <i,j> takes value 'v'. The constraints are as follows:
' 1. Each cell must take exactly one value (sum_v x(i,j,v) = 1)
' 2. Each value is used exactly once per row (sum_i x(i,j,v) = 1)
' 3. Each value is used exactly once per column (sum_j x(i,j,v) = 1)
' 4. Each value is used exactly once per 3x3 subgrid (sum_grid x(i,j,v) = 1)
',
' Input datasets for this example can be found in examples/data/sudoku*.

Imports System
Imports System.IO
Imports Gurobi

Class sudoku_vb
    Shared Sub Main(ByVal args as String())
        Dim n As Integer = 9
        Dim s As Integer = 3

        If args.Length < 1 Then
            Console.WriteLine("Usage: sudoku_vb filename")
            Return
        End If

        Try
            Dim env As New GRBEnv()
            Dim model As New GRBModel(env)

            ' Create 3-D array of model variables

            Dim vars As GRBVar(,,) = New GRBVar(n - 1, n - 1, n - 1) {}

            For i As Integer = 0 To n - 1
                For j As Integer = 0 To n - 1
                    For v As Integer = 0 To n - 1
                        Dim st As String = "G_" & i & "_" & j & "_" & v
```

```

        vars(i, j, v) = model.AddVar(0.0, 1.0, 0.0, GRB.BINARY, st)
    Next
Next
Next
' Integrate variables into model

model.Update()

' Add constraints

Dim expr As GRBLinExpr

' Each cell must take one value

For i As Integer = 0 To n - 1
    For j As Integer = 0 To n - 1
        expr = 0
        For v As Integer = 0 To n - 1
            expr.AddTerm(1.0, vars(i, j, v))
        Next
        Dim st As String = "V_" & i & "_" & j
        model.AddConstr(expr = 1, st)
    Next
Next

' Each value appears once per row

For i As Integer = 0 To n - 1
    For v As Integer = 0 To n - 1
        expr = 0
        For j As Integer = 0 To n - 1
            expr.AddTerm(1.0, vars(i, j, v))
        Next
        Dim st As String = "R_" & i & "_" & v
        model.AddConstr(expr = 1, st)
    Next
Next

' Each value appears once per column

For j As Integer = 0 To n - 1
    For v As Integer = 0 To n - 1
        expr = 0
        For i As Integer = 0 To n - 1

```

```

        expr.AddTerm(1.0, vars(i, j, v))
    Next
    Dim st As String = "C_" & j & "_" & v
    model.AddConstr(expr = 1, st)
Next
Next

' Each value appears once per sub-grid

For v As Integer = 0 To n - 1
    For i0 As Integer = 0 To s - 1
        For j0 As Integer = 0 To s - 1
            expr = 0
            For i1 As Integer = 0 To s - 1
                For j1 As Integer = 0 To s - 1
                    expr.AddTerm(1.0, vars(i0 * s + i1, j0 * s + j1, v))
                Next
            Next
            Dim st As String = "Sub_" & v & "_" & i0 & "_" & j0
            model.AddConstr(expr = 1, st)
        Next
    Next
Next

' Update model

model.Update()

' Fix variables associated with pre-specified cells

Dim sr As StreamReader = File.OpenText(args(0))

For i As Integer = 0 To n - 1
    Dim input As String = sr.ReadLine()
    For j As Integer = 0 To n - 1
        Dim val As Integer = Microsoft.VisualBasic.Asc(input(j)) - 48 - 1
        ' 0-based
        If val >= 0 Then
            vars(i, j, val).Set(GRB.DoubleAttr.LB, 1.0)
        End If
    Next
Next

' Optimize model

```

```

model.Optimize()

' Write model to file
model.Write("sudoku.lp")

Dim x As Double(,,) = model.Get(GRB.DoubleAttr.X, vars)

Console.WriteLine()
For i As Integer = 0 To n - 1
    For j As Integer = 0 To n - 1
        For v As Integer = 0 To n - 1
            If x(i, j, v) > 0.5 Then
                Console.Write(v + 1)
            End If
        Next
    Next
    Console.WriteLine()
Next

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## tsp\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
',
' Solve a traveling salesman problem on a randomly generated set of
' points using lazy constraints. The base MIP model only includes
' 'degree-2' constraints, requiring each node to have exactly
' two incident edges. Solutions to this model may contain subtours -
' tours that don't visit every node. The lazy constraint callback
' adds new constraints to cut them off.

Imports Gurobi

Class tsp_vb
    Inherits GRBCallback
    Private vars As GRBVar(,)

    Public Sub New(xvars As GRBVar(,))
        vars = xvars
    End Sub

    ' Subtour elimination callback. Whenever a feasible solution is found,
    ' find the smallest subtour, and add a subtour elimination constraint
    ' if the tour doesn't visit every node.

    Protected Overrides Sub Callback()
        Try
            If where = GRB.Callback.MIPSOL Then
                ' Found an integer feasible solution - does it visit every node?

                Dim n As Integer = vars.GetLength(0)
                Dim tour As Integer() = findsubtour(GetSolution(vars))

                If tour.Length < n Then
                    ' Add subtour elimination constraint
                    Dim expr As GRBLinExpr = 0
                    For i As Integer = 0 To tour.Length - 1
                        For j As Integer = 0 To tour.Length - 1
                            expr.AddTerm(1.0, vars(tour(i), tour(j)))
                        Next
                    Next
                    AddLazy(expr <= tour.Length - 1)
                End If
            End If
        Catch e As GRBException
            Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
        End Try
    End Sub
End Class
```

```

        Console.WriteLine(e.StackTrace)
    End Try
End Sub

' Given an integer-feasible solution 'sol', returns the smallest
' sub-tour (as a list of node indices).

Protected Shared Function findsubtour(sol As Double(,)) As Integer()
    Dim n As Integer = sol.GetLength(0)
    Dim seen As Boolean() = New Boolean(n - 1) {}
    Dim tour As Integer() = New Integer(n - 1) {}
    Dim bestind As Integer, bestlen As Integer
    Dim i As Integer, node As Integer, len As Integer, start As Integer

    For i = 0 To n - 1
        seen(i) = False
    Next

    start = 0
    bestlen = n+1
    bestind = -1
    node = 0
    While start < n
        For node = 0 To n - 1
            if Not seen(node)
                Exit For
            End if
        Next
        if node = n
            Exit While
        End if
        For len = 0 To n - 1
            tour(start+len) = node
            seen(node) = true
            For i = 0 To n - 1
                if sol(node, i) > 0.5 AndAlso Not seen(i)
                    node = i
                    Exit For
                End If
            Next
            If i = n
                len = len + 1
                If len < bestlen
                    bestlen = len
                    bestind = start
                End If
            End If
        Next
    End While
End Function

```

```

        End If
        start = start + len
        Exit For
    End If
Next
End While

For i = 0 To bestlen - 1
    tour(i) = tour(bestind+i)
Next
System.Array.Resize(tour, bestlen)

Return tour
End Function

' Euclidean distance between points 'i' and 'j'

Protected Shared Function distance(x As Double(), y As Double(), _
                                   i As Integer, j As Integer) As Double
    Dim dx As Double = x(i) - x(j)
    Dim dy As Double = y(i) - y(j)
    Return Math.Sqrt(dx * dx + dy * dy)
End Function

Public Shared Sub Main(args As String())

    If args.Length < 1 Then
        Console.WriteLine("Usage: tsp_vb nnodes")
        Return
    End If

    Dim n As Integer = Convert.ToInt32(args(0))

    Try
        Dim env As New GRBEnv()
        Dim model As New GRBModel(env)

        ' Must set LazyConstraints parameter when using lazy constraints

        model.GetEnv().Set(GRB.IntParam.LazyConstraints, 1)

        Dim x As Double() = New Double(n - 1) {}
        Dim y As Double() = New Double(n - 1) {}

        Dim r As New Random()

```

```

For i As Integer = 0 To n - 1
    x(i) = r.NextDouble()
    y(i) = r.NextDouble()
Next

' Create variables

Dim vars As GRBVar(,) = New GRBVar(n - 1, n - 1) {}

For i As Integer = 0 To n - 1
    For j As Integer = 0 To n - 1
        vars(i, j) = model.AddVar(0.0, 1.0, distance(x, y, i, j), _
            GRB.BINARY, "x" & i & "_" & j)
    Next
Next

' Integrate variables

model.Update()

' Degree-2 constraints

For i As Integer = 0 To n - 1
    Dim expr As GRBLinExpr = 0
    For j As Integer = 0 To n - 1
        expr.AddTerm(1.0, vars(i, j))
    Next
    model.AddConstr(expr = 2.0, "deg2_" & i)
Next

' Forbid edge from node back to itself

For i As Integer = 0 To n - 1
    vars(i, i).Set(GRB.DoubleAttr.UB, 0.0)
Next

' Symmetric TSP

For i As Integer = 0 To n - 1
    For j As Integer = 0 To i - 1
        model.AddConstr(vars(i, j) = vars(j, i), "")
    Next
Next

model.SetCallback(New tsp_vb(vars))

```

```

model.Optimize()

If model.Get(GRB.IntAttr.SolCount) > 0 Then
    Dim tour As Integer() = findsubtour(model.Get(GRB.DoubleAttr.X, vars))

    Console.WriteLine("Tour: ")
    For i As Integer = 0 To tour.Length - 1
        Console.WriteLine(tour(i) & " ")
    Next
    Console.WriteLine()
End If

' Dispose of model and environment
model.Dispose()

env.Dispose()
Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
    Console.WriteLine(e.StackTrace)
End Try
End Sub
End Class

```

## tune\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc. */
',
' This example reads a model from a file and tunes it.
' It then writes the best parameter settings to a file
' and solves the model using these parameters.

Imports System
Imports Gurobi

Class tune_vb
    Shared Sub Main(ByVal args As String())

        If args.Length < 1 Then
            Console.Out.WriteLine("Usage: tune_vb filename")
            Return
        End If

        Try
            Dim env As New GRBEnv()

            ' Read model from file
            Dim model As New GRBModel(env, args(0))

            ' Set the TuneResults parameter to 1
            model.GetEnv().Set(GRB.IntParam.TuneResults, 1)

            ' Tune the model
            model.Tune()

            ' Get the number of tuning results
            Dim resultcount As Integer = model.Get(GRB.IntAttr.TuneResultCount)

            If resultcount > 0 Then

                ' Load the tuned parameters into the model's environment
                model.GetTuneResult(0)

                ' Write the tuned parameters to a file
                model.Write("tune.prm")

                ' Solve the model using the tuned parameters
                model.Optimize()
            End If
        End Try
    End Sub
End Class
```

```
        ' Dispose of model and environment
        model.Dispose()
        env.Dispose()

    Catch e As GRBException
        Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
    End Try
End Sub
End Class
```

## workforce1\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
,
' Assign workers to shifts; each worker may or may not be available on a
' particular day. If the problem cannot be solved, use IIS to find a set of
' conflicting constraints. Note that there may be additional conflicts
' besides what is reported via IIS.

Imports System
Imports Gurobi

Class workforce1_vb
    Shared Sub Main()
        Try

            ' Sample data
            ' Sets of days and workers
            Dim Shifts As String() = New String() {"Mon1", "Tue2", "Wed3", "Thu4", _
                                                "Fri5", "Sat6", "Sun7", "Mon8", _
                                                "Tue9", "Wed10", "Thu11", _
                                                "Fri12", "Sat13", "Sun14"}

            Dim Workers As String() = New String() {"Amy", "Bob", "Cathy", "Dan", _
                                                "Ed", "Fred", "Gu"}

            Dim nShifts As Integer = Shifts.Length
            Dim nWorkers As Integer = Workers.Length

            ' Number of workers required for each shift
            Dim shiftRequirements As Double() = New Double() {3, 2, 4, 4, 5, 6, _
                                                            5, 2, 2, 3, 4, 6, _
                                                            7, 5}

            ' Amount each worker is paid to work one shift
            Dim pay As Double() = New Double() {10, 12, 10, 8, 8, 9, 11}

            ' Worker availability: 0 if the worker is unavailable for a shift
            Dim availability As Double(,) = New Double(,) { _
                {0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0}, _
                {0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1}, _
                {0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1}, _
                {1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1}, _
                {1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}}
        End Try
    End Sub
End Class
```

```

' Model
Dim env As New GRBEnv()
Dim model As New GRBModel(env)
model.Set(GRB.StringAttr.ModelName, "assignment")

' Assignment variables: x(w)(s) == 1 if worker w is assigned
' to shift s. Since an assignment model always produces integer
' solutions, we use continuous variables and solve as an LP.
Dim x As GRBVar(,) = New GRBVar(nWorkers - 1, nShifts - 1) {}
For w As Integer = 0 To nWorkers - 1
    For s As Integer = 0 To nShifts - 1
        x(w, s) = model.AddVar(0, availability(w, s), pay(w), _
                                GRB.CONTINUOUS, _
                                Workers(w) & "." & Shifts(s))
    Next
Next

' The objective is to minimize the total pay costs
model.Set(GRB.IntAttr.ModelSense, 1)

' Update model to integrate new variables
model.Update()

' Constraint: assign exactly shiftRequirements(s) workers
' to each shift s
For s As Integer = 0 To nShifts - 1
    Dim lhs As GRBLinExpr = 0
    For w As Integer = 0 To nWorkers - 1
        lhs.AddTerm(1.0, x(w, s))
    Next
    model.AddConstr(lhs = shiftRequirements(s), Shifts(s))
Next

' Optimize
model.Optimize()
Dim status As Integer = model.Get(GRB.IntAttr.Status)
If status = GRB.Status.UNBOUNDED Then
    Console.WriteLine("The model cannot be solved " & _
                      "because it is unbounded")
    Exit Sub
End If
If status = GRB.Status.OPTIMAL Then
    Console.WriteLine("The optimal objective is " & _
                      model.Get(GRB.DoubleAttr.ObjVal))
    Exit Sub

```

```

End If
If (status <> GRB.Status.INF_OR_UNBD) AndAlso _
    (status <> GRB.Status.INFEASIBLE) Then
    Console.WriteLine("Optimization was stopped with status " & status)
    Exit Sub
End If

' Do IIS
Console.WriteLine("The model is infeasible; computing IIS")
model.ComputeIIS()
Console.WriteLine(vbLf & "The following constraint(s) " & _
    "cannot be satisfied:")
For Each c As GRBConstr In model.GetConstrs()
    If c.Get(GRB.IntAttr.IISConstr) = 1 Then
        Console.WriteLine(c.Get(GRB.StringAttr.ConstrName))
    End If
Next

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class

```

## workforce2\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
,
' Assign workers to shifts; each worker may or may not be available on a
' particular day. If the problem cannot be solved, use IIS iteratively to
' find all conflicting constraints.

Imports System
Imports System.Collections.Generic
Imports Gurobi

Class workforce2_vb
    Shared Sub Main()
        Try

            ' Sample data
            ' Sets of days and workers
            Dim Shifts As String() = New String() {"Mon1", "Tue2", "Wed3", "Thu4", _
                                                "Fri5", "Sat6", "Sun7", "Mon8", _
                                                "Tue9", "Wed10", "Thu11", _
                                                "Fri12", "Sat13", "Sun14"}

            Dim Workers As String() = New String() {"Amy", "Bob", "Cathy", "Dan", _
                                                "Ed", "Fred", "Gu"}

            Dim nShifts As Integer = Shifts.Length
            Dim nWorkers As Integer = Workers.Length

            ' Number of workers required for each shift
            Dim shiftRequirements As Double() = New Double() {3, 2, 4, 4, 5, 6, _
                                                            5, 2, 2, 3, 4, 6, _
                                                            7, 5}

            ' Amount each worker is paid to work one shift
            Dim pay As Double() = New Double() {10, 12, 10, 8, 8, 9, 11}

            ' Worker availability: 0 if the worker is unavailable for a shift
            Dim availability As Double(,) = New Double(,) { _
                {0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0}, _
                {0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1}, _
                {0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1}, _
                {1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1}, _
                {1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}}
        End Try
    End Sub
End Class
```

```

' Model
Dim env As New GRBEnv()
Dim model As New GRBModel(env)
model.Set(GRB.StringAttr.ModelName, "assignment")

' Assignment variables: x(w)(s) == 1 if worker w is assigned
' to shift s. Since an assignment model always produces integer
' solutions, we use continuous variables and solve as an LP.
Dim x As GRBVar(,) = New GRBVar(nWorkers - 1, nShifts - 1) {}
For w As Integer = 0 To nWorkers - 1
    For s As Integer = 0 To nShifts - 1
        x(w, s) = model.AddVar(0, availability(w, s), pay(w), _
                                GRB.CONTINUOUS, _
                                Workers(w) & "." & Shifts(s))
    Next
Next

' The objective is to minimize the total pay costs
model.Set(GRB.IntAttr.ModelSense, 1)

' Update model to integrate new variables
model.Update()

' Constraint: assign exactly shiftRequirements(s) workers
' to each shift s
For s As Integer = 0 To nShifts - 1
    Dim lhs As GRBLinExpr = 0
    For w As Integer = 0 To nWorkers - 1
        lhs.AddTerm(1.0, x(w, s))
    Next
    model.AddConstr(lhs = shiftRequirements(s), Shifts(s))
Next

' Optimize
model.Optimize()
Dim status As Integer = model.Get(GRB.IntAttr.Status)
If status = GRB.Status.UNBOUNDED Then
    Console.WriteLine("The model cannot be solved " & _
                      "because it is unbounded")
    Exit Sub
End If
If status = GRB.Status.OPTIMAL Then
    Console.WriteLine("The optimal objective is " & _
                      model.Get(GRB.DoubleAttr.ObjVal))
    Exit Sub

```

```

End If
If (status <> GRB.Status.INF_OR_UNBD) AndAlso _
    (status <> GRB.Status.INFEASIBLE) Then
    Console.WriteLine("Optimization was stopped with status " & status)
    Exit Sub
End If

' Do IIS
Console.WriteLine("The model is infeasible; computing IIS")
Dim removed As LinkedList(Of String) = New LinkedList(Of String)()

' Loop until we reduce to a model that can be solved
While True
    model.ComputeIIS()
    Console.WriteLine(vbLf & "The following constraint cannot be satisfied:")
    For Each c As GRBConstr In model.GetConstrs()
        If c.Get(GRB.IntAttr.IISConstr) = 1 Then
            Console.WriteLine(c.Get(GRB.StringAttr.ConstrName))
            ' Remove a single constraint from the model
            removed.AddFirst(c.Get(GRB.StringAttr.ConstrName))
            model.Remove(c)
        End If
    Next

    Console.WriteLine()
    model.Optimize()
    status = model.Get(GRB.IntAttr.Status)

    If status = GRB.Status.UNBOUNDED Then
        Console.WriteLine("The model cannot be solved " & _
            "because it is unbounded")
        Exit Sub
    End If
    If status = GRB.Status.OPTIMAL Then
        Exit While
    End If
    If (status <> GRB.Status.INF_OR_UNBD) AndAlso _
        (status <> GRB.Status.INFEASIBLE) Then
        Console.WriteLine("Optimization was stopped with status " & _
            status)
        Exit Sub
    End If
End While

```

```
Console.WriteLine(vbLf & "The following constraints were removed " & _
                  "to get a feasible LP:")
For Each s As String In removed
    Console.Write(s & " ")
Next

Console.WriteLine()

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class
```

## workforce3\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
,
' Assign workers to shifts; each worker may or may not be available on a
' particular day. If the problem cannot be solved, add slack variables
' to determine which constraints cannot be satisfied, and how much
' they need to be relaxed.

Imports System
Imports System.Collections.Generic
Imports Gurobi

Class workforce3_vb
    Shared Sub Main()
        Try

            ' Sample data
            ' Sets of days and workers
            Dim Shifts As String() = New String() {"Mon1", "Tue2", "Wed3", "Thu4", _
                "Fri5", "Sat6", "Sun7", "Mon8", _
                "Tue9", "Wed10", "Thu11", _
                "Fri12", "Sat13", "Sun14"}

            Dim Workers As String() = New String() {"Amy", "Bob", "Cathy", "Dan", _
                "Ed", "Fred", "Gu"}

            Dim nShifts As Integer = Shifts.Length
            Dim nWorkers As Integer = Workers.Length

            ' Number of workers required for each shift
            Dim shiftRequirements As Double() = New Double() {3, 2, 4, 4, 5, 6, _
                5, 2, 2, 3, 4, 6, _
                7, 5}

            ' Amount each worker is paid to work one shift
            Dim pay As Double() = New Double() {10, 12, 10, 8, 8, 9, 11}

            ' Worker availability: 0 if the worker is unavailable for a shift
            Dim availability As Double(,) = New Double(,) { _
                {0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0}, _
                {0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1}, _
                {0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1}, _
                {1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1}, _
                {1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}}
```

```

' Model
Dim env As New GRBEnv()
Dim model As New GRBModel(env)
model.Set(GRB.StringAttr.ModelName, "assignment")

' Assignment variables: x(w)(s) == 1 if worker w is assigned
' to shift s. Since an assignment model always produces integer
' solutions, we use continuous variables and solve as an LP.
Dim x As GRBVar(,) = New GRBVar(nWorkers - 1, nShifts - 1) {}
For w As Integer = 0 To nWorkers - 1
    For s As Integer = 0 To nShifts - 1
        x(w, s) = model.AddVar(0, availability(w, s), pay(w), _
                                GRB.CONTINUOUS, _
                                Workers(w) & "." & Shifts(s))
    Next
Next

' The objective is to minimize the total pay costs
model.Set(GRB.IntAttr.ModelSense, 1)

' Update model to integrate new variables
model.Update()

' Constraint: assign exactly shiftRequirements(s) workers
' to each shift s
Dim reqCts As New LinkedList(Of GRBConstr)()
For s As Integer = 0 To nShifts - 1
    Dim lhs As GRBLinExpr = 0
    For w As Integer = 0 To nWorkers - 1
        lhs.AddTerm(1.0, x(w, s))
    Next
    Dim newCt As GRBConstr = model.AddConstr(lhs = shiftRequirements(s), _
                                                Shifts(s))
    reqCts.AddFirst(newCt)
Next

' Optimize
model.Optimize()
Dim status As Integer = model.Get(GRB.IntAttr.Status)
If status = GRB.Status.UNBOUNDED Then
    Console.WriteLine("The model cannot be solved " & _
                      "because it is unbounded")
    Exit Sub
End If

```

```

If status = GRB.Status.OPTIMAL Then
    Console.WriteLine("The optimal objective is " & _
        model.Get(GRB.DoubleAttr.ObjVal))
    Exit Sub
End If
If (status <> GRB.Status.INF_OR_UNBD) AndAlso _
    (status <> GRB.Status.INFEASIBLE) Then
    Console.WriteLine("Optimization was stopped with status " & status)
    Exit Sub
End If

' Add slack variables to make the model feasible
Console.WriteLine("The model is infeasible; adding slack variables")

' Set original objective coefficients to zero
model.SetObjective(New GRBLinExpr())

' Add a new slack variable to each shift constraint so that the shifts
' can be satisfied
Dim slacks As New LinkedList(Of GRBVar)()
For Each c As GRBConstr In reqCts
    Dim col As New GRBColumn()
    col.AddTerm(1.0, c)
    Dim newvar As GRBVar = model.AddVar(0, GRB.INFINITY, 1.0, _
        GRB.CONTINUOUS, col, _
        c.Get(GRB.StringAttr.ConstrName) & _
        "Slack")
    slacks.AddFirst(newvar)
Next

' Solve the model with slacks
model.Optimize()
status = model.Get(GRB.IntAttr.Status)
If (status = GRB.Status.INF_OR_UNBD) OrElse _
    (status = GRB.Status.INFEASIBLE) OrElse _
    (status = GRB.Status.UNBOUNDED) Then
    Console.WriteLine("The model with slacks cannot be solved " & _
        "because it is infeasible or unbounded")
    Exit Sub
End If
If status <> GRB.Status.OPTIMAL Then
    Console.WriteLine("Optimization was stopped with status " & status)
    Exit Sub
End If

```

```
Console.WriteLine(vbLf & "Slack values:")
For Each sv As GRBVar In slacks
    If sv.Get(GRB.DoubleAttr.X) > 0.000001 Then
        Console.WriteLine(sv.Get(GRB.StringAttr.VarName) & " = " & _
            sv.Get(GRB.DoubleAttr.X))
    End If
Next

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub
End Class
```

## workforce4\_vb.vb

```
' Copyright 2013, Gurobi Optimization, Inc.
,
' Assign workers to shifts; each worker may or may not be available on a
' particular day. We use Pareto optimization to solve the model:
' first, we minimize the linear sum of the slacks. Then, we constrain
' the sum of the slacks, and we minimize a quadratic objective that
' tries to balance the workload among the workers.

Imports System
Imports Gurobi

Class workforce4_vb
    Shared Sub Main()
        Try

            ' Sample data
            ' Sets of days and workers
            Dim Shifts As String() = New String() {"Mon1", "Tue2", "Wed3", "Thu4", _
                "Fri5", "Sat6", "Sun7", "Mon8", _
                "Tue9", "Wed10", "Thu11", _
                "Fri12", "Sat13", "Sun14"}

            Dim Workers As String() = New String() {"Amy", "Bob", "Cathy", "Dan", _
                "Ed", "Fred", "Gu"}

            Dim nShifts As Integer = Shifts.Length
            Dim nWorkers As Integer = Workers.Length

            ' Number of workers required for each shift
            Dim shiftRequirements As Double() = New Double() {3, 2, 4, 4, 5, 6, _
                5, 2, 2, 3, 4, 6, _
                7, 5}

            ' Worker availability: 0 if the worker is unavailable for a shift
            Dim availability As Double(,) = New Double(,) { _
                {0, 1, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 0, 0, 1, 1, 0, 1, 0, 0, 1, 0, 1, 0}, _
                {0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1}, _
                {0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1}, _
                {1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 1, 0, 1, 1}, _
                {1, 1, 1, 0, 0, 1, 0, 1, 1, 0, 0, 1, 1, 1}, _
                {1, 1, 1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}}

            ' Model
            Dim env As New GRBEnv()
```

```

Dim model As New GRBModel(env)
model.Set(GRB.StringAttr.ModelName, "assignment")

' Assignment variables: x(w)(s) == 1 if worker w is assigned
' to shift s. This is no longer a pure assignment model, so we
' must use binary variables.
Dim x As GRBVar(,) = New GRBVar(nWorkers - 1, nShifts - 1) {}
For w As Integer = 0 To nWorkers - 1
    For s As Integer = 0 To nShifts - 1
        x(w, s) = model.AddVar(0, availability(w, s), 0, _
                                GRB.BINARY, _
                                Workers(w) & "." & Shifts(s))
    Next
Next

' Add a new slack variable to each shift constraint so that the
' shifts can be satisfied
Dim slacks As GRBVar() = New GRBVar(nShifts - 1) {}
For s As Integer = 0 To nShifts - 1
    slacks(s) = _
        model.AddVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS, _
                    Shifts(s) & "Slack")
Next

' Variable to represent the total slack
Dim totSlack As GRBVar = model.AddVar(0, GRB.INFINITY, 0, _
                                       GRB.CONTINUOUS, "totSlack")

' Variables to count the total shifts worked by each worker
Dim totShifts As GRBVar() = New GRBVar(nWorkers - 1) {}
For w As Integer = 0 To nWorkers - 1
    totShifts(w) = _
        model.AddVar(0, GRB.INFINITY, 0, GRB.CONTINUOUS, _
                    Workers(w) & "TotShifts")
Next

' Update model to integrate new variables
model.Update()

Dim lhs As GRBLinExpr

' Constraint: assign exactly shiftRequirements(s) workers
' to each shift s, plus the slack
For s As Integer = 0 To nShifts - 1
    lhs = 0

```

```

    lhs.AddTerm(1.0, slacks(s))
  For w As Integer = 0 To nWorkers - 1
    lhs.AddTerm(1.0, x(w, s))
  Next
  model.AddConstr(lhs = shiftRequirements(s), Shifts(s))
Next

' Constraint: set totSlack equal to the total slack
lhs = 0
For s As Integer = 0 To nShifts - 1
  lhs.AddTerm(1.0, slacks(s))
Next
model.AddConstr(lhs = totSlack, "totSlack")

' Constraint: compute the total number of shifts for each worker
For w As Integer = 0 To nWorkers - 1
  lhs = 0
  For s As Integer = 0 To nShifts - 1
    lhs.AddTerm(1.0, x(w, s))
  Next
  model.AddConstr(lhs = totShifts(w), "totShifts" & Workers(w))
Next

' Objective: minimize the total slack
model.SetObjective(1.0*totSlack)

' Optimize
Dim status As Integer = _
  solveAndPrint(model, totSlack, nWorkers, Workers, totShifts)
If status <> GRB.Status.OPTIMAL Then
  Exit Sub
End If

' Constrain the slack by setting its upper and lower bounds
totSlack.Set(GRB.DoubleAttr.UB, totSlack.Get(GRB.DoubleAttr.X))
totSlack.Set(GRB.DoubleAttr.LB, totSlack.Get(GRB.DoubleAttr.X))

' Variable to count the average number of shifts worked
Dim avgShifts As GRBVar = model.AddVar(0, GRB.INFINITY, 0, _
  GRB.CONTINUOUS, "avgShifts")

' Variables to count the difference from average for each worker;
' note that these variables can take negative values.
Dim diffShifts As GRBVar() = New GRBVar(nWorkers - 1) {}
For w As Integer = 0 To nWorkers - 1

```

```

        diffShifts(w) = _
            model.AddVar(-GRB.INFINITY, GRB.INFINITY, 0, _
                GRB.CONTINUOUS, Workers(w) & "Diff")
Next

' Update model to integrate new variables
model.Update()

' Constraint: compute the average number of shifts worked
lhs = 0
For w As Integer = 0 To nWorkers - 1
    lhs.AddTerm(1.0, totShifts(w))
Next
model.AddConstr(lhs = nWorkers * avgShifts, "avgShifts")

' Constraint: compute the difference from the average number of shifts
For w As Integer = 0 To nWorkers - 1
    model.AddConstr(totShifts(w) - avgShifts = diffShifts(w), _
        Workers(w) & "Diff")
Next

' Objective: minimize the sum of the square of the difference
' from the average number of shifts worked
Dim qobj As GRBQuadExpr = New GRBQuadExpr
For w As Integer = 0 To nWorkers - 1
    qobj.AddTerm(1.0, diffShifts(w), diffShifts(w))
Next
model.SetObjective(qobj)

' Optimize
status = solveAndPrint(model, totSlack, nWorkers, Workers, totShifts)
If status <> GRB.Status.OPTIMAL Then
    Exit Sub
End If

' Dispose of model and env
model.Dispose()
env.Dispose()

Catch e As GRBException
    Console.WriteLine("Error code: " & e.ErrorCode & ". " & e.Message)
End Try
End Sub

Private Shared Function solveAndPrint(ByVal model As GRBModel, _

```

```

ByVal totSlack As GRBVar, _
ByVal nWorkers As Integer, _
ByVal Workers As String(), _
ByVal totShifts As GRBVar()) As Integer

model.Optimize()
Dim status As Integer = model.Get(GRB.IntAttr.Status)
solveAndPrint = status
If (status = GRB.Status.INF_OR_UNBD) OrElse _
    (status = GRB.Status.INFEASIBLE) OrElse _
    (status = GRB.Status.UNBOUNDED) Then
    Console.WriteLine("The model cannot be solved because " & _
        "it is infeasible or unbounded")
    Exit Function
End If
If status <> GRB.Status.OPTIMAL Then
    Console.WriteLine("Optimization was stopped with status " & _
        & status)
    Exit Function
End If

' Print total slack and the number of shifts worked for each worker
Console.WriteLine(vbLf & "Total slack required: " & _
    totSlack.Get(GRB.DoubleAttr.X))
For w As Integer = 0 To nWorkers - 1
    Console.WriteLine(Workers(w) & " worked " & _
        totShifts(w).Get(GRB.DoubleAttr.X) & _
        " shifts")
Next

Console.WriteLine(vbLf)
End Function
End Class

```

## 3.6 Python Examples

This section includes source code for all of the Gurobi Python examples. The same source code can be found in the `examples/python` directory of the Gurobi distribution.

### `callback.py`

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example reads an LP or a MIP from a file, sets a callback
# to monitor the optimization progress, and outputs progress
# information to the screen and to the log file. If the input model
# is a MIP, the callback aborts the optimization after 10000 nodes have
# been explored.

import sys
from gurobipy import *

# Define callback function

def mycallback(model, where):
    if where == GRB.callback.PRESOLVE:
        # Presolve callback
        print('Removed %d columns and %d rows' % \
              (model.cbGet(GRB.callback.PRE_COLDEL), \
               model.cbGet(GRB.callback.PRE_ROWDEL)))
    elif where == GRB.callback.SIMPLEX:
        # Simplex callback
        itcnt = model.cbGet(GRB.callback.SPX_ITRCNT)
        if itcnt - model._lastiter >= 100:
            model._lastiter = itcnt
            obj = model.cbGet(GRB.callback.SPX_OBJVAL)
            pinf = model.cbGet(GRB.callback.SPX_PRIMINF)
            dinf = model.cbGet(GRB.callback.SPX_DUALINF)
            pert = model.cbGet(GRB.callback.SPX_ISPERT)
            if pert == 0:
                ch = ' '
            elif pert == 1:
                ch = 'S'
            else:
                ch = 'P'
            print('%d %g %s %g %g' % (int(itcnt), obj, ch, pinf, dinf))
```

```

elif where == GRB.callback.MIP:
    # General MIP callback
    nodecnt = model.cbGet(GRB.callback.MIP_NODCNT)
    if nodecnt - model._lastnode >= 100:
        model._lastnode = nodecnt
        objbst = model.cbGet(GRB.callback.MIP_OBJBST)
        objbnd = model.cbGet(GRB.callback.MIP_OBJBND)
        print('%d %g %g' % (int(nodecnt), objbst, objbnd))
    if nodecnt > model._mynodelimit:
        model.terminate()
elif where == GRB.callback.MIPSOL:
    # MIP solution callback
    obj = model.cbGet(GRB.callback.MIPSOL_OBJ)
    nodecnt = int(model.cbGet(GRB.callback.MIPSOL_NODCNT))
    print('*** New solution at node %g objective %g' % (nodecnt, obj))
    print(model.cbGetSolution(model.getVars()))
elif where == GRB.callback.MIPNODE:
    # MIP node callback
    print('*** New node')
    if model.cbGet(GRB.callback.MIPNODE_STATUS) == GRB.status.OPTIMAL:
        x = model.cbGetNodeRel(model.getVars())
        model.cbSetSolution(model.getVars(), x)

if len(sys.argv) < 2:
    print('Usage: callback.py filename')
    quit()

# Read and solve model

model = read(sys.argv[1])

# Pass data into my callback function

model._mynodelimit = 10000
model._lastnode = -1
model._lastiter = -1

model.params.heuristics = 0

model.optimize(mycallback)

```

## custom.py

```
#
# Copyright 2013, Gurobi Optimization, Inc.
#
# Interactive shell customization example
#
# Define a set of customizations for the Gurobi shell.
# Type 'from custom import *' to import them into your shell.
#

from gurobipy import *

# custom read command --- change directory as appropriate

def myread(name):
    return read('/home/jones/models/' + name)

# simple termination callback

def mycallback(model, where):
    if where == GRB.callback.MIP:
        time = model.cbGet(GRB.callback.RUNTIME)
        best = model.cbGet(GRB.callback.MIP_OBJBST)
        if time > 10 and best < GRB.INFINITY:
            model.terminate()

# custom optimize() function that uses callback

def myopt(model):
    model.optimize(mycallback)
```

## dense.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example formulates and solves the following simple QP model:
#
#   minimize    x + y + x^2 + x*y + y^2 + y*z + z^2
#   subject to  x + 2 y + 3 z >= 4
#               x +   y       >= 1
#
# The example illustrates the use of dense matrices to store A and Q
# (and dense vectors for the other relevant data). We don't recommend
# that you use dense matrices, but this example may be helpful if you
# already have your data in this format.

import sys
from gurobipy import *

def dense_optimize(rows, cols, c, Q, A, sense, rhs, lb, ub, vtype,
                  solution):

    model = Model()

    # Add variables to model
    for j in range(cols):
        model.addVar(lb=lb[j], ub=ub[j], vtype=vtype[j])
    model.update()
    vars = model.getVars()

    # Populate A matrix
    for i in range(rows):
        expr = LinExpr()
        for j in range(cols):
            if A[i][j] != 0:
                expr += A[i][j]*vars[j]
        model.addConstr(expr, sense[i], rhs[i])

    # Populate objective
    obj = QuadExpr()
    for i in range(cols):
        for j in range(cols):
            if Q[i][j] != 0:
                obj += Q[i][j]*vars[i]*vars[j]
    for j in range(cols):
```

```

    if c[j] != 0:
        obj += c[j]*vars[j]
model.setObjective(obj)

# Write model to a file
model.update()
model.write('dense.lp')

# Solve
model.optimize()

if model.status == GRB.OPTIMAL:
    x = model.getAttr('x', vars)
    for i in range(cols):
        solution[i] = x[i]
    return True
else:
    return False

# Put model data into dense matrices

c = [1, 1, 0]
Q = [[1, 1, 0], [0, 1, 1], [0, 0, 1]]
A = [[1, 2, 3], [1, 1, 0]]
sense = [GRB.GREATER_EQUAL, GRB.GREATER_EQUAL]
rhs = [4, 1]
lb = [0, 0, 0]
ub = [GRB.INFINITY, GRB.INFINITY, GRB.INFINITY]
vtype = [GRB.CONTINUOUS, GRB.CONTINUOUS, GRB.CONTINUOUS]
sol = [0]*3

# Optimize

success = dense_optimize(2, 3, c, Q, A, sense, rhs, lb, ub, vtype, sol)

if success:
    print('x: %g, y: %g, z: %g' % (sol[0], sol[1], sol[2]))

```

## diet.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Solve the classic diet model, showing how to add constraints
# to an existing model.

from gurobipy import *

# Nutrition guidelines, based on
# USDA Dietary Guidelines for Americans, 2005
# http://www.health.gov/DietaryGuidelines/dga2005/

categories, minNutrition, maxNutrition = multidict({
    'calories': [1800, 2200],
    'protein': [91, GRB.INFINITY],
    'fat':      [0, 65],
    'sodium':  [0, 1779] })

foods, cost = multidict({
    'hamburger': 2.49,
    'chicken':   2.89,
    'hot dog':   1.50,
    'fries':     1.89,
    'macaroni':  2.09,
    'pizza':     1.99,
    'salad':     2.49,
    'milk':      0.89,
    'ice cream': 1.59 })

# Nutrition values for the foods
nutritionValues = {
    ('hamburger', 'calories'): 410,
    ('hamburger', 'protein'): 24,
    ('hamburger', 'fat'): 26,
    ('hamburger', 'sodium'): 730,
    ('chicken', 'calories'): 420,
    ('chicken', 'protein'): 32,
    ('chicken', 'fat'): 10,
    ('chicken', 'sodium'): 1190,
    ('hot dog', 'calories'): 560,
    ('hot dog', 'protein'): 20,
    ('hot dog', 'fat'): 32,
    ('hot dog', 'sodium'): 1800,
```

```

('fries',      'calories'): 380,
('fries',      'protein'):  4,
('fries',      'fat'):       19,
('fries',      'sodium'):    270,
('macaroni',   'calories'): 320,
('macaroni',   'protein'):  12,
('macaroni',   'fat'):       10,
('macaroni',   'sodium'):    930,
('pizza',      'calories'): 320,
('pizza',      'protein'):  15,
('pizza',      'fat'):       12,
('pizza',      'sodium'):    820,
('salad',      'calories'): 320,
('salad',      'protein'):  31,
('salad',      'fat'):       12,
('salad',      'sodium'):    1230,
('milk',       'calories'): 100,
('milk',       'protein'):   8,
('milk',       'fat'):       2.5,
('milk',       'sodium'):    125,
('ice cream',  'calories'): 330,
('ice cream',  'protein'):   8,
('ice cream',  'fat'):       10,
('ice cream',  'sodium'):    180 }

```

```

# Model
m = Model("diet")

# Create decision variables for the nutrition information,
# which we limit via bounds
nutrition = {}
for c in categories:
    nutrition[c] = m.addVar(lb=minNutrition[c], ub=maxNutrition[c], name=c)

# Create decision variables for the foods to buy
buy = {}
for f in foods:
    buy[f] = m.addVar(obj=cost[f], name=f)

# The objective is to minimize the costs
m.modelSense = GRB.MINIMIZE

# Update model to integrate new variables
m.update()

```

```

# Nutrition constraints
for c in categories:
    m.addConstr(
        quicksum(nutritionValues[f,c] * buy[f] for f in foods) == nutrition[c],
        c)

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

# Solve
m.optimize()
printSolution()

print('\nAdding constraint: at most 6 servings of dairy')
m.addConstr(buy['milk'] + buy['ice cream'] <= 6, "limit_dairy")

# Solve
m.optimize()
printSolution()

```

## diet2.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Separate the model (dietmodel.py) from the data file (diet2.py), so
# that the model can be solved with different data files.
#
# Nutrition guidelines, based on
# USDA Dietary Guidelines for Americans, 2005
# http://www.health.gov/DietaryGuidelines/dga2005/

from gurobipy import *

categories, minNutrition, maxNutrition = multidict({
    'calories': [1800, 2200],
    'protein': [91, GRB.INFINITY],
    'fat': [0, 65],
    'sodium': [0, 1779] })

foods, cost = multidict({
    'hamburger': 2.49,
    'chicken': 2.89,
    'hot dog': 1.50,
    'fries': 1.89,
    'macaroni': 2.09,
    'pizza': 1.99,
    'salad': 2.49,
    'milk': 0.89,
    'ice cream': 1.59 })

# Nutrition values for the foods
nutritionValues = {
    ('hamburger', 'calories'): 410,
    ('hamburger', 'protein'): 24,
    ('hamburger', 'fat'): 26,
    ('hamburger', 'sodium'): 730,
    ('chicken', 'calories'): 420,
    ('chicken', 'protein'): 32,
    ('chicken', 'fat'): 10,
    ('chicken', 'sodium'): 1190,
    ('hot dog', 'calories'): 560,
    ('hot dog', 'protein'): 20,
    ('hot dog', 'fat'): 32,
    ('hot dog', 'sodium'): 1800,
```

```
('fries', 'calories'): 380,  
( 'fries', 'protein'): 4,  
( 'fries', 'fat'): 19,  
( 'fries', 'sodium'): 270,  
( 'macaroni', 'calories'): 320,  
( 'macaroni', 'protein'): 12,  
( 'macaroni', 'fat'): 10,  
( 'macaroni', 'sodium'): 930,  
( 'pizza', 'calories'): 320,  
( 'pizza', 'protein'): 15,  
( 'pizza', 'fat'): 12,  
( 'pizza', 'sodium'): 820,  
( 'salad', 'calories'): 320,  
( 'salad', 'protein'): 31,  
( 'salad', 'fat'): 12,  
( 'salad', 'sodium'): 1230,  
( 'milk', 'calories'): 100,  
( 'milk', 'protein'): 8,  
( 'milk', 'fat'): 2.5,  
( 'milk', 'sodium'): 125,  
( 'ice cream', 'calories'): 330,  
( 'ice cream', 'protein'): 8,  
( 'ice cream', 'fat'): 10,  
( 'ice cream', 'sodium'): 180 }
```

```
import dietmodel  
dietmodel.solve(categories, minNutrition, maxNutrition,  
                foods, cost, nutritionValues)
```

## diet3.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Use a SQLite database with the diet model (dietmodel.py). The database
# (diet.db) can be recreated using the included SQL script (diet.sql).
#
# Note that this example reads an external data file (..\data\diet.db).
# As a result, it must be run from the Gurobi examples/python directory.

import os
import sqlite3
from gurobipy import *

con = sqlite3.connect(os.path.join '..', 'data', 'diet.db'))
cur = con.cursor()

cur.execute('select category,minnutrition,maxnutrition from categories')
result = cur.fetchall()
categories, minNutrition, maxNutrition = multidict(
    (cat,[minv,maxv]) for cat,minv,maxv in result)

cur.execute('select food,cost from foods')
result = cur.fetchall()
foods, cost = multidict(result)

cur.execute('select food,category,value from nutrition')
result = cur.fetchall()
nutritionValues = dict(((f,c),v) for f,c,v in result)

con.close()

import dietmodel
dietmodel.solve(categories, minNutrition, maxNutrition,
                foods, cost, nutritionValues)
```

## diet4.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Read diet model data from an Excel spreadsheet (diet.xls).
# Pass the imported data into the diet model (dietmodel.py).
#
# Note that this example reads an external data file (..\data\diet.xls).
# As a result, it must be run from the Gurobi examples/python directory.
#
# This example requires Python package 'xlrd', which isn't included
# in most Python distributions. You can obtain it from
# http://pypi.python.org/pypi/xlrd.

import os
import xlrd

book = xlrd.open_workbook(os.path.join("../", "data", "diet.xls"))

sh = book.sheet_by_name("Categories")
categories = []
minNutrition = {}
maxNutrition = {}
i = 1
while True:
    try:
        c = sh.cell_value(i, 0)
        categories.append(c)
        minNutrition[c] = sh.cell_value(i,1)
        maxNutrition[c] = sh.cell_value(i,2)
        i = i + 1
    except IndexError:
        break

sh = book.sheet_by_name("Foods")
foods = []
cost = {}
i = 1
while True:
    try:
        f = sh.cell_value(i, 0)
        foods.append(f)
        cost[f] = sh.cell_value(i,1)
        i = i + 1
```

```
except IndexError:
    break

sh = book.sheet_by_name("Nutrition")
nutritionValues = {}
for i in range(len(foods)):
    for j in range(len(categories)):
        nutritionValues[foods[i],categories[j]] = sh.cell_value(i+1,j+1)

import dietmodel
dietmodel.solve(categories, minNutrition, maxNutrition,
                foods, cost, nutritionValues)
```

## dietmodel.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Solve the classic diet model. This file implements
# a function that formulates and solves the model,
# but it contains no model data. The data is
# passed in by the calling program. Run example 'diet2.py',
# 'diet3.py', or 'diet4.py' to invoke this function.

from gurobipy import *

def solve(categories, minNutrition, maxNutrition, foods, cost,
          nutritionValues):
    # Model
    m = Model("diet")

    # Create decision variables for the nutrition information,
    # which we limit via bounds
    nutrition = {}
    for c in categories:
        nutrition[c] = m.addVar(lb=minNutrition[c], ub=maxNutrition[c], name=c)

    # Create decision variables for the foods to buy
    buy = {}
    for f in foods:
        buy[f] = m.addVar(obj=cost[f], name=f)

    # The objective is to minimize the costs
    m.modelSense = GRB.MINIMIZE

    # Update model to integrate new variables
    m.update()

    # Nutrition constraints
    for c in categories:
        m.addConstr(
            quicksum(nutritionValues[f,c] * buy[f] for f in foods) ==
            nutrition[c], c)

def printSolution():
    if m.status == GRB.status.OPTIMAL:
        print('\nCost: %g' % m.objVal)
```

```

    print('\nBuy:')
    for f in foods:
        if buy[f].x > 0.0001:
            print('%s %g' % (f, buy[f].x))
    print('\nNutrition:')
    for c in categories:
        print('%s %g' % (c, nutrition[c].x))
else:
    print('No solution')

# Solve
m.optimize()
printSolution()

print('\nAdding constraint: at most 6 servings of dairy')
m.addConstr(buy['milk'] + buy['ice cream'] <= 6, "limit_dairy")

# Solve
m.optimize()
printSolution()

```

## facility.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Facility location: a company currently ships its product from 5 plants
# to 4 warehouses. It is considering closing some plants to reduce
# costs. What plant(s) should the company close, in order to minimize
# transportation and fixed costs?
#
# Note that this example uses lists instead of dictionaries. Since
# it does not work with sparse data, lists are a reasonable option.
#
# Based on an example from Frontline Systems:
# http://www.solver.com/disfacility.htm
# Used with permission.

from gurobipy import *

# Warehouse demand in thousands of units
demand = [15, 18, 14, 20]

# Plant capacity in thousands of units
capacity = [20, 22, 17, 19, 18]

# Fixed costs for each plant
fixedCosts = [12000, 15000, 17000, 13000, 16000]

# Transportation costs per thousand units
transCosts = [[4000, 2000, 3000, 2500, 4500],
               [2500, 2600, 3400, 3000, 4000],
               [1200, 1800, 2600, 4100, 3000],
               [2200, 2600, 3100, 3700, 3200]]

# Range of plants and warehouses
plants = range(len(capacity))
warehouses = range(len(demand))

# Model
m = Model("facility")

# Plant open decision variables: open[p] == 1 if plant p is open.
open = []
for p in plants:
    open.append(m.addVar(vtype=GRB.BINARY, name="Open%d" % p))
```

```

# Transportation decision variables: how much to transport from
# a plant p to a warehouse w
transport = []
for w in warehouses:
    transport.append([])
    for p in plants:
        transport[w].append(m.addVar(obj=transCosts[w][p],
                                     name="Trans%d.%d" % (p, w)))

# The objective is to minimize the total fixed and variable costs
m.modelSense = GRB.MINIMIZE

# Update model to integrate new variables
m.update()

# Set optimization objective - minimize sum of fixed costs
m.setObjective(quicksum([fixedCosts[p]*open[p] for p in plants]))

# Production constraints
# Note that the right-hand limit sets the production to zero if the plant
# is closed
for p in plants:
    m.addConstr(
        quicksum(transport[w][p] for w in warehouses) <= capacity[p] * open[p],
        "Capacity%d" % p)

# Demand constraints
for w in warehouses:
    m.addConstr(quicksum(transport[w][p] for p in plants) == demand[w],
                "Demand%d" % w)

# Guess at the starting point: close the plant with the highest fixed costs;
# open all others

# First, open all plants
for p in plants:
    open[p].start = 1.0

# Now close the plant with the highest fixed cost
print('Initial guess:')
maxFixed = max(fixedCosts)
for p in plants:
    if fixedCosts[p] == maxFixed:
        open[p].start = 0.0

```

```

        print('Closing plant %s' % p)
        break
print('')

# Use barrier to solve root relaxation
m.params.method = 2

# Solve
m.optimize()

# Print solution
print('\nTOTAL COSTS: %g' % m.objVal)
print('SOLUTION:')
for p in plants:
    if open[p].x == 1.0:
        print('Plant %s open' % p)
        for w in warehouses:
            if transport[w][p].x > 0:
                print('  Transport %g units to warehouse %s' % \
                    (transport[w][p].x, w))
    else:
        print('Plant %s closed!' % p)

```

## feasopt.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example reads a MIP model from a file, adds artificial
# variables to each constraint, and then minimizes the sum of the
# artificial variables. A solution with objective zero corresponds
# to a feasible solution to the input model.
#
# We can also use FeasRelax feature to do it. In this example, we
# use minrelax=1, i.e. optimizing the returned model finds a solution
# that minimizes the original objective, but only from among those
# solutions that minimize the sum of the artificial variables.

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: feaso.py filename')
    quit()

feasmodel = gurobi.read(sys.argv[1])

#create a copy to use FeasRelax feature later

feasmodel1 = feasmodel.copy()

# clear objective

feasmodel.setObjective(0.0)

# add slack variables

for c in feasmodel.getConstrs():
    sense = c.sense
    if sense != '>':
        feasmodel.addVar(obj=1.0, name="ArtN_" + c.constrName,
                          column=Column([-1], [c]))
    if sense != '<':
        feasmodel.addVar(obj=1.0, name="ArtP_" + c.constrName,
                          column=Column([1], [c]))

feasmodel.update()
```

```
# optimize modified model

feasmodel.write('feasopt.lp')

feasmodel.optimize()

# use FeasRelax feature

feasmodel1.feasRelaxS(0, True, False, True);

feasmodel1.write("feasopt1.lp");

feasmodel1.optimize();
```

## fixanddive.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Implement a simple MIP heuristic. Relax the model,
# sort variables based on fractionality, and fix the 25% of
# the fractional variables that are closest to integer variables.
# Repeat until either the relaxation is integer feasible or
# linearly infeasible.

import sys
from gurobipy import *

# Key function used to sort variables based on relaxation fractionality

def sortkey(v1):
    sol = v1.x
    return abs(sol-int(sol+0.5))

if len(sys.argv) < 2:
    print('Usage: fixanddive.py filename')
    quit()

# Read model

model = gurobi.read(sys.argv[1])

# Collect integer variables and relax them
intvars = []
for v in model.getVars():
    if v.vType != GRB.CONTINUOUS:
        intvars += [v]
        v.vType = GRB.CONTINUOUS

model.params.outputFlag = 0

model.optimize()

# Perform multiple iterations. In each iteration, identify the first
# quartile of integer variables that are closest to an integer value in the
# relaxation, fix them to the nearest integer, and repeat.
```

```

for iter in range(1000):

# create a list of fractional variables, sorted in order of increasing
# distance from the relaxation solution to the nearest integer value

    fractional = []
    for v in intvars:
        sol = v.x
        if abs(sol - int(sol+0.5)) > 1e-5:
            fractional += [v]

    fractional.sort(key=sortkey)

    print('Iteration %d, obj %g, fractional %d' % \
          (iter, model.objVal, len(fractional)))

    if len(fractional) == 0:
        print('Found feasible solution - objective %g' % model.objVal)
        break

# Fix the first quartile to the nearest integer value
    nfix = max(int(len(fractional)/4), 1)
    for i in range(nfix):
        v = fractional[i]
        fixval = int(v.x+0.5)
        v.lb = fixval
        v.ub = fixval
        print(' Fix %s to %g (rel %g)' % (v.varName, fixval, v.x))

    model.optimize()

# Check optimization result

    if model.status != GRB.status.OPTIMAL:
        print('Relaxation is infeasible')
        break

```

## lp.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example reads an LP model from a file and solves it.
# If the model is infeasible or unbounded, the example turns off
# presolve and solves the model again. If the model is infeasible,
# the example computes an Irreducible Infeasible Subsystem (IIS),
# and writes it to a file

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: lp.py filename')
    quit()

# Read and solve model

model = read(sys.argv[1])
model.optimize()

if model.status == GRB.status.INF_OR_UNBD:
    # Turn presolve off to determine whether model is infeasible
    # or unbounded
    model.setParam(GRB.param.presolve, 0)
    model.optimize()

if model.status == GRB.status.OPTIMAL:
    print('Optimal objective: %g' % model.objVal)
    model.write('model.sol')
    exit(0)
elif model.status != GRB.status.INFEASIBLE:
    print('Optimization was stopped with status %d' % model.status)
    exit(0)

# Model is infeasible - compute an Irreducible Infeasible Subsystem (IIS)

print('')
print('Model is infeasible')
model.computeIIS()
model.write("model.ilp")
print("IIS written to file 'model.ilp'")
```

## lpmethod.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Solve a model with different values of the Method parameter;
# show which value gives the shortest solve time.

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: lpmethod.py filename')
    quit()

# Read model
m = read(sys.argv[1])

# Solve the model with different values of Method
bestTime = m.params.timeLimit
bestMethod = -1
for i in range(3):
    m.reset()
    m.params.method = i
    m.optimize()
    if m.status == GRB.status.OPTIMAL:
        bestTime = m.Runtime
        bestMethod = i
        # Reduce the TimeLimit parameter to save time with other methods
        m.params.timeLimit = bestTime

# Report which method was fastest
if bestMethod == -1:
    print('Unable to solve this model')
else:
    print('Solved in %g seconds with Method %d' % (bestTime, bestMethod))
```

## lpmod.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example reads an LP model from a file and solves it.
# If the model can be solved, then it finds the smallest positive variable,
# sets its upper bound to zero, and resolves the model two ways:
# first with an advanced start, then without an advanced start
# (i.e. 'from scratch').

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: lpmod.py filename')
    quit()

# Read model and determine whether it is an LP

model = read(sys.argv[1])
if model.isMIP == 1:
    print('The model is not a linear program')
    exit(1)

model.optimize()

status = model.status

if status == GRB.status.INF_OR_UNBD or status == GRB.status.INFEASIBLE \
    or status == GRB.status.UNBOUNDED:
    print('The model cannot be solved because it is infeasible or unbounded')
    exit(1)

if status != GRB.status.OPTIMAL:
    print('Optimization was stopped with status %d' % status)
    exit(0)

# Find the smallest variable value
minVal = GRB.INFINITY
for v in model.getVars():
    if v.x > 0.0001 and v.x < minVal and v.lb == 0.0:
        minVal = v.x
        minVar = v
```

```
print('\n*** Setting %s from %g to zero ***\n' % (minVar.varName, minVal))
minVar.ub = 0.0

# Solve from this starting point
model.optimize()

# Save iteration & time info
warmCount = model.IterCount
warmTime = model.Runtime

# Reset the model and resolve
print('\n*** Resetting and solving without an advanced start ***\n')
model.reset()
model.optimize()

coldCount = model.IterCount
coldTime = model.Runtime

print('')
print('*** Warm start: %g iterations, %g seconds' % (warmCount, warmTime))
print('*** Cold start: %g iterations, %g seconds' % (coldCount, coldTime))
```

## mip1.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example formulates and solves the following simple MIP model:
# maximize
#      x + y + 2 z
# subject to
#      x + 2 y + 3 z <= 4
#      x + y >= 1
# x, y, z binary

from gurobipy import *

try:

    # Create a new model
    m = Model("mip1")

    # Create variables
    x = m.addVar(vtype=GRB.BINARY, name="x")
    y = m.addVar(vtype=GRB.BINARY, name="y")
    z = m.addVar(vtype=GRB.BINARY, name="z")

    # Integrate new variables
    m.update()

    # Set objective
    m.setObjective(x + y + 2 * z, GRB.MAXIMIZE)

    # Add constraint: x + 2 y + 3 z <= 4
    m.addConstr(x + 2 * y + 3 * z <= 4, "c0")

    # Add constraint: x + y >= 1
    m.addConstr(x + y >= 1, "c1")

    m.optimize()

    for v in m.getVars():
        print('%s %g' % (v.varName, v.x))

    print('Obj: %g' % m.objVal)
```

```
except GurobiError:  
    print('Error reported')
```

## mip2.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example reads a MIP model from a file, solves it and prints
# the objective values from all feasible solutions generated while
# solving the MIP. Then it creates the associated fixed model and
# solves that model.

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: mip2.py filename')
    quit()

# Read and solve model

model = read(sys.argv[1])

if model.isMIP == 0:
    print('Model is not a MIP')
    exit(0)

model.optimize()

if model.status == GRB.status.OPTIMAL:
    print('Optimal objective: %g' % model.objVal)
elif model.status == GRB.status.INF_OR_UNBD:
    print('Model is infeasible or unbounded')
    exit(0)
elif model.status == GRB.status.INFEASIBLE:
    print('Model is infeasible')
    exit(0)
elif model.status == GRB.status.UNBOUNDED:
    print('Model is unbounded')
    exit(0)
else:
    print('Optimization ended with status %d' % model.status)
    exit(0)

# Iterate over the solutions and compute the objectives
model.params.outputFlag = 0
print('')
```

```

for k in range(model.solCount):
    model.params.solutionNumber = k
    objn = 0
    for v in model.getVars():
        objn += v.obj * v.xn
    print('Solution %d has objective %g' % (k, objn))
print('')
model.params.outputFlag = 1

fixed = model.fixed()
fixed.params.presolve = 0
fixed.optimize()

if fixed.status != GRB.status.OPTIMAL:
    print("Error: fixed model isn't optimal")
    exit(1)

diff = model.objVal - fixed.objVal

if abs(diff) > 1e-6 * (1.0 + abs(model.objVal)):
    print('Error: objective values are different')
    exit(1)

# Print values of nonzero variables
for v in fixed.getVars():
    if v.x != 0:
        print('%s %g' % (v.varName, v.x))

```

## netflow.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Solve a multi-commodity flow problem. Two products ('Pencils' and 'Pens')
# are produced in 2 cities ('Detroit' and 'Denver') and must be sent to
# warehouses in 3 cities ('Boston', 'New York', and 'Seattle') to
# satisfy demand ('inflow[h,i]').
#
# Flows on the transportation network must respect arc capacity constraints
# ('capacity[i,j]'). The objective is to minimize the sum of the arc
# transportation costs ('cost[i,j]').

from gurobipy import *

# Model data

commodities = ['Pencils', 'Pens']
nodes = ['Detroit', 'Denver', 'Boston', 'New York', 'Seattle']

arcs, capacity = multidict({
    ('Detroit', 'Boston'): 100,
    ('Detroit', 'New York'): 80,
    ('Detroit', 'Seattle'): 120,
    ('Denver', 'Boston'): 120,
    ('Denver', 'New York'): 120,
    ('Denver', 'Seattle'): 120 })
arcs = tuplelist(arcs)

cost = {
    ('Pencils', 'Detroit', 'Boston'): 10,
    ('Pencils', 'Detroit', 'New York'): 20,
    ('Pencils', 'Detroit', 'Seattle'): 60,
    ('Pencils', 'Denver', 'Boston'): 40,
    ('Pencils', 'Denver', 'New York'): 40,
    ('Pencils', 'Denver', 'Seattle'): 30,
    ('Pens', 'Detroit', 'Boston'): 20,
    ('Pens', 'Detroit', 'New York'): 20,
    ('Pens', 'Detroit', 'Seattle'): 80,
    ('Pens', 'Denver', 'Boston'): 60,
    ('Pens', 'Denver', 'New York'): 70,
    ('Pens', 'Denver', 'Seattle'): 30 }

inflow = {
```

```

('Pencils', 'Detroit'): 50,
('Pencils', 'Denver'): 60,
('Pencils', 'Boston'): -50,
('Pencils', 'New York'): -50,
('Pencils', 'Seattle'): -10,
('Pens', 'Detroit'): 60,
('Pens', 'Denver'): 40,
('Pens', 'Boston'): -40,
('Pens', 'New York'): -30,
('Pens', 'Seattle'): -30 }

# Create optimization model
m = Model('netflow')

# Create variables
flow = {}
for h in commodities:
    for i,j in arcs:
        flow[h,i,j] = m.addVar(ub=capacity[i,j], obj=cost[h,i,j],
                                name='flow_%s_%s_%s' % (h, i, j))
m.update()

# Arc capacity constraints
for i,j in arcs:
    m.addConstr(quicksum(flow[h,i,j] for h in commodities) <= capacity[i,j],
                'cap_%s_%s' % (i, j))

# Flow conservation constraints
for h in commodities:
    for j in nodes:
        m.addConstr(
            quicksum(flow[h,i,j] for i,j in arcs.select('*',j)) +
            inflow[h,j] ==
            quicksum(flow[h,j,k] for j,k in arcs.select(j,'*')),
            'node_%s_%s' % (h, j))

# Compute optimal solution
m.optimize()

# Print solution
if m.status == GRB.status.OPTIMAL:
    solution = m.getAttr('x', flow)
    for h in commodities:
        print('\nOptimal flows for %s:' % h)
        for i,j in arcs:

```

```
if solution[h,i,j] > 0:  
    print('%s -> %s: %g' % (i, j, solution[h,i,j]))
```

## params.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Use parameters that are associated with a model.
#
# A MIP is solved for 5 seconds with different sets of parameters.
# The one with the smallest MIP gap is selected, and the optimization
# is resumed until the optimal solution is found.

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: params.py filename')
    quit()

# Simple function to determine the MIP gap
def gap(model):
    if model.solCount == 0 or abs(model.objVal) < 1e-6:
        return GRB.INFINITY
    return abs(model.objBound - model.objVal)/abs(model.objVal)

# Read model and verify that it is a MIP
base = read(sys.argv[1])
if base.isMIP == 0:
    print('The model is not an integer program')
    exit(1)

# Set a 5 second time limit
base.params.timeLimit = 5

# Now solve the model with different values of MIPFocus
bestGap = GRB.INFINITY
bestModel = None
for i in range(4):
    m = base.copy()
    m.params.MIPFocus = i
    m.optimize()
    if bestModel == None or bestGap > gap(m):
        bestModel = m
        bestGap = gap(bestModel)
```

```
# Finally, reset the time limit and continue to solve the
# best model to optimality
bestModel.params.timeLimit = "default"
bestModel.optimize()
print('Solved with MIPFocus: %d' % bestModel.params.MIPFocus)
```

## qcp.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example formulates and solves the following simple QCP model:
#   maximize    x
#   subject to  x + y + z = 1
#               x^2 + y^2 <= z^2 (second-order cone)
#               x^2 <= yz        (rotated second-order cone)

from gurobipy import *

# Create a new model
m = Model("qcp")

# Create variables
x = m.addVar(name="x")
y = m.addVar(name="y")
z = m.addVar(name="z")

# Integrate new variables
m.update()

# Set objective: x
obj = 1.0*x
m.setObjective(obj, GRB.MAXIMIZE)

# Add constraint: x + y + z = 1
m.addConstr(x + y + z == 1, "c0")

# Add second-order cone: x^2 + y^2 <= z^2
m.addQConstr(x*x + y*y <= z*z, "qc0")

# Add rotated cone: x^2 <= yz
m.addQConstr(x*x <= y*z, "qc1")

m.optimize()

for v in m.getVars():
    print('%s %g' % (v.varName, v.x))

print('Obj: %g' % obj.getValue())
```

## qp.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example formulates and solves the following simple QP model:
# minimize
#   x^2 + x*y + y^2 + y*z + z^2 + 2 x
# subject to
#   x + 2 y + 3 z >= 4
#   x +   y           >= 1
#
# It solves it once as a continuous model, and once as an integer model.

from gurobipy import *

# Create a new model
m = Model("qp")

# Create variables
x = m.addVar(ub=1.0, name="x")
y = m.addVar(ub=1.0, name="y")
z = m.addVar(ub=1.0, name="z")

# Integrate new variables
m.update()

# Set objective: x^2 + x*y + y^2 + y*z + z^2 + 2 x
obj = x*x + x*y + y*y + y*z + z*z + 2*x
m.setObjective(obj)

# Add constraint: x + 2 y + 3 z <= 4
m.addConstr(x + 2 * y + 3 * z >= 4, "c0")

# Add constraint: x + y >= 1
m.addConstr(x + y >= 1, "c1")

m.optimize()

for v in m.getVars():
    print('%s %g' % (v.varName, v.x))

print('Obj: %g' % obj.getValue())

x.vType = GRB.INTEGER
```

```
y.vType = GRB.INTEGER
z.vType = GRB.INTEGER

m.optimize()

for v in m.getVars():
    print('%s %g' % (v.varName, v.x))

print('Obj: %g' % obj.getValue())
```

## sensitivity.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Simple MIP sensitivity analysis example.
# For each integer variable, fix it to its lower and upper bound
# and check the impact on the objective.

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: sensitivity.py filename')
    quit()

a = gurobi.read(sys.argv[1])
a.optimize()
a.params.outputFlag = 0

# Extract variables from model

avars = a.getVars()

# Iterate through binary variables in model

for i in range(len(avars)):
    v = avars[i]
    if v.vType == GRB.BINARY:

# Create clone and fix variable

        b = a.copy()
        bv = b.getVars()[i]
        if v.x - v.lb < 0.5:
            bv.lb = bv.ub
        else:
            bv.ub = bv.lb

        b.optimize()

        if b.status == GRB.status.OPTIMAL:
            objchg = b.objVal - a.objVal
            if objchg < 0:
```

```
        objchg = 0
    print('Objective sensitivity for variable %s is %g' % \
          (v.varName, objchg))
else:
    print('Objective sensitivity for variable %s is infinite' % \
          v.varName)
```

## SOS.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example creates a very simple Special Ordered Set (SOS) model.
# The model consists of 3 continuous variables, no linear constraints,
# and a pair of SOS constraints of type 1.

from gurobipy import *

try:

    # Create a new model

    model = Model("sos")

    # Create variables

    x0 = model.addVar(ub=1.0, name="x0")
    x1 = model.addVar(ub=1.0, name="x1")
    x2 = model.addVar(ub=2.0, name="x2")

    # Integrate new variables

    model.update()

    # Set objective
    model.setObjective(2 * x0 + x1 + x2, GRB.MAXIMIZE)

    # Add first SOS:  $x_0 = 0$  or  $x_1 = 0$ 
    model.addSOS(GRB.SOS_TYPE1, [x0, x1], [1, 2])

    # Add second SOS:  $x_0 = 0$  or  $x_2 = 0$ 
    model.addSOS(GRB.SOS_TYPE1, [x0, x2], [1, 2])

    model.optimize()

    for v in model.getVars():
        print('%s %g' % (v.varName, v.x))

    print('Obj: %g' % model.objVal)

except GurobiError:
```

```
print('Encountered an error')
```

## sudoku.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Sudoku example.

# The Sudoku board is a 9x9 grid, which is further divided into a 3x3 grid
# of 3x3 grids. Each cell in the grid must take a value from 0 to 9.
# No two grid cells in the same row, column, or 3x3 subgrid may take the
# same value.
#
# In the MIP formulation, binary variables  $x[i,j,v]$  indicate whether
# cell  $\langle i,j \rangle$  takes value 'v'. The constraints are as follows:
# 1. Each cell must take exactly one value ( $\sum_v x[i,j,v] = 1$ )
# 2. Each value is used exactly once per row ( $\sum_i x[i,j,v] = 1$ )
# 3. Each value is used exactly once per column ( $\sum_j x[i,j,v] = 1$ )
# 4. Each value is used exactly once per 3x3 subgrid ( $\sum_{\text{grid}} x[i,j,v] = 1$ )
#
# Input datasets for this example can be found in examples/data/sudoku*.

import sys
import math
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: sudoku.py filename')
    quit()

f = open(sys.argv[1])

grid = f.read().split()

n = len(grid[0])
s = int(math.sqrt(n))

# 3-D array of variables will be indexed by (i,j,v) tuples

vars = {}

# Create our 3-D array of model variables

model = Model('sudoku')
```

```

for i in range(n):
    for j in range(n):
        for v in range(n):
            vars[i,j,v] = model.addVar(vtype=GRB.BINARY,
                                       name='G_'+ str(i)+'_'+str(j)+'_'+str(v))

# Update model to integrate new variables

model.update()

# Fix variables associated with cells whose values are pre-specified

for i in range(n):
    for j in range(n):
        if grid[i][j] != '.':
            v = int(grid[i][j]) - 1
            model.addConstr(vars[i,j,v] == 1, 'Fix_' + str(i) + '_' + str(j))

# Each cell must take one value

for i in range(n):
    for j in range(n):
        model.addConstr(quicksum([vars[i,j,v] for v in range(n)]) == 1,
                        'V_' + str(i) + '_' + str(j))

# Each value appears once per row

for i in range(n):
    for v in range(n):
        model.addConstr(quicksum([vars[i,j,v] for j in range(n)]) == 1,
                        'R_' + str(i) + '_' + str(v))

# Each value appears once per column

for j in range(n):
    for v in range(n):
        model.addConstr(quicksum([vars[i,j,v] for i in range(n)]) == 1,
                        'C_' + str(j) + '_' + str(v))

# Each value appears once per subgrid

for v in range(n):
    for i0 in range(s):

```

```

    for j0 in range(s):
        subgrid = [vars[i,j,v] for i in range(i0*s, (i0+1)*s)
                    for j in range(j0*s, (j0+1)*s)]
        model.addConstr(quicksum(subgrid) == 1,
                        'Sub_' + str(i0) + '_' + str(j0) + '_' + str(v))

model.optimize()

model.write('sudoku.lp')

print('')
print('Solution:')
print('')

# Retrieve optimization result

solution = model.getAttr('X', vars)

for i in range(n):
    sol = ''
    for j in range(n):
        for v in range(n):
            if solution[i,j,v] > 0.5:
                sol += str(v+1)
    print(sol)

```

## tsp.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Solve a traveling salesman problem on a randomly generated set of
# points using lazy constraints. The base MIP model only includes
# 'degree-2' constraints, requiring each node to have exactly
# two incident edges. Solutions to this model may contain subtours -
# tours that don't visit every city. The lazy constraint callback
# adds new constraints to cut them off.

import sys
import math
import random
from gurobipy import *

# Callback - use lazy constraints to eliminate sub-tours

def subtourelim(model, where):
    if where == GRB.callback.MIPSOL:
        selected = []
        # make a list of edges selected in the solution
        for i in range(n):
            sol = model.cbGetSolution([model._vars[i,j] for j in range(n)])
            selected += [(i,j) for j in range(n) if sol[j] > 0.5]
        # find the shortest cycle in the selected edge list
        tour = subtour(selected)
        if len(tour) < n:
            # add a subtour elimination constraint
            expr = 0
            for i in range(len(tour)):
                for j in range(i+1, len(tour)):
                    expr += model._vars[tour[i], tour[j]]
            model.cbLazy(expr <= len(tour)-1)

# Euclidean distance between two points

def distance(points, i, j):
    dx = points[i][0] - points[j][0]
    dy = points[i][1] - points[j][1]
    return math.sqrt(dx*dx + dy*dy)
```

```

# Given a list of edges, finds the shortest subtour

def subtour(edges):
    visited = [False]*n
    cycles = []
    lengths = []
    selected = [[] for i in range(n)]
    for x,y in edges:
        selected[x].append(y)
    while True:
        current = visited.index(False)
        thiscycle = [current]
        while True:
            visited[current] = True
            neighbors = [x for x in selected[current] if not visited[x]]
            if len(neighbors) == 0:
                break
            current = neighbors[0]
            thiscycle.append(current)
        cycles.append(thiscycle)
        lengths.append(len(thiscycle))
        if sum(lengths) == n:
            break
    return cycles[lengths.index(min(lengths))]

# Parse argument

if len(sys.argv) < 2:
    print('Usage: tsp.py npoints')
    exit(1)
n = int(sys.argv[1])

# Create n random points

random.seed(1)
points = []
for i in range(n):
    points.append((random.randint(0,100),random.randint(0,100)))

m = Model()

# Create variables

```

```

vars = {}
for i in range(n):
    for j in range(i+1):
        vars[i,j] = m.addVar(obj=distance(points, i, j), vtype=GRB.BINARY,
                             name='e'+str(i)+'_'+str(j))
        vars[j,i] = vars[i,j]
m.update()

# Add degree-2 constraint, and forbid loops

for i in range(n):
    m.addConstr(quicksum(vars[i,j] for j in range(n)) == 2)
    vars[i,i].ub = 0
m.update()

# Optimize model

m._vars = vars
m.params.LazyConstraints = 1
m.optimize(subtourelim)

solution = m.getAttr('x', vars)
selected = [(i,j) for i in range(n) for j in range(n) if solution[i,j] > 0.5]
assert len(subtour(selected)) == n

print('')
print('Optimal tour: %s' % str(subtour(selected)))
print('Optimal cost: %g' % m.objVal)
print('')

```

## tune.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# This example reads a model from a file and tunes it.
# It then writes the best parameter settings to a file
# and solves the model using these parameters.

import sys
from gurobipy import *

if len(sys.argv) < 2:
    print('Usage: tune.py filename')
    quit()

# Read the model
model = read(sys.argv[1])

# Set the TuneResults parameter to 1
model.params.tuneResults = 1

# Tune the model
model.tune()

if model.tuneResultCount > 0:

    # Load the best tuned parameters into the model
    model.getTuneResult(0)

    # Write tuned parameters to a file
    model.write('tune.prm')

    # Solve the model using the tuned parameters
    model.optimize()
```

## workforce1.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Assign workers to shifts; each worker may or may not be available on a
# particular day. If the problem cannot be solved, use IIS to find a set of
# conflicting constraints. Note that there may be additional conflicts besides
# what is reported via IIS.

from gurobipy import *

# Number of workers required for each shift
shifts, shiftRequirements = multidict({
    "Mon1": 3,
    "Tue2": 2,
    "Wed3": 4,
    "Thu4": 4,
    "Fri5": 5,
    "Sat6": 6,
    "Sun7": 5,
    "Mon8": 2,
    "Tue9": 2,
    "Wed10": 3,
    "Thu11": 4,
    "Fri12": 6,
    "Sat13": 7,
    "Sun14": 5 })

# Amount each worker is paid to work one shift
workers, pay = multidict({
    "Amy": 10,
    "Bob": 12,
    "Cathy": 10,
    "Dan": 8,
    "Ed": 8,
    "Fred": 9,
    "Gu": 11 })

# Worker availability
availability = tuplelist([
    ('Amy', 'Tue2'), ('Amy', 'Wed3'), ('Amy', 'Fri5'), ('Amy', 'Sun7'),
    ('Amy', 'Tue9'), ('Amy', 'Wed10'), ('Amy', 'Thu11'), ('Amy', 'Fri12'),
    ('Amy', 'Sat13'), ('Amy', 'Sun14'), ('Bob', 'Mon1'), ('Bob', 'Tue2'),
    ('Bob', 'Fri5'), ('Bob', 'Sat6'), ('Bob', 'Mon8'), ('Bob', 'Thu11'),
```

```

('Bob', 'Sat13'), ('Cathy', 'Wed3'), ('Cathy', 'Thu4'), ('Cathy', 'Fri5'),
('Cathy', 'Sun7'), ('Cathy', 'Mon8'), ('Cathy', 'Tue9'), ('Cathy', 'Wed10'),
('Cathy', 'Thu11'), ('Cathy', 'Fri12'), ('Cathy', 'Sat13'),
('Cathy', 'Sun14'), ('Dan', 'Tue2'), ('Dan', 'Wed3'), ('Dan', 'Fri5'),
('Dan', 'Sat6'), ('Dan', 'Mon8'), ('Dan', 'Tue9'), ('Dan', 'Wed10'),
('Dan', 'Thu11'), ('Dan', 'Fri12'), ('Dan', 'Sat13'), ('Dan', 'Sun14'),
('Ed', 'Mon1'), ('Ed', 'Tue2'), ('Ed', 'Wed3'), ('Ed', 'Thu4'),
('Ed', 'Fri5'), ('Ed', 'Sun7'), ('Ed', 'Mon8'), ('Ed', 'Tue9'),
('Ed', 'Thu11'), ('Ed', 'Sat13'), ('Ed', 'Sun14'), ('Fred', 'Mon1'),
('Fred', 'Tue2'), ('Fred', 'Wed3'), ('Fred', 'Sat6'), ('Fred', 'Mon8'),
('Fred', 'Tue9'), ('Fred', 'Fri12'), ('Fred', 'Sat13'), ('Fred', 'Sun14'),
('Gu', 'Mon1'), ('Gu', 'Tue2'), ('Gu', 'Wed3'), ('Gu', 'Fri5'),
('Gu', 'Sat6'), ('Gu', 'Sun7'), ('Gu', 'Mon8'), ('Gu', 'Tue9'),
('Gu', 'Wed10'), ('Gu', 'Thu11'), ('Gu', 'Fri12'), ('Gu', 'Sat13'),
('Gu', 'Sun14')
])

```

```
# Model
```

```
m = Model("assignment")
```

```
# Assignment variables: x[w,s] == 1 if worker w is assigned to shift s.
```

```
# Since an assignment model always produces integer solutions, we use
```

```
# continuous variables and solve as an LP.
```

```
x = {}
```

```
for w,s in availability:
```

```
    x[w,s] = m.addVar(ub=1, obj=pay[w], name=w+"."+s)
```

```
# The objective is to minimize the total pay costs
```

```
m.modelSense = GRB.MINIMIZE
```

```
# Update model to integrate new variables
```

```
m.update()
```

```
# Constraint: assign exactly shiftRequirements[s] workers to each shift s
```

```
reqCts = {}
```

```
for s in shifts:
```

```
    reqCts[s] = m.addConstr(
```

```
        quicksum(x[w,s] for w,s in availability.select('*', s)) ==
        shiftRequirements[s], s)
```

```
# Optimize
```

```
m.optimize()
```

```
status = m.status
```

```
if status == GRB.status.UNBOUNDED:
```

```
    print('The model cannot be solved because it is unbounded')
```

```
    exit(0)
if status == GRB.status.OPTIMAL:
    print('The optimal objective is %g' % m.objVal)
    exit(0)
if status != GRB.status.INF_OR_UNBD and status != GRB.status.INFEASIBLE:
    print('Optimization was stopped with status %d' % status)
    exit(0)

# do IIS
print('The model is infeasible; computing IIS')
m.computeIIS()
print('\nThe following constraint(s) cannot be satisfied:')
for c in m.getConstrs():
    if c.IISConstr:
        print('%s' % c.constrName)
```

## workforce2.py

```
#!/usr/bin/python
```

```
# Copyright 2013, Gurobi Optimization, Inc.
```

```
# Assign workers to shifts; each worker may or may not be available on a  
# particular day. If the problem cannot be solved, use IIS iteratively to  
# find all conflicting constraints.
```

```
from gurobipy import *
```

```
# Number of workers required for each shift  
shifts, shiftRequirements = multidict({
```

```
    "Mon1": 3,  
    "Tue2": 2,  
    "Wed3": 4,  
    "Thu4": 4,  
    "Fri5": 5,  
    "Sat6": 6,  
    "Sun7": 5,  
    "Mon8": 2,  
    "Tue9": 2,  
    "Wed10": 3,  
    "Thu11": 4,  
    "Fri12": 6,  
    "Sat13": 7,  
    "Sun14": 5 })
```

```
# Amount each worker is paid to work one shift
```

```
workers, pay = multidict({
```

```
    "Amy": 10,  
    "Bob": 12,  
    "Cathy": 10,  
    "Dan": 8,  
    "Ed": 8,  
    "Fred": 9,  
    "Gu": 11 })
```

```
# Worker availability
```

```
availability = tuplelist([
```

```
    ('Amy', 'Tue2'), ('Amy', 'Wed3'), ('Amy', 'Fri5'), ('Amy', 'Sun7'),  
    ('Amy', 'Tue9'), ('Amy', 'Wed10'), ('Amy', 'Thu11'), ('Amy', 'Fri12'),  
    ('Amy', 'Sat13'), ('Amy', 'Sun14'), ('Bob', 'Mon1'), ('Bob', 'Tue2'),  
    ('Bob', 'Fri5'), ('Bob', 'Sat6'), ('Bob', 'Mon8'), ('Bob', 'Thu11'),  
    ('Bob', 'Sat13'), ('Cathy', 'Wed3'), ('Cathy', 'Thu4'), ('Cathy', 'Fri5'),
```

```

('Cathy', 'Sun7'), ('Cathy', 'Mon8'), ('Cathy', 'Tue9'), ('Cathy', 'Wed10'),
('Cathy', 'Thu11'), ('Cathy', 'Fri12'), ('Cathy', 'Sat13'),
('Cathy', 'Sun14'), ('Dan', 'Tue2'), ('Dan', 'Wed3'), ('Dan', 'Fri5'),
('Dan', 'Sat6'), ('Dan', 'Mon8'), ('Dan', 'Tue9'), ('Dan', 'Wed10'),
('Dan', 'Thu11'), ('Dan', 'Fri12'), ('Dan', 'Sat13'), ('Dan', 'Sun14'),
('Ed', 'Mon1'), ('Ed', 'Tue2'), ('Ed', 'Wed3'), ('Ed', 'Thu4'),
('Ed', 'Fri5'), ('Ed', 'Sun7'), ('Ed', 'Mon8'), ('Ed', 'Tue9'),
('Ed', 'Thu11'), ('Ed', 'Sat13'), ('Ed', 'Sun14'), ('Fred', 'Mon1'),
('Fred', 'Tue2'), ('Fred', 'Wed3'), ('Fred', 'Sat6'), ('Fred', 'Mon8'),
('Fred', 'Tue9'), ('Fred', 'Fri12'), ('Fred', 'Sat13'), ('Fred', 'Sun14'),
('Gu', 'Mon1'), ('Gu', 'Tue2'), ('Gu', 'Wed3'), ('Gu', 'Fri5'),
('Gu', 'Sat6'), ('Gu', 'Sun7'), ('Gu', 'Mon8'), ('Gu', 'Tue9'),
('Gu', 'Wed10'), ('Gu', 'Thu11'), ('Gu', 'Fri12'), ('Gu', 'Sat13'),
('Gu', 'Sun14')
]
]

```

```

# Model
m = Model("assignment")

# Assignment variables: x[w,s] == 1 if worker w is assigned to shift s.
# Since an assignment model always produces integer solutions, we use
# continuous variables and solve as an LP.
x = {}
for w,s in availability:
    x[w,s] = m.addVar(ub=1, obj=pay[w], name=w+"."+s)

# The objective is to minimize the total pay costs
m.modelSense = GRB.MINIMIZE

# Update model to integrate new variables
m.update()

# Constraint: assign exactly shiftRequirements[s] workers to each shift s
reqCts = {}
for s in shifts:
    reqCts[s] = m.addConstr(
        quicksum(x[w,s] for w,s in availability.select('*', s)) ==
        shiftRequirements[s], s)

# Optimize
m.optimize()
status = m.status
if status == GRB.status.UNBOUNDED:
    print('The model cannot be solved because it is unbounded')
    exit(0)

```

```

if status == GRB.status.OPTIMAL:
    print('The optimal objective is %g' % m.objVal)
    exit(0)
if status != GRB.status.INF_OR_UNBD and status != GRB.status.INFEASIBLE:
    print('Optimization was stopped with status %d' % status)
    exit(0)

# do IIS
print('The model is infeasible; computing IIS')
removed = []

# Loop until we reduce to a model that can be solved
while True:

    m.computeIIS()
    print('\nThe following constraint cannot be satisfied:')
    for c in m.getConstrs():
        if c.IISConstr:
            print('%s' % c.constrName)
            # Remove a single constraint from the model
            removed.append(str(c.constrName))
            m.remove(c)
            break
    print('')

    m.optimize()
    status = m.status

    if status == GRB.status.UNBOUNDED:
        print('The model cannot be solved because it is unbounded')
        exit(0)
    if status == GRB.status.OPTIMAL:
        break
    if status != GRB.status.INF_OR_UNBD and status != GRB.status.INFEASIBLE:
        print('Optimization was stopped with status %d' % status)
        exit(0)

print('\nThe following constraints were removed to get a feasible LP:')
print(removed)

```

## workforce3.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Assign workers to shifts; each worker may or may not be available on a
# particular day. If the problem cannot be solved, add slack variables
# to determine which constraints cannot be satisfied, and how much
# they need to be relaxed.

from gurobipy import *

# Number of workers required for each shift
shifts, shiftRequirements = multidict({
    "Mon1": 3,
    "Tue2": 2,
    "Wed3": 4,
    "Thu4": 4,
    "Fri5": 5,
    "Sat6": 6,
    "Sun7": 5,
    "Mon8": 2,
    "Tue9": 2,
    "Wed10": 3,
    "Thu11": 4,
    "Fri12": 6,
    "Sat13": 7,
    "Sun14": 5 })

# Amount each worker is paid to work one shift
workers, pay = multidict({
    "Amy": 10,
    "Bob": 12,
    "Cathy": 10,
    "Dan": 8,
    "Ed": 8,
    "Fred": 9,
    "Gu": 11 })

# Worker availability
availability = tuplelist([
    ('Amy', 'Tue2'), ('Amy', 'Wed3'), ('Amy', 'Fri5'), ('Amy', 'Sun7'),
    ('Amy', 'Tue9'), ('Amy', 'Wed10'), ('Amy', 'Thu11'), ('Amy', 'Fri12'),
    ('Amy', 'Sat13'), ('Amy', 'Sun14'), ('Bob', 'Mon1'), ('Bob', 'Tue2'),
    ('Bob', 'Fri5'), ('Bob', 'Sat6'), ('Bob', 'Mon8'), ('Bob', 'Thu11'),
```

```

('Bob', 'Sat13'), ('Cathy', 'Wed3'), ('Cathy', 'Thu4'), ('Cathy', 'Fri5'),
('Cathy', 'Sun7'), ('Cathy', 'Mon8'), ('Cathy', 'Tue9'), ('Cathy', 'Wed10'),
('Cathy', 'Thu11'), ('Cathy', 'Fri12'), ('Cathy', 'Sat13'),
('Cathy', 'Sun14'), ('Dan', 'Tue2'), ('Dan', 'Wed3'), ('Dan', 'Fri5'),
('Dan', 'Sat6'), ('Dan', 'Mon8'), ('Dan', 'Tue9'), ('Dan', 'Wed10'),
('Dan', 'Thu11'), ('Dan', 'Fri12'), ('Dan', 'Sat13'), ('Dan', 'Sun14'),
('Ed', 'Mon1'), ('Ed', 'Tue2'), ('Ed', 'Wed3'), ('Ed', 'Thu4'),
('Ed', 'Fri5'), ('Ed', 'Sun7'), ('Ed', 'Mon8'), ('Ed', 'Tue9'),
('Ed', 'Thu11'), ('Ed', 'Sat13'), ('Ed', 'Sun14'), ('Fred', 'Mon1'),
('Fred', 'Tue2'), ('Fred', 'Wed3'), ('Fred', 'Sat6'), ('Fred', 'Mon8'),
('Fred', 'Tue9'), ('Fred', 'Fri12'), ('Fred', 'Sat13'), ('Fred', 'Sun14'),
('Gu', 'Mon1'), ('Gu', 'Tue2'), ('Gu', 'Wed3'), ('Gu', 'Fri5'),
('Gu', 'Sat6'), ('Gu', 'Sun7'), ('Gu', 'Mon8'), ('Gu', 'Tue9'),
('Gu', 'Wed10'), ('Gu', 'Thu11'), ('Gu', 'Fri12'), ('Gu', 'Sat13'),
('Gu', 'Sun14')
])

```

```
# Model
```

```
m = Model("assignment")
```

```
# Assignment variables: x[w,s] == 1 if worker w is assigned to shift s.
```

```
# Since an assignment model always produces integer solutions, we use
```

```
# continuous variables and solve as an LP.
```

```
x = {}
```

```
for w,s in availability:
```

```
    x[w,s] = m.addVar(ub=1, obj=pay[w], name=w+"."+s)
```

```
# The objective is to minimize the total pay costs
```

```
m.modelSense = GRB.MINIMIZE
```

```
# Update model to integrate new variables
```

```
m.update()
```

```
# Constraint: assign exactly shiftRequirements[s] workers to each shift s
```

```
reqCts = {}
```

```
for s in shifts:
```

```
    reqCts[s] = m.addConstr(
```

```
        quicksum(x[w,s] for w,s in availability.select('*', s)) ==
        shiftRequirements[s], s)
```

```
# Optimize
```

```
m.optimize()
```

```
status = m.status
```

```
if status == GRB.status.UNBOUNDED:
```

```
    print('The model cannot be solved because it is unbounded')
```

```

    exit(0)
if status == GRB.status.OPTIMAL:
    print('The optimal objective is %g' % m.objVal)
    exit(0)
if status != GRB.status.INF_OR_UNBD and status != GRB.status.INFEASIBLE:
    print('Optimization was stopped with status %d' % status)
    exit(0)

# Add slack variables to make the model feasible
print('The model is infeasible; adding slack variables')

# Set original objective coefficients to zero
m.setObjective(0.0)

# Add a new slack variable to each shift constraint so that the shifts can
# be satisfied
slacks = {}
for s,c in reqCts.items():
    slacks[s] = m.addVar(obj=1.0, name=s+"Slack", column=Column([1], [c]))

# Solve the model with slacks
m.optimize()
status = m.status
if status == GRB.status.INF_OR_UNBD or status == GRB.status.INFEASIBLE \
or status == GRB.status.UNBOUNDED:
    print('The model with slacks cannot be solved \
because it is infeasible or unbounded')
    exit(1)

if status != GRB.status.OPTIMAL:
    print('Optimization was stopped with status %d' % status)
    exit(1)

print('\nSlack values:')
for sv in slacks.values():
    if sv.x > 1e-6:
        print('%s = %g' % (sv.varName, sv.x))

```

## workforce4.py

```
#!/usr/bin/python

# Copyright 2013, Gurobi Optimization, Inc.

# Assign workers to shifts; each worker may or may not be available on a
# particular day. We use lexicographic optimization to solve the model:
# first, we minimize the linear sum of the slacks. Then, we constrain
# the sum of the slacks, and we minimize a quadratic objective that
# tries to balance the workload among the workers.

from gurobipy import *

# Number of workers required for each shift
shifts, shiftRequirements = multidict({
    "Mon1": 3,
    "Tue2": 2,
    "Wed3": 4,
    "Thu4": 4,
    "Fri5": 5,
    "Sat6": 6,
    "Sun7": 5,
    "Mon8": 2,
    "Tue9": 2,
    "Wed10": 3,
    "Thu11": 4,
    "Fri12": 6,
    "Sat13": 7,
    "Sun14": 5 })

# Amount each worker is paid to work one shift
workers, pay = multidict({
    "Amy": 10,
    "Bob": 12,
    "Cathy": 10,
    "Dan": 8,
    "Ed": 8,
    "Fred": 9,
    "Gu": 11 })

# Worker availability
availability = tuplelist([
    ('Amy', 'Tue2'), ('Amy', 'Wed3'), ('Amy', 'Fri5'), ('Amy', 'Sun7'),
    ('Amy', 'Tue9'), ('Amy', 'Wed10'), ('Amy', 'Thu11'), ('Amy', 'Fri12'),
    ('Amy', 'Sat13'), ('Amy', 'Sun14'), ('Bob', 'Mon1'), ('Bob', 'Tue2'),
```

```

('Bob', 'Fri5'), ('Bob', 'Sat6'), ('Bob', 'Mon8'), ('Bob', 'Thu11'),
('Bob', 'Sat13'), ('Cathy', 'Wed3'), ('Cathy', 'Thu4'), ('Cathy', 'Fri5'),
('Cathy', 'Sun7'), ('Cathy', 'Mon8'), ('Cathy', 'Tue9'), ('Cathy', 'Wed10'),
('Cathy', 'Thu11'), ('Cathy', 'Fri12'), ('Cathy', 'Sat13'),
('Cathy', 'Sun14'), ('Dan', 'Tue2'), ('Dan', 'Wed3'), ('Dan', 'Fri5'),
('Dan', 'Sat6'), ('Dan', 'Mon8'), ('Dan', 'Tue9'), ('Dan', 'Wed10'),
('Dan', 'Thu11'), ('Dan', 'Fri12'), ('Dan', 'Sat13'), ('Dan', 'Sun14'),
('Ed', 'Mon1'), ('Ed', 'Tue2'), ('Ed', 'Wed3'), ('Ed', 'Thu4'),
('Ed', 'Fri5'), ('Ed', 'Sun7'), ('Ed', 'Mon8'), ('Ed', 'Tue9'),
('Ed', 'Thu11'), ('Ed', 'Sat13'), ('Ed', 'Sun14'), ('Fred', 'Mon1'),
('Fred', 'Tue2'), ('Fred', 'Wed3'), ('Fred', 'Sat6'), ('Fred', 'Mon8'),
('Fred', 'Tue9'), ('Fred', 'Fri12'), ('Fred', 'Sat13'), ('Fred', 'Sun14'),
('Gu', 'Mon1'), ('Gu', 'Tue2'), ('Gu', 'Wed3'), ('Gu', 'Fri5'),
('Gu', 'Sat6'), ('Gu', 'Sun7'), ('Gu', 'Mon8'), ('Gu', 'Tue9'),
('Gu', 'Wed10'), ('Gu', 'Thu11'), ('Gu', 'Fri12'), ('Gu', 'Sat13'),
('Gu', 'Sun14')
])

```

```

# Model
m = Model("assignment")

# Assignment variables: x[w,s] == 1 if worker w is assigned to shift s.
# This is no longer a pure assignment model, so we must use binary variables.
x = {}
for w,s in availability:
    x[w,s] = m.addVar(vtype=GRB.BINARY, obj=pay[w], name=w+"."+s)

# Slack variables for each shift constraint so that the shifts can
# be satisfied
slacks = {}
for s in shifts:
    slacks[s] = m.addVar(name=s+"Slack")

# Variable to represent the total slack
totSlack = m.addVar(name="totSlack")

# Variables to count the total shifts worked by each worker
totShifts = {}
for w in workers:
    totShifts[w] = m.addVar(name=w+"TotShifts")

# Update model to integrate new variables
m.update()

# Constraint: assign exactly shiftRequirements[s] workers to each shift s,

```

```

# plus the slack
for s in shifts:
    m.addConstr(slacks[s] +
        quicksum(x[w,s] for w,s in availability.select('*', s)) ==
        shiftRequirements[s], s)

# Constraint: set totSlack equal to the total slack
m.addConstr(totSlack == quicksum(slacks[s] for s in shifts), "totSlack")

# Constraint: compute the total number of shifts for each worker
for w in workers:
    m.addConstr(totShifts[w] ==
        quicksum(x[w,s] for w,s in availability.select(w, '*')),
        "totShifts" + w)

# Objective: minimize the total slack
# Note that this replaces the previous 'pay' objective coefficients
m.setObjective(totSlack)

# Optimize
def solveAndPrint():
    m.optimize()
    status = m.status
    if status == GRB.status.INF_OR_UNBD or status == GRB.status.INFEASIBLE \
        or status == GRB.status.UNBOUNDED:
        print('The model cannot be solved because it is infeasible or \
            unbounded')
        exit(1)

    if status != GRB.status.OPTIMAL:
        print('Optimization was stopped with status %d' % status)
        exit(0)

    # Print total slack and the number of shifts worked for each worker
    print('')
    print('Total slack required: %g' % totSlack.x)
    for w in workers:
        print('%s worked %g shifts' % (w, totShifts[w].x))
    print('')

solveAndPrint()

# Constrain the slack by setting its upper and lower bounds
totSlack.ub = totSlack.x

```

```

totSlack.lb = totSlack.x

# Variable to count the average number of shifts worked
avgShifts = m.addVar(name="avgShifts")

# Variables to count the difference from average for each worker;
# note that these variables can take negative values.
diffShifts = {}
for w in workers:
    diffShifts[w] = \
        m.addVar(lb=-GRB.INFINITY, ub=GRB.INFINITY, name=w+"Diff")

# Update model to integrate new variables
m.update()

# Constraint: compute the average number of shifts worked
m.addConstr(len(workers) * avgShifts ==
            quicksum(totShifts[w] for w in workers),
            "avgShifts")

# Constraint: compute the difference from the average number of shifts
for w in workers:
    m.addConstr(diffShifts[w] == totShifts[w] - avgShifts, w + "Diff")

# Objective: minimize the sum of the square of the difference from the
# average number of shifts worked
m.setObjective(quicksum(diffShifts[w]*diffShifts[w] for w in workers))

# Optimize
solveAndPrint()

```

## 3.7 MATLAB Examples

This section includes source code for all of the Gurobi MATLAB examples. The same source code can be found in the `examples/matlab` directory of the Gurobi distribution.

### diet.m

```
function diet()
% diet Solve the classic diet model

% Copyright 2013, Gurobi Optimization, Inc

% Nutrition guidelines, based on
% USDA Dietary Guidelines for Americans, 2005
% http://www.health.gov/DietaryGuidelines/dga2005/

ncategories = 4;
categories = {'calories'; 'protein'; 'fat'; 'sodium'};
%           minNutrition maxNutrition
categorynutrition = [ 1800 2200; % calories
                     91  inf; % protein
                     0  65; % fat
                     0  1779]; % sodium

nfoods = 9;
foods = {'hamburger';
        'chicken';
        'hot dog';
        'fries';
        'macaroni';
        'pizza';
        'salad';
        'milk';
        'ice cream'};

foodcost = [2.49; % hamburger
            2.89; % chicken
            1.50; % hot dog
            1.89; % fries
            2.09; % macaroni
            1.99; % pizza
            2.49; % salad
            0.89; % milk
            1.59]; % ice cream
```

```

        % calories protein fat sodium
nutritionValues = [ 410    24    26 730; % hamburger
                   420    32    10 1190; % chicken
                   560    20    32 1800; % hot dog
                   380     4    19 270;  % fries
                   320    12    10 930;  % macaroni
                   320    15    12 820;  % pizza
                   320    31    12 1230; % salad
                   100     8     2.5 125; % milk
                   330     8     10 180]; % ice cream
nutritionValues = sparse(nutritionValues);
model.modelName = 'diet';

% The variables are layed out as [ buy; nutrition]
model.obj = [ foodcost;          zeros(ncategories, 1)];
model.lb = [ zeros(nfoods, 1); categorynutrition(:, 1)];
model.ub = [ inf(nfoods, 1); categorynutrition(:, 2)];
model.A = [ nutritionValues' -speye(ncategories)];
model.rhs = zeros(ncategories, 1);
model.sense = repmat('=', ncategories, 1);

function printSolution(result)
    if strcmp(result.status, 'OPTIMAL')
        buy = result.x(1:nfoods);
        nutrition = result.x(nfoods+1:nfoods+ncategories);
        fprintf('\nCost: %f\n', result.objval);
        fprintf('\nBuy:\n')
        for f=1:nfoods
            if buy(f) > 0.0001
                fprintf('%10s %g\n', foods{f}, buy(f));
            end
        end
        fprintf('\nNutrition:\n')
        for c=1:ncategories
            fprintf('%10s %g\n', categories{c}, nutrition(c));
        end
    else
        fprintf('No solution\n');
    end
end

% Solve
results = gurobi(model);
printSolution(results);

```

```
fprintf('\nAdding constraint at most 6 servings of dairy\n')
milk = find(strcmp('milk', foods));
icecream = find(strcmp('ice cream', foods));
model.A(end+1,:) = sparse([1; 1], [milk; icecream], 1, ...
    1, nfoods + ncategories);
model.rhs(end+1) = 6;
model.sense(end+1) = '<';

% Solve
results = gurobi(model);
printSolution(results)

end
```

## linprog.m

```
function [x, fval, exitflag] = linprog(f, A, b, Aeq, beq, lb, ub)
%LINPROG A linear programming example using the Gurobi MATLAB interface
%
% This example is based on the linprog interface defined in the
% MATLAB Optimization Toolbox. The Optimization Toolbox
% is a registered trademark of The MathWorks, Inc.
%
% x = LINPROG(f,A,b) solves the linear programming problem:
%
% minimize      f'*x
% subject to    A*x <= b
%
%
% x = LINPROG(f,A,b,Aeq,beq) solves the problem:
%
% minimize      f'*x
% subject to    A*x <= b,
%               Aeq*x == beq.
%
%
% x = LINPROG(f,A,b,Aeq,beq,lb,ub) solves the problem:
%
% minimize      f'*x
% subject to    A*x <= b,
%               Aeq*x == beq,
%               lb <= x <= ub.
%
% You can set lb(j) = -inf, if x(j) has no lower bound,
% and ub(j) = inf, if x(j) has no upper bound.
%
% [x, fval] = LINPROG(f, A, b) returns the objective value
% at the solution. That is, fval = f'*x.
%
% [x, fval, exitflag] = LINPROG(f, A, b) returns an exitflag
% containing the status of the optimization. The values for
% exitflag and corresponding status codes are:
%     1 - OPTIMAL,
%     0 - ITERATION_LIMIT,
%    -2 - INFEASIBLE,
%    -3 - UNBOUNDED.
%
if nargin < 3
    error('linprog(f, A, b)')
end
```

```

if nargin > 7
    error('linprog(f, A, b, Aeq, beq, lb, ub)');
end

n = size(A, 2);

model.obj = f;

if nargin < 4
    model.A = A;
    model.rhs = b;
    model.sense = '<';
else
    model.A = [A; Aeq];
    model.rhs = [b; beq];
    model.sense = [repmat('<', size(A,1), 1); repmat('=', size(Aeq,1), 1)];
end

if nargin < 6
    model.lb = -inf(n,1);
else
    model.lb = lb;
end

if nargin == 7
    model.ub = ub;
end

params.outputflag = 0;
result = gurobi(model, params);

if strcmp(result.status, 'OPTIMAL')
    exitflag = 1;
elseif strcmp(result.status, 'ITERATION_LIMIT')
    exitflag = 0;
elseif strcmp(result.status, 'INF_OR_UNBD')
    params.dualreductions = 0;
    result = gurobi(model, params);
    if strcmp(result.status, 'INFEASIBLE')
        exitflag = -2;
    elseif strcmp(result.status, 'UNBOUNDED')
        exitflag = -3;
    else

```

```
        exitflag = nan;
    end
else
    exitflag = nan;
end

if isfield(result, 'x')
    x = result.x;
else
    x = nan(n,1);
end

if isfield(result, 'objval')
    fval = result.objval;
else
    fval = nan;
end
```

## lp.m

```
% Copyright 2013, Gurobi Optimization, Inc.
%
% This example formulates and solves the following simple LP model:
% maximize
%      x + 2 y + 3 z
% subject to
%      x +   y           <= 1
%           y +   z      <= 1
%
clear model;
model.A = sparse([1 1 0; 0 1 1]);
model.obj = [1 2 3];
model.modelsense = 'Max';
model.rhs = [1 1];
model.sense = [ '<' '<'];

result = gurobi(model)

disp(result.objval);
disp(result.x);

% Alternative representation of A - as sparse triplet matrix
i = [1; 1; 2; 2];
j = [1; 2; 2; 3];
x = [1; 1; 1; 1];
model.A = sparse(i, j, x, 2, 3);

clear params;
params.method = 2;
params.timelimit = 100;

result = gurobi(model, params);

disp(result.objval);
disp(result.x)
```

## lp2.m

```
% Copyright 2013, Gurobi Optimization, Inc.
%
% Formulate a simple linear program, solve it, and then solve it
% again using the optimal basis.

clear model;
model.A = sparse([1 3 4; 8 2 3]);
model.obj = [1 2 3];
model.rhs = [4 7];
model.sense = ['>' '>'];

% First solve requires a few simplex iterations
result = gurobi(model)

model.vbasis = result.vbasis;
model.cbasis = result.cbasis;

% Second solve - start from an optimal basis, so no iterations

result = gurobi(model)
```

## mip1.m

```
% Copyright 2013, Gurobi Optimization, Inc.

% This example formulates and solves the following simple MIP model:
% maximize
%      x +  y + 2 z
% subject to
%      x + 2 y + 3 z <= 4
%      x +  y      >= 1
% x, y, z binary

names = {'x'; 'y'; 'z'};

try
    clear model;
    model.A = sparse([1 2 3; 1 1 0]);
    model.obj = [1 1 2];
    model.rhs = [4; 1];
    model.sense = '<>';
    model.vtype = 'B';
    model.modelsense = 'max';
    model.varnames = names;

    gurobi_write(model, 'mip1.lp');

    clear params;
    params.outputflag = 0;

    result = gurobi(model, params);

    disp(result)

    for v=1:length(names)
        fprintf('%s %d\n', names{v}, result.x(v));
    end

    fprintf('Obj: %e\n', result.objval);

catch gurobiError
    fprintf('Error reported\n');
end
```

## qcp.m

```
% Copyright 2013, Gurobi Optimization, Inc.

% This example formulates and solves the following simple QCP model:
% maximize
%     x
% subject to
%     x + y + z = 1
%     x^2 + y^2 <= z^2 (second-order cone)
%     x^2 <= yz        (rotated second-order cone)

clear model
names = {'x', 'y', 'z'};
model.varnames = names;

% Set objective: x
model.obj = [ 1 0 0 ];
model.modelsense = 'max';

% Add constraint: x + y + z = 1
model.A = sparse([1 1 1]);
model.rhs = 1;
model.sense = '=';

% Add second-order cone: x^2 + y^2 <= z^2
model.quadcon(1).Qc = sparse([ 1 0 0;
                             0 1 0;
                             0 0 -1]);
model.quadcon(1).q = zeros(3,1);
model.quadcon(1).rhs = 0.0;

% Add rotated cone: x^2 <= yz
model.quadcon(2).Qc = sparse([ 1 0 0;
                              0 0 -1;
                              0 0 0]);
model.quadcon(2).q = zeros(3,1);
model.quadcon(2).rhs = 0;

gurobi_write(model, 'qcp.lp');

result = gurobi(model);

for j=1:3
    fprintf('%s %e\n', names{j}, result.x(j))
end
```

```
fprintf('Obj: %e\n', result.objval);
```

## qp.m

```
% Copyright 2013, Gurobi Optimization, Inc.

% This example formulates and solves the following simple QP model:
% minimize
%      x^2 + x*y + y^2 + y*z + z^2 + 2 x
% subject to
%      x + 2 y + 3 z >= 4
%      x +   y       >= 1
%
% It solves it once as a continuous model, and once as an integer
% model.

clear model;
names = {'x', 'y', 'z'};
model.varnames = names;
model.Q = sparse([1 0.5 0; 0.5 1 0.5; 0 0.5 1]);
model.A = sparse([1 2 3; 1 1 0]);
model.obj = [2 0 0];
model.rhs = [4 1];
model.sense = '>';

gurobi_write(model, 'qp.lp');

results = gurobi(model);

for v=1:length(names)
    fprintf('%s %e\n', names{v}, results.x(v));
end

fprintf('Obj: %e\n', results.objval);

model.vtype = 'B';

results = gurobi(model);

for v=1:length(names)
    fprintf('%s %e\n', names{v}, results.x(v));
end

fprintf('Obj: %e\n', results.objval);
```

## SOS.m

% Copyright 2013, Gurobi Optimization, Inc.

% This example creates a very simple Special Ordered Set (SOS)  
% model. The model consists of 3 continuous variables, no linear  
% constraints, and a pair of SOS constraints of type 1.

```
try
    clear model;
    model.ub = [1 1 2];
    model.obj = [2 1 1];
    model.modelsense = 'Max';
    model.A = sparse(1,3);
    model.rhs = 0;
    model.sense = '=';

    % Add first SOS:  $x_1 = 0$  or  $x_2 = 0$ 
    model.sos(1).type = 1;
    model.sos(1).index = [1 2];
    model.sos(1).weight = [1 2];

    % Add second SOS:  $x_1 = 0$  or  $x_3 = 0$ 
    model.sos(2).type = 1;
    model.sos(2).index = [1 3];
    model.sos(2).weight = [1 2];

    % Write model to file
    gurobi_write(model, 'sos.lp');

    result = gurobi(model);

    for i=1:3
        fprintf('x%d %e\n', i, result.x(i))
    end

    fprintf('Obj: %e\n', result.objval);

catch gurobiError
    fprintf('Encountered an error\n')
end
```

## 3.8 R Examples

This section includes source code for all of the Gurobi R examples. The same source code can be found in the `examples/R` directory of the Gurobi distribution.

### lp.R

```
# Copyright 2013, Gurobi Optimization, Inc.
#
# This example formulates and solves the following simple LP model:
# maximize
#      x + 2 y + 3 z
# subject to
#      x +   y      <= 1
#           y +   z <= 1

library("Matrix")
library("gurobi")

model <- list()

model$A      <- matrix(c(1,1,0,0,1,1), nrow=2, byrow=T)
model$obj    <- c(1,1,2)
model$model sense <- "max"
model$rhs    <- c(1,1)
model$sense  <- c('<=', '<=')

result <- gurobi(model)

print(result$objval)
print(result$x)

# Second option for A - as a sparseMatrix (using the Matrix package)...

model$A <- spMatrix(2, 3, c(1, 1, 2, 2), c(1, 2, 2, 3), c(1, 1, 1, 1))

params <- list(Method=2, TimeLimit=100)

result <- gurobi(model, params)

print(result$objval)
print(result$x)

# Third option for A - as a sparse triplet matrix (using the slam package)...

model$A <- simple_triplet_matrix(c(1, 1, 2, 2), c(1, 2, 2, 3), c(1, 1, 1, 1))
```

```
params <- list(Method=2, TimeLimit=100)

result <- gurobi(model, params)

print(result$objval)
print(result$x)
```

## lp2.R

```
# Copyright 2013, Gurobi Optimization, Inc.
#
# Formulate a simple linear program, solve it, and then solve it
# again using the optimal basis.

library("gurobi")

model <- list()

model$A      <- matrix(c(1,3,4,8,2,3), nrow=2, byrow=T)
model$obj    <- c(1,2,3)
model$rhs    <- c(4,7)
model$sense  <- c('>=', '>=')

# First solve - requires a few simplex iterations

result <- gurobi(model)

model$vbasis <- result$vbasis
model$cbasis <- result$cbasis

# Second solve - start from optimal basis, so no iterations

result <- gurobi(model)
```

## mip.R

```
# Copyright 2013, Gurobi Optimization, Inc.
#
# This example formulates and solves the following simple MIP model:
# maximize
#      x + y + 2 z
# subject to
#      x + 2 y + 3 z <= 4
#      x + y >= 1
#      x, y, z binary

library("gurobi")

model <- list()

model$A      <- matrix(c(1,2,3,1,1,0), nrow=2, ncol=3, byrow=T)
model$obj    <- c(1,1,2)
model$model sense <- "max"
model$rhs    <- c(4,1)
model$sense  <- c('<=', '>=')
model$vtype  <- 'B'

params <- list(OutputFlag=0)

result <- gurobi(model, params)

print('Solution:')
print(result$objval)
print(result$x)
```

## qcp.R

```
# Copyright 2013, Gurobi Optimization, Inc.
#
# This example formulates and solves the following simple QCP model:
# minimize
#       x^2 + x*y + y^2 + y*z + z^2
# subject to
#       x + 2 y + 3z   >= 4
#       x +   y       >= 1
#       t = 0.7071
#       [ x ^ 2 + y ^ 2 - t ^ 2 ] <= 0 (a second-order cone constraint)

library("gurobi")

model <- list()

model$A      <- matrix(c(1,2,3,0,1,1,0,0,0,0,0,1), nrow=3, byrow=T)
model$Q      <- matrix(c(2,1,0,0,1,2,1,0,0,1,2,0,0,0,0,0), nrow=4, byrow=T)
model$cones  <- list(list(4,1,2))
model$obj    <- c(1,2,3,0)
model$rhs    <- c(4,1,0.717067811)
model$sense  <- c('>=', '>=', '=')

result <- gurobi(model)

print(result$objval)
print(result$x)
```

## qp.R

```
# Copyright 2013, Gurobi Optimization, Inc.
#
# This example formulates and solves the following simple QP model:
# minimize
#       x^2 + x*y + y^2 + y*z + z^2 + 2 x
# subject to
#       x + 2 y + 3z >= 4
#       x +   y       >= 1

library("gurobi")

model <- list()

model$A    <- matrix(c(1,2,3,1,1,0), nrow=2, byrow=T)
model$Q    <- matrix(c(2,1,0,1,2,1,0,1,2), nrow=3, byrow=T)
model$obj  <- c(2,0,0)
model$rhs  <- c(4,1)
model$sense <- c('>=', '>=')

result <- gurobi(model)

print(result$objval)
print(result$x)
```