CPLEX Concert Technology Tutorial

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1. About CPLEX and Concert

CPLEX is a suite of tools by ILOG (now under IBM) that solve linear programming, integer programming and mixed integer programming problems. There are several ways in which an LP or MIP can be solved using CPLEX. One of the most powerful ways is to define the LP in a programming language, using CPLEX to solve it and returning the results using the programming language in a user-friendly format. To do this, CPLEX provides libraries that can be called by several programming languages such as C++, Java, Python etc. 'Concert' is the name of the technology that provides an interface to call CPLEX libraries using C++, C# and JAVA. This tutorial uses C++.

2. Installing CPLEX and Visual Studio

Visual Studio is an Integrated Development Environment (IDE) i.e. a tool to build and maintain all code related to your projects. The CPLEX documentation recommends using Visual Studio to write C++ code. The "Community" Version is free for students and open-source developers. The Professional edition is for professional developers and universities. Texas A&M University provides access to Visual Studio Professional in some labs. If it is not available on the system or you wish to run the code on your personal computer, all versions can be downloaded from: https://www.visualstudio.com/.
CPLEX is free for students and academics. If it is not already installed on the system you are using (university or personal), it can be downloaded from:

a. For students: https://ibm.onthehub.com/WebStore/OfferingDetails.aspx?o=9b4eadea-9776-e611-9421-b8ca3a5db7a1
b. For academics: https://ibm.onthehub.com/WebStore/OfferingDetails.aspx?o=6fcc1096-7169-e611-9420-b8ca3a5db7a1

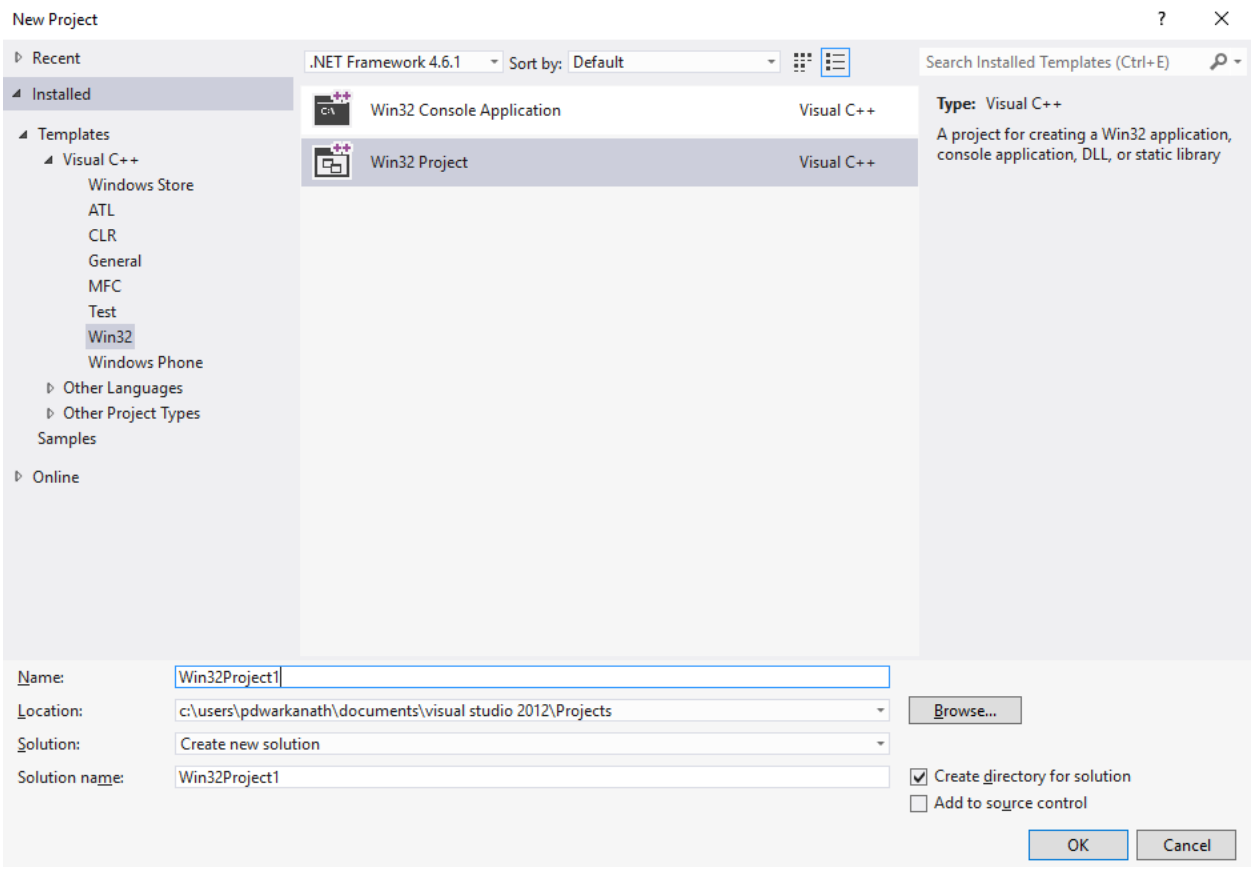
In the following steps, the folder in which CPLEX is installed on your computer will be referred to as `<CPLEXDIR>`. If using Windows and following defaults, this will be `C:\Program Files\IBM\ILOG\CPLEX_Studioxxxx` (Here xxxx is the version of CPLEX installed)
Please keep a note of the `<CPLEXDIR>` for future reference.

3. Setting up CPLEX Concert with C++ in Release Mode

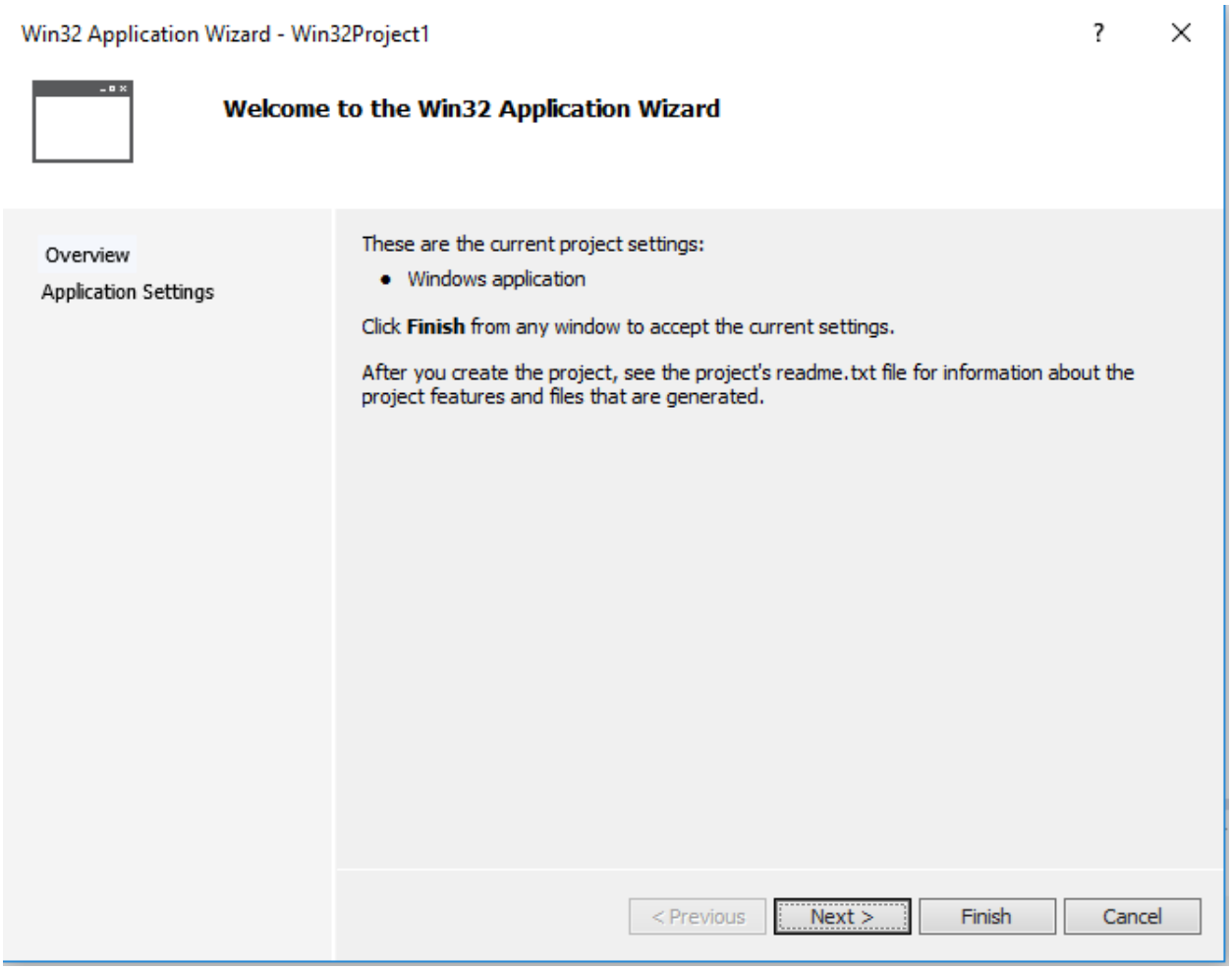
Follow the steps in this order

a. Open a new project.

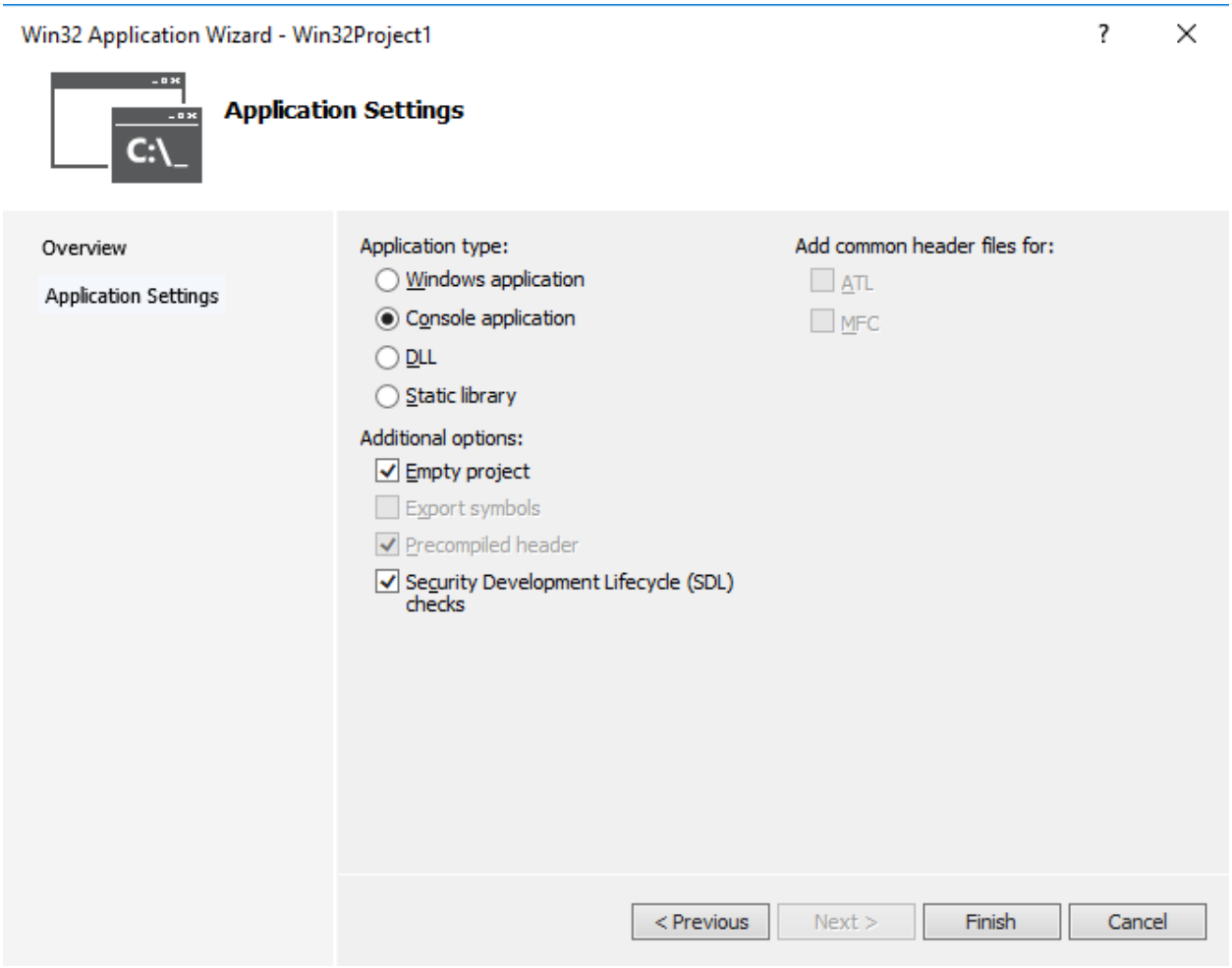
i. Open Visual Studio
ii. Select File > New > Project
iii. In the left pane, select Installed > Templates > Visual C++
iv. Select "Win32 Application"
v. Change name and location of project, if necessary.
vi. Click "OK"



vii. After this, the Win32 Application wizard appears. Click “Next”

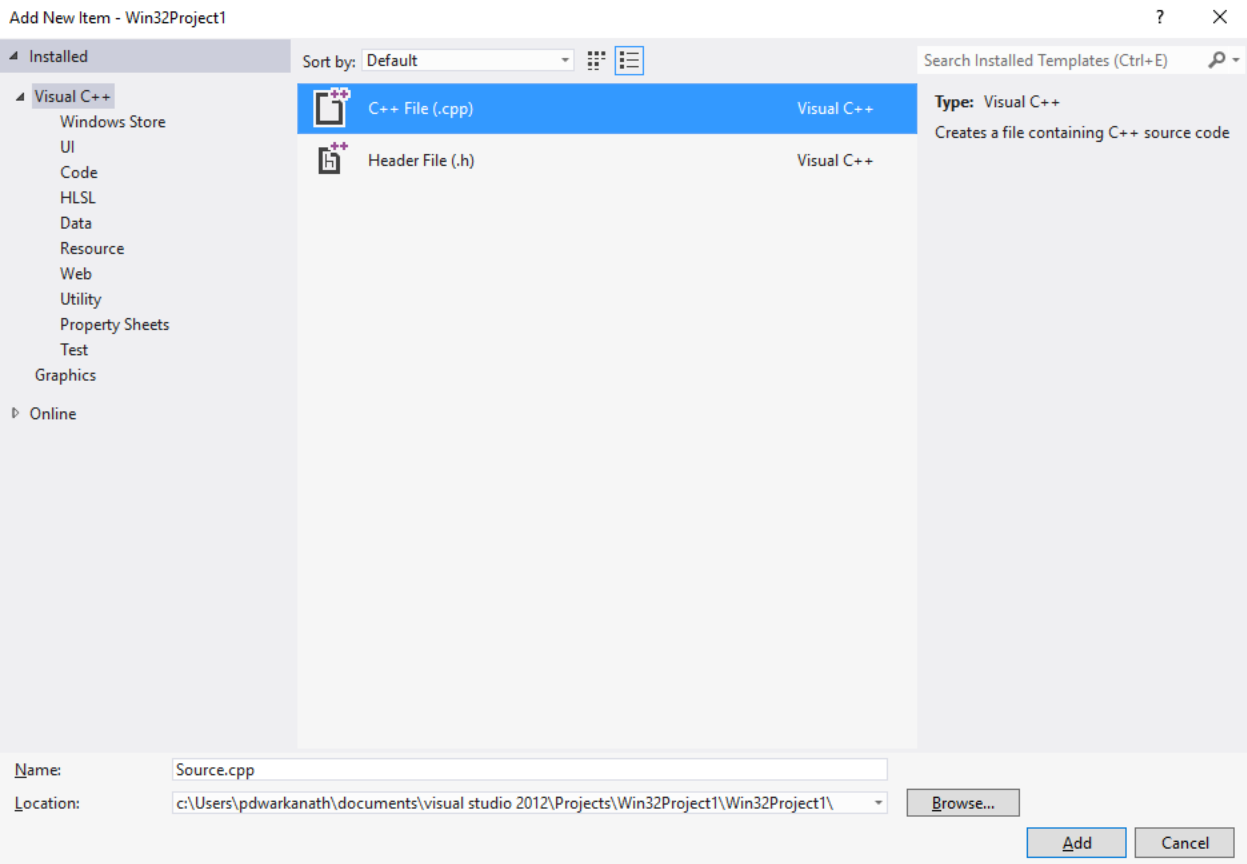


viii. Select “Console Application” and “Empty Project”
ix. Click Finish



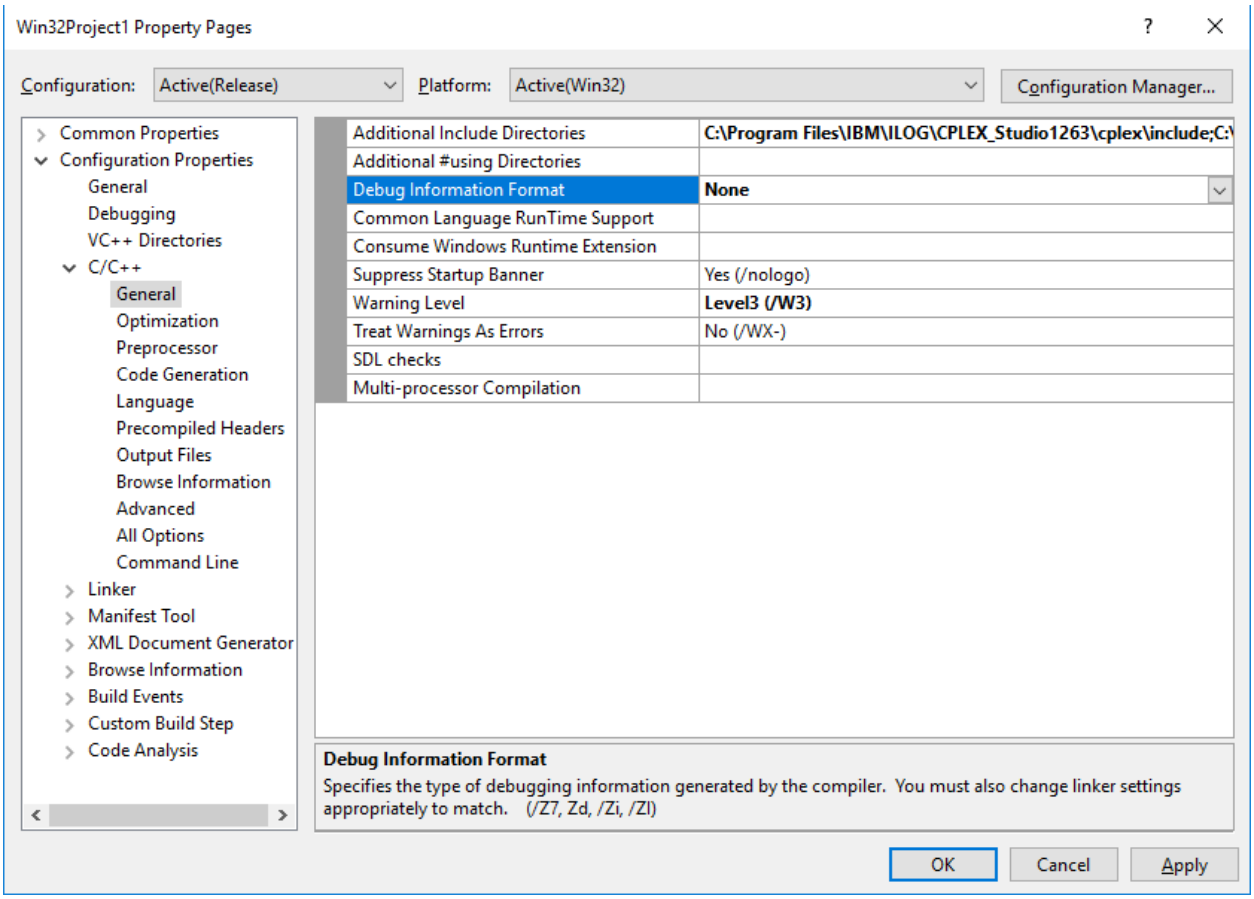
b. Open a new C++ file

i. Select Project > Add New Item
ii. In the left pane, select Installed > Visual C++
iii. Select C++ file (.cpp)
iv. Change name if necessary
v. Click Add



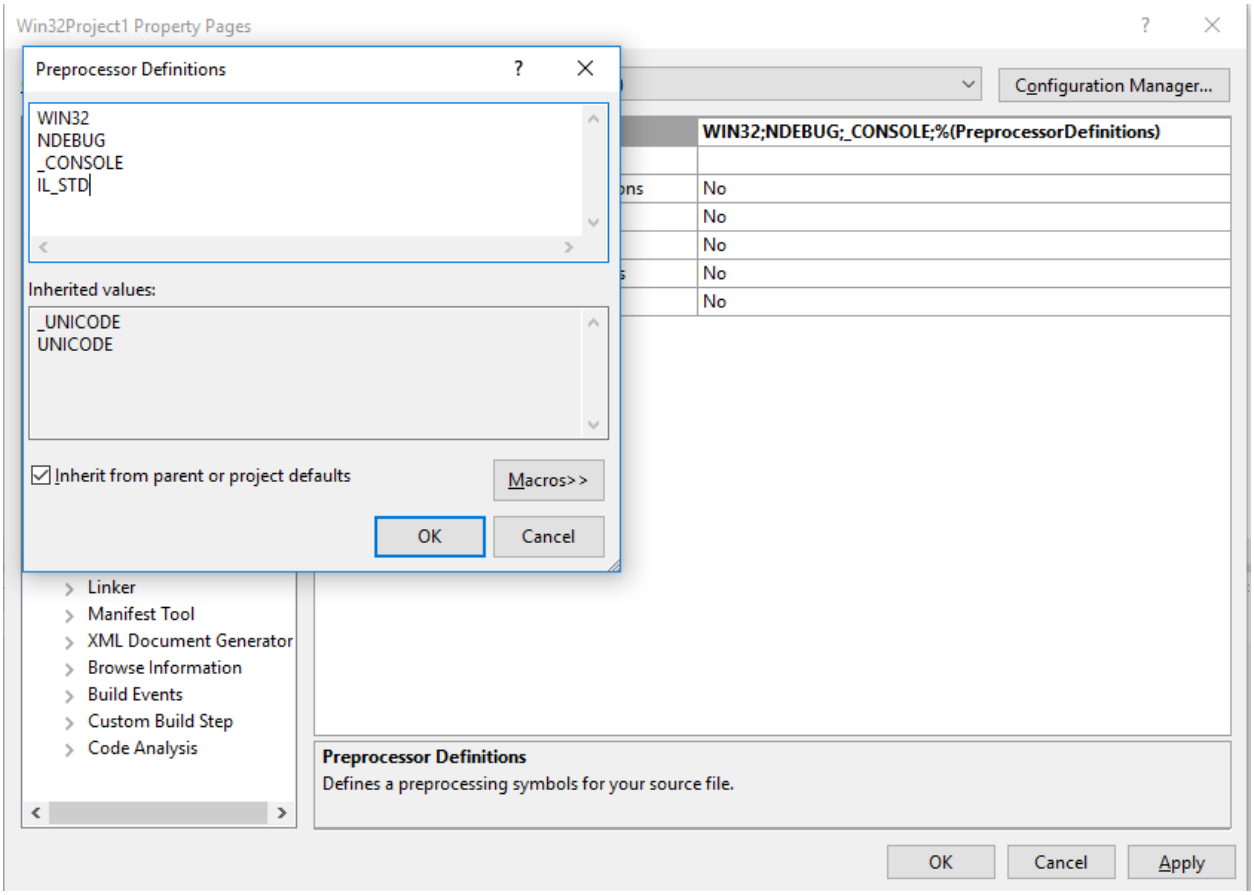
c. Link CPLEX and Concert to your project

i. Select Project > Properties
ii. In the project properties box, select Configuration Properties > C++ > General
iii. Add these two pathnames:
    - <CPLEXDIR>\cplex\include
    - <CPLEXDIR>\concert\include
iv. Select SDL checks as “No”
v. Select Debug Information Format as “None”



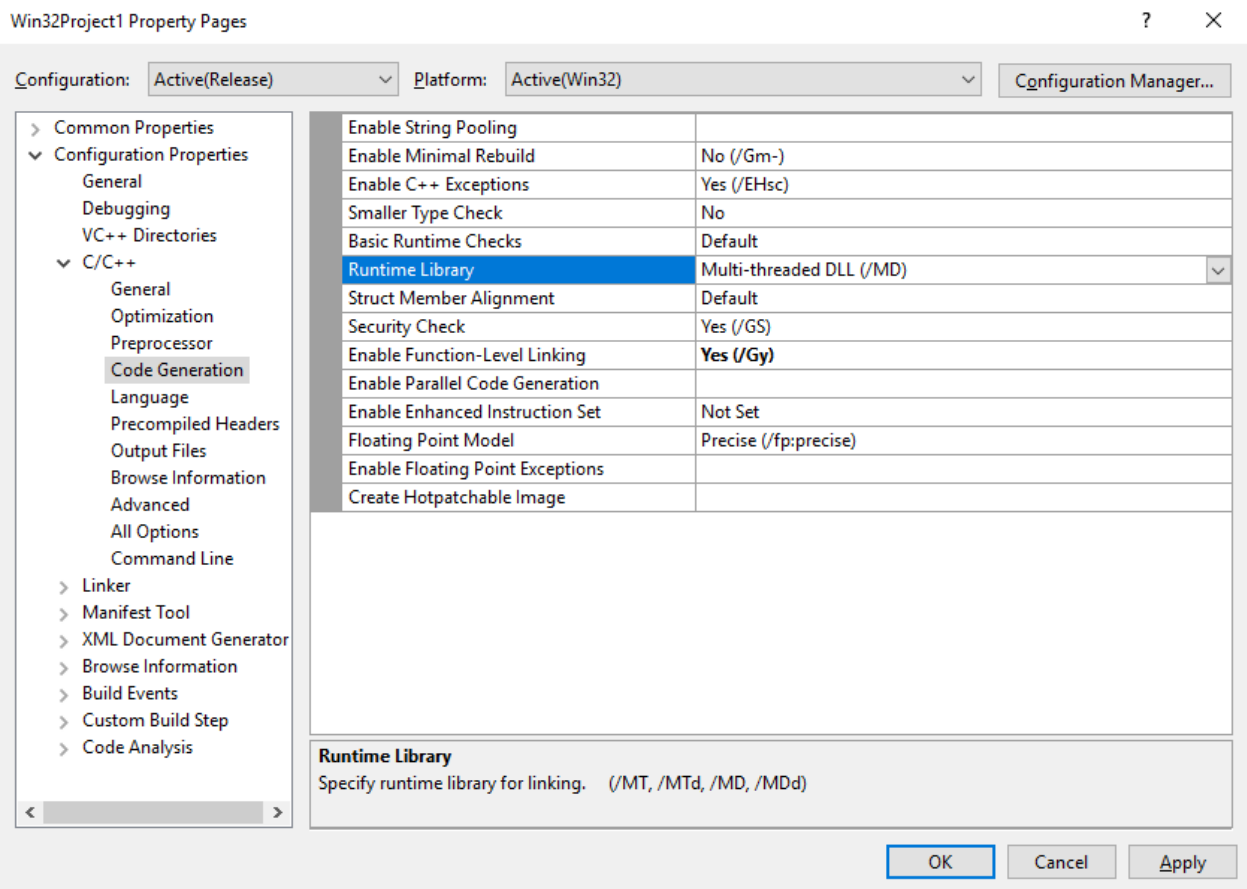
vi. On the left pane, select Configuration Properties > C++ > Preprocessor

vii. Add IL_STD to the Preprocessor Definitions



viii. Select Configuration Properties > C++ > Code Generation

ix. Set Runtime Library to Multi-threaded DLL (/MD) (for pre-2012 versions of Visual Studio, use Multi-threaded (/MT))

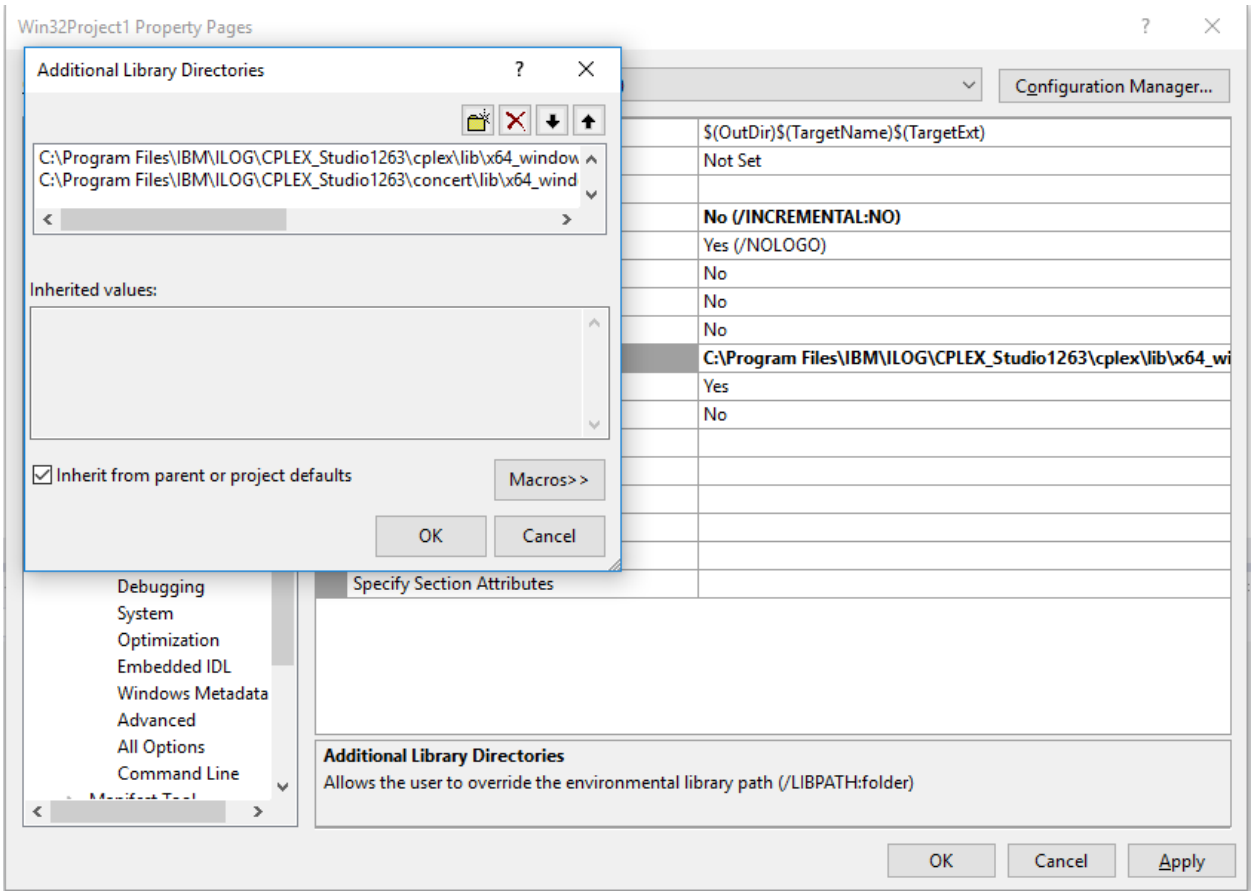


x. Select Configuration Properties > Linker > General

xi. In the “Additional Library Directories” add:

- <CPLEXDIR> \cplex\lib\x64_windows_vs2012\stat_mda
- <CPLEXDIR> \concert\lib\x64_windows_vs2012\stat_mda

(vs2012 can be replaced by vs20xx where 20xx is the Visual Studio edition. This tutorial was made with Visual Studio 2012 and hence uses vs2012)

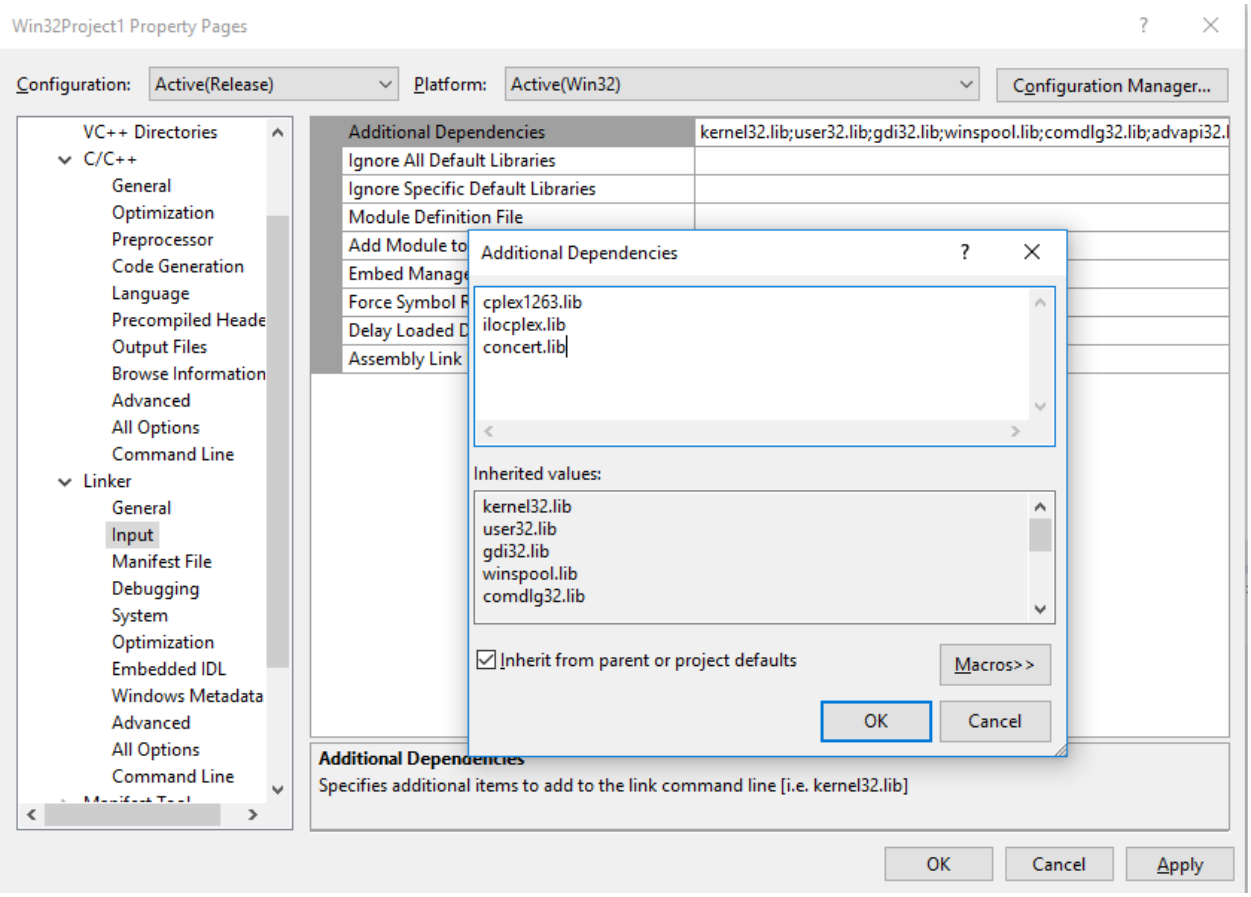


xii. Select Configurations Properties > Linker > Input

xiii. In “Additional Dependencies” add:

- cplex1263.lib
- ilocplex.lib
- concert.lib

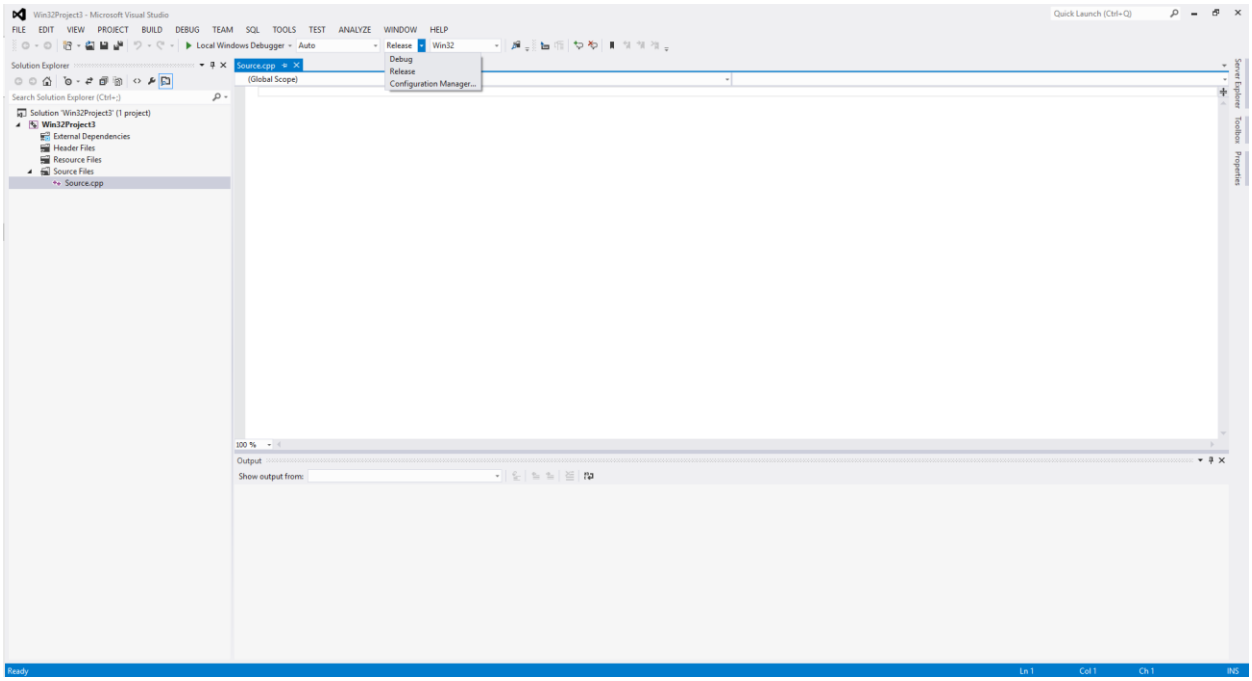
(cplex1263.lib can be replaced by cplexXXxx.lib where XXxx is the CPLEX version. This tutorial was made with CPLEX 12.63 and hence uses cplex1263)



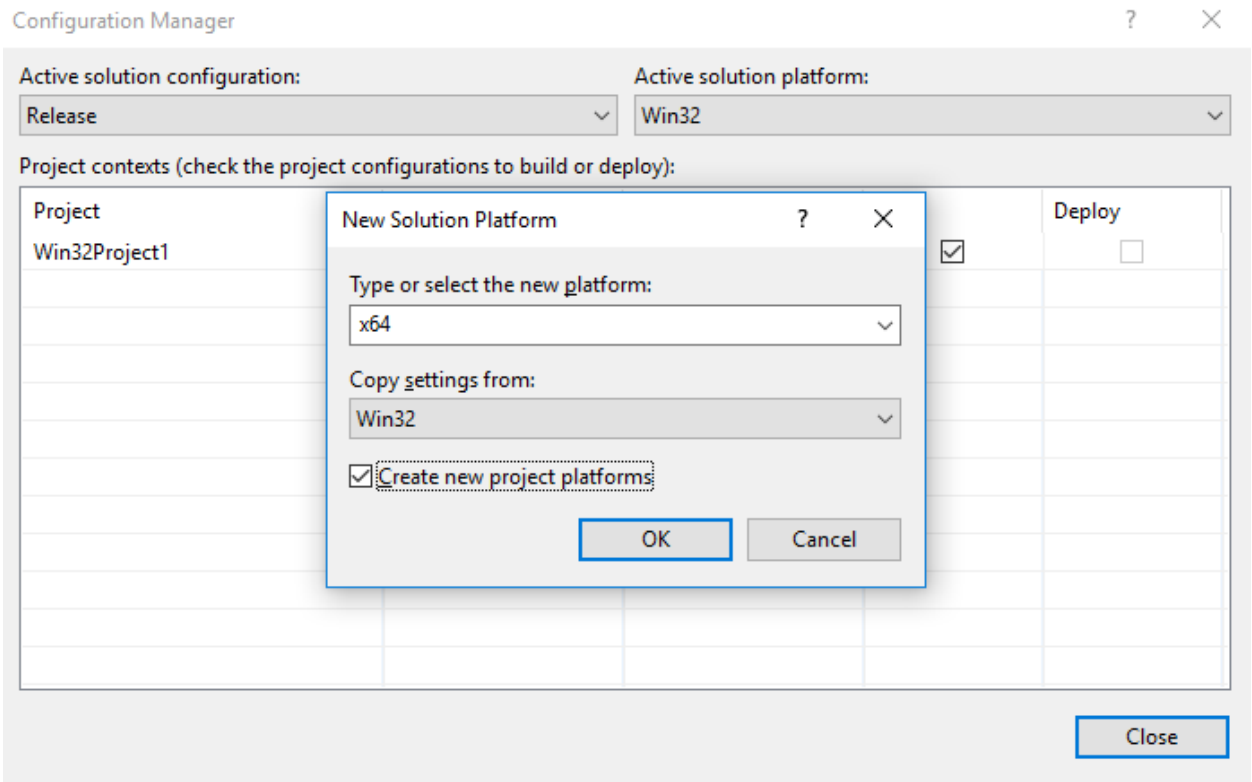
xiv. Click OK to close the Properties box

d. Change to win64 platform

i. From the top ribbon, select “Release” and then “Configuration Manager”



ii. Under Active solution platform, select <New>
iii. Select x64 under “Type or select the new platform:”
iv. Select Win32 under “Copy settings from:”
v. Keep the “Create new project platforms” option checked



vi. Click OK to close the box
vii. Click Close to close the Configuration Manager

e. Add CPLEX DLL file to project folder

i. Go to <CPLEXDIR>\cplex\bin\x64_win64 and copy the file cplex1263.dll
ii. Paste the file in the project folder <MYPROJDIR>\<ProjName>\<ProjName>. In the case of this tutorial the folder is: C:\Users\pdwarkanath\Documents\Visual Studio 2012\Projects\Win32Project1\Win32Project1

4. Running a simple example program

Now that CPLEX is set up, we can run an example program to test it. A simple integer program is presented below:

Max: $x_1 + 0.64x_2$
s.t.: $50x_1 + 31x_2 \leq 250$
$3x_1 - 2x_2 \geq -4$
$x_1, x_2 \in \mathbb{Z}_+$

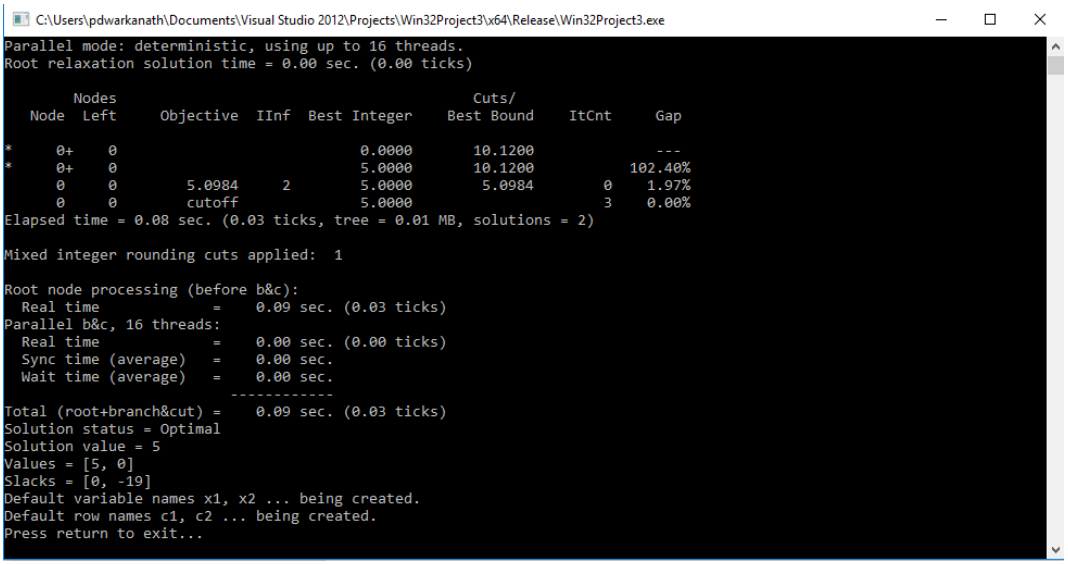
In order to solve this, it can be written in C++ as follows. The comments in green explain the steps below it.

```
#include <ilcplex/ilocplex.h>

ILOSTLBEGIN

static void
       populatebyrow (IloModel model, IloNumVarArray var, IloRangeArray con);

int main (void){

       // Setting up the CPLEX environment

       IloEnv env;

       // CPLEX solution block

       try {

              // Declaring the objects

              IloModel model(env);
              IloNumVarArray var (env);
              IloRangeArray con(env);
              populatebyrow(model, var, con);

              // Solving using CPLEX
```

```
		IloCplex cplex(model);
		cplex.solve();

		// Output solutions

		env.out() << "Solution status = " << cplex.getStatus() << endl;
		env.out() << "Solution value = " << cplex.getObjValue() << endl;

		IloNumArray vals(env);
		cplex.getValues(vals, var);
		env.out() << "Values = " << vals << endl;

		IloNumArray slacks(env);
		cplex.getSlacks(slacks, con);
		env.out() << "Slacks = " << slacks << endl;

		// Write model to file

		cplex.exportModel("ipex1.lp");

	}

	// Error handling

	catch (IloException e){
		cerr << "Concert exception caught: " << e << endl;
	}

	catch (...){
		cerr << "Unknown exception caught." << endl;
	}

	// End environment

	env.out() << "Press return to exit..." << endl;
	std::getchar();
	env.end();
	return 0;

}

static void
	populatebyrow (IloModel model, IloNumVarArray x, IloRangeArray c){

		// retrieve model environment

		IloEnv env = model.getEnv();

		// Define variables

		x.add(IloNumVar(env, 0.0, IloInfinity, ILOINT));
		x.add(IloNumVar(env, 0.0, IloInfinity, ILOINT));

		// Add objective

		model.add(IloMaximize(env, 1.00 * x[0] + 0.64 * x[1] ));

		// Add constraints
```

```
            c.add( 50 * x[0] + 31 * x[1] <= 250);
            c.add( 3 * x[0] - 2 * x[1] >= -4);
            model.add(c);
}
```

The optimal integer solution is (5, 0) with slacks (0, -19).



5. Running another example program

The previous example is a very simple use case for CPLEX. Linear programming problems can run into 100s and even thousands of variables. In the first case, there were only 2. So, it was possible to write the coefficients for constraints and objective functions directly in the code. However, as the problem becomes larger, this becomes tedious.

C++ allows a programmer to separately read a file with all the coefficients and build large expressions for objective functions and constraints using for loops. The next example will deal with a slightly larger problem with 9 variables. The necessary data will be stored in a separate file and will be read using C++ code.

Problem:

Assume you run a power supply company. You have 9 power generators available, each of which has a minimum and maximum production level and a cost per unit output. The question is which generators to use in order to minimize the overall operation cost while satisfying the demand of 187 MW.

Generator no.	Min Output	Max Output	Cost
0	12	22	13
1	12	22	13
2	15	23	13
3	17.8	27.8	9.5

4	17.8	27.8	9.5
5	17.9	28.8	9.3
6	19	29	7.2
7	19	29	7.2
8	19	29	7.2

Model:

Decision variables:

- Let x_i be the output from generator i in MW for all $i \in \{0, \dots, 8\}$

Parameters:

- Let a_i be the minimum output from generator i in MW for all $i \in \{0, \dots, 8\}$
- Let b_i be the maximum output from generator i in MW for all $i \in \{0, \dots, 8\}$
- Let c_i be the cost of producing of power from generator i in \$/MW for all $i \in \{0, \dots, 8\}$
- Let d be the demand to be met

Objective Function:

$$\text{Min: } \sum_{i=0}^{8} c_i x_i$$

Constraints:

- Upper and lower bounds: $a_i \leq x_i \leq b_i$ for all $i \in \{0, \dots, 8\}$
- Demand constraint: $\sum_{i=0}^{8} x_i \geq d$

In order to solve this, it can be written in C++ as given below. The data required for this code to run is available in a C++ friendly format in the file "rates.dat" (Click here to download). The comments in green explain the steps below it.

IMPORTANT: Make sure that the "rates.dat" file is available in the <ProjectName>\<ProjectName> or the same folder in which the C++ file (extension: .cpp) is in the project directory.

```
#include <ilcplex/ilocplex.h>

ILOSTLBEGIN

int main(void){
	IloEnv env;
	try {
		// Declare parameters

		IloNumArray minArray(env), maxArray(env), cost(env);
		IloNum demand;

		// Read data file
```

```
        ifstream in("rates.dat");
        in >> minArray >> maxArray >> cost >> demand;

        // Create model

        IloModel mdl(env);

        // Define variables

        IloNumVarArray production(env);
        IloInt generators = minArray.getSize();

        // Set upper and lower bounds for variables

        for (IloInt j = 0; j < generators; j++) {
               production.add(IloNumVar(env, minArray[j], maxArray[j]));
        }

        // Build objective function expression

        mdl.add(IloMinimize(env, IloScalProd(cost, production)));

        // Demand constraint

        mdl.add(IloSum(production) >= demand);

        // Solve and output solutions to a file

        IloCplex cplex(mdl);
          cplex.exportModel("rates.lp");
          ofstream f_out("rates.sol");
          if (cplex.solve()) {

                f_out << "Solution status: " << cplex.getStatus() << endl;
                for (IloInt j = 0; j < generators; j++) {
                      f_out << "generator " << j << ": "
                                          << cplex.getValue(production[j]) << endl;
                }
                f_out << "Total cost = " << cplex.getObjValue() << endl;
          }
          else {
                 f_out << "No solution" << endl;
          cplex.printTime();
    }
}

// Error handling

catch (IloException& ex) {
       cerr << "Error: " << ex << endl;
}

catch (...) {
       cerr << "Error" << endl;
}

// End environment
```

```
        env.end();
        return 0;
}
```

The optimal solution is:

generator 0: 12
generator 1: 12
generator 2: 15
generator 3: 17.8
generator 4: 17.8
generator 5: 25.4
generator 6: 29
generator 7: 29
generator 8: 29

Total cost = 1707.82

This solution will be saved in a file named “rates.sol” in the <ProjectName>\<ProjectName> folder.

Appendix – Files and Code

The files used in this tutorial and the code snippets can be downloaded from the following links:

- Example 1 C++ Code: http://people.tamu.edu/~pdwarkanath/example1.cpp
- Example 2 data file: http://people.tamu.edu/~pdwarkanath/rates.dat
- Example 1 C++ Code: http://people.tamu.edu/~pdwarkanath/rates.cpp
- Example 2 solution file: http://people.tamu.edu/~pdwarkanath/rates.sol

References:

- Kianfar, K., Bansal, M. (2013). *CPLEX Concert Technology using C++*
- Rodriguez-Carbonell, E. (2017). *Tutorial on CPLEX Linear Programming*
- *Using IBM ILOG CPLEX optimizers with Microsoft Visual C++* (c_cpp.html)