Constraint Programming in AMPL

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AMPL Optimization

CP Solvers: Modeling, Applications, Integration, and Standardization
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About AMPL

- **AMPL** is a popular modeling system
  - used in businesses, government agencies, and academic institutions (over 100 courses in 2012)
  - large community
    (> 1,400 members in **AMPL Google Group** alone)
  - the most popular input format on **NEOS**
    (> 200,000 or 57% submissions in 2012)
- AMPL is high-level, solver-independent and efficient.
- Supports a variety of solvers and problem types: linear, mixed integer, quadratic, second-order cone, nonlinear, complementarity problems and more.

AMPL Application Areas

- Transportation (air, rail, truck)
- Production planning and supply chain
- Finance (investment banking, insurance)
- Natural resources (electric power, gas, mining)
- Telecommunications
- Internet services

Examples:

ZARA - clothing and accessories retailer

Norske Skog - paper manufacturer

Solver Support

- AMPL provides consistent interface to a large number of solvers.
- Switching between solvers is easy.
- Connecting new solvers is easy using the open-source AMPL Solver Library.
- Solver-specific features are supported such as the whole set of solver options.
- Features missing in a solver are often implemented in an AMPL solver driver. Examples: meaningful solution log, reformulation of missing constructs.

Connected CP Solvers

- Solvers:
  - ilogcp: **IBM/ILOG CP Optimizer**
  - gecode: **Generic constraint development environment**. **New:** Gecode 4.2
  - jacop: **Java constraint solver**
- How to get:
  - Ilogcp is available to all CPLEX-for-AMPL users
  - AMPL Gecode and JaCoP (soon) downloads: **https://code.google.com/p/ampl/**
  - Source code: **https://github.com/vitaut/ampl** **solvers/gecode** | **solvers/ilogcp** | **solvers/jacop**

AMPL User Interfaces

- Classical command-line interactive environment
- Eclipse-based IDEs:
  - AMPL IDE
  - AMPLDev (adds stochastic programming features)
- Solver Studio for Excel
- Matlab (TOMLAB)
- IPython (experimental)

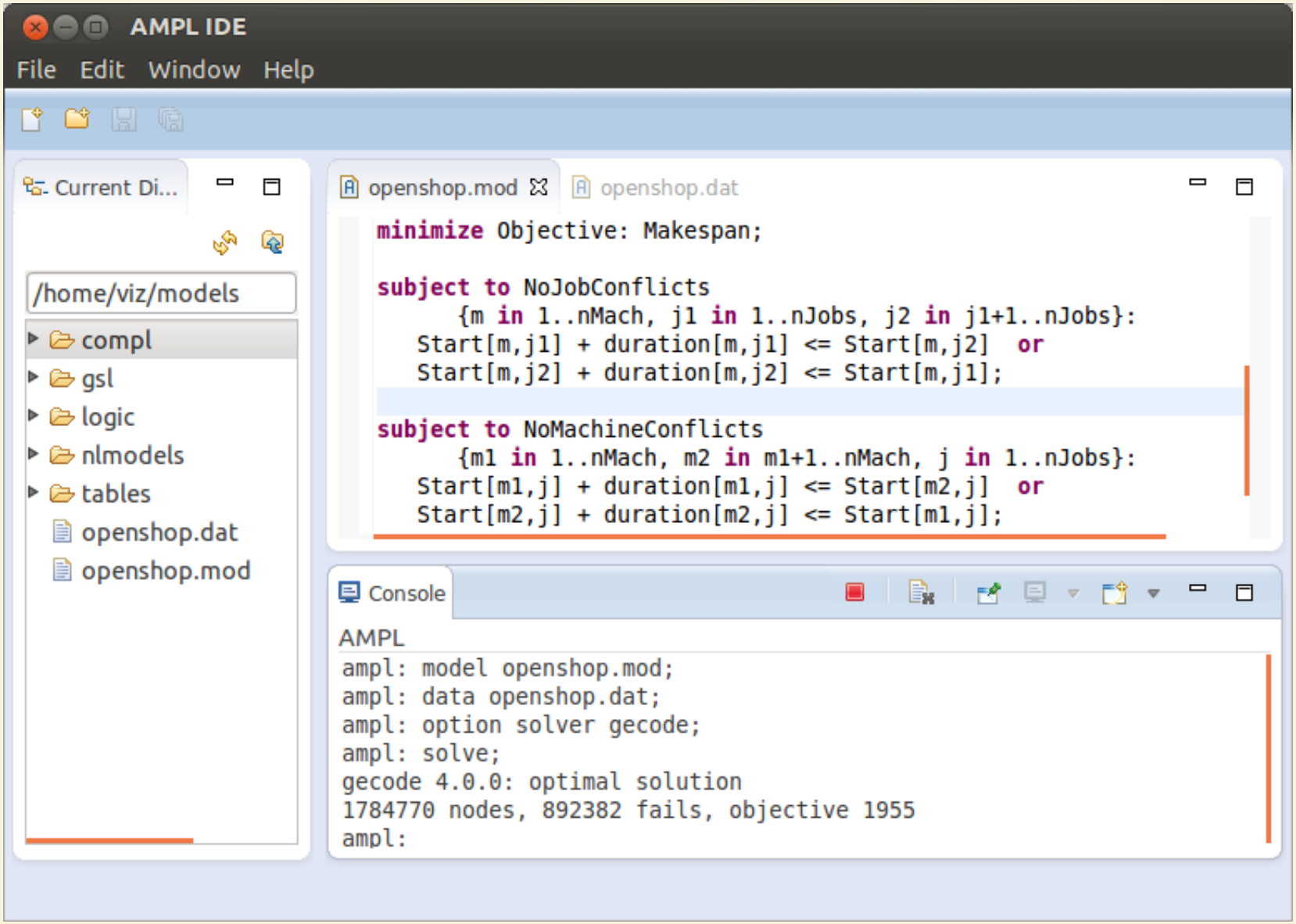
AMPL IDE (Beta)

Based on the Eclipse platform well-known for its Java and Android IDEs.

Some of the features:

- Cross-platform with native look and feel on each platform
- Interactive console with command history
- Context-sensitive syntax highlighting
- Quick links to error locations
- Solution process can be interrupted by a user at any time and the best solution found so far will be available
- Freely available from **http://www.ampl.com/IDE/beta.html**

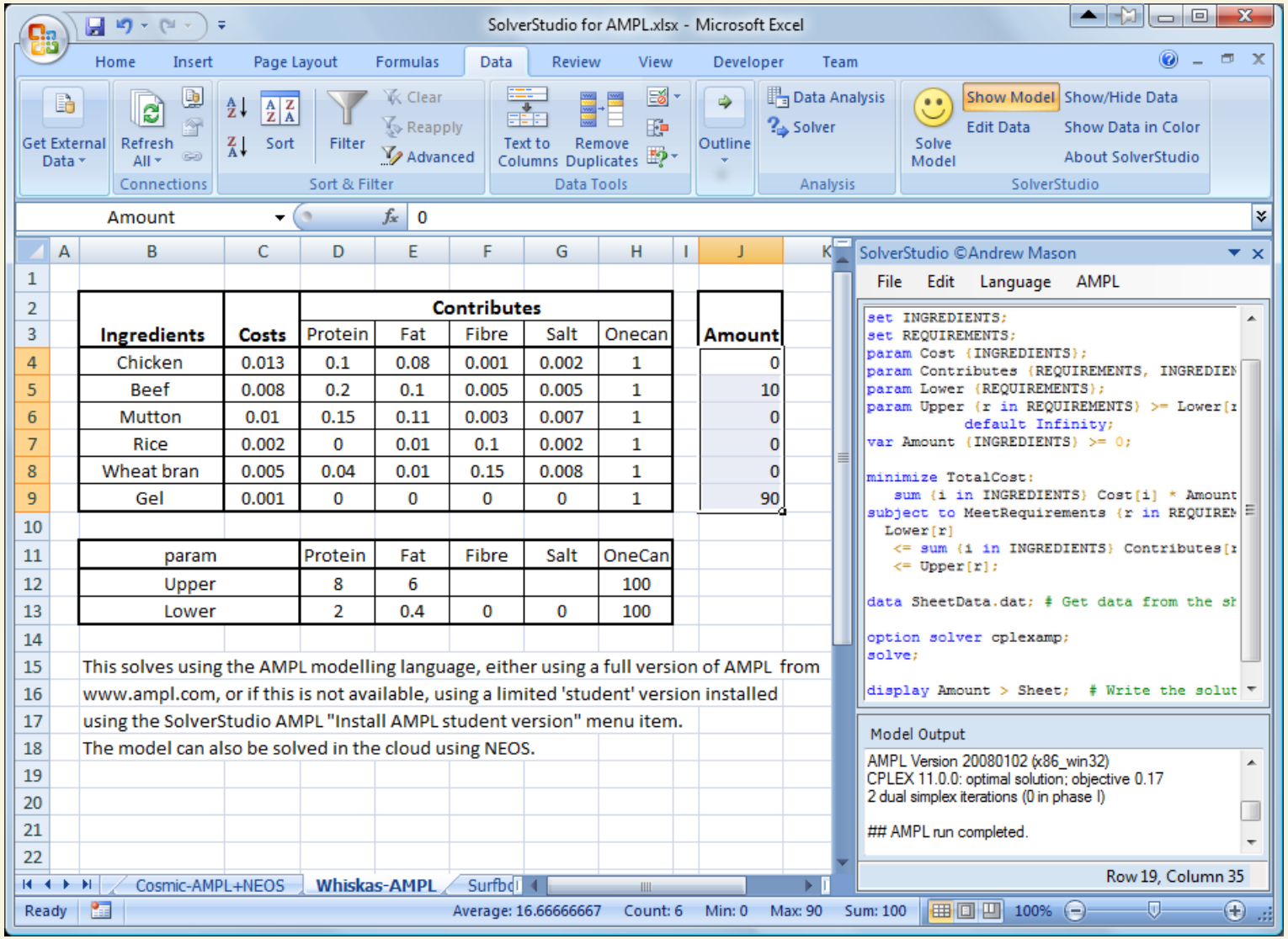
AMPL IDE (Beta)



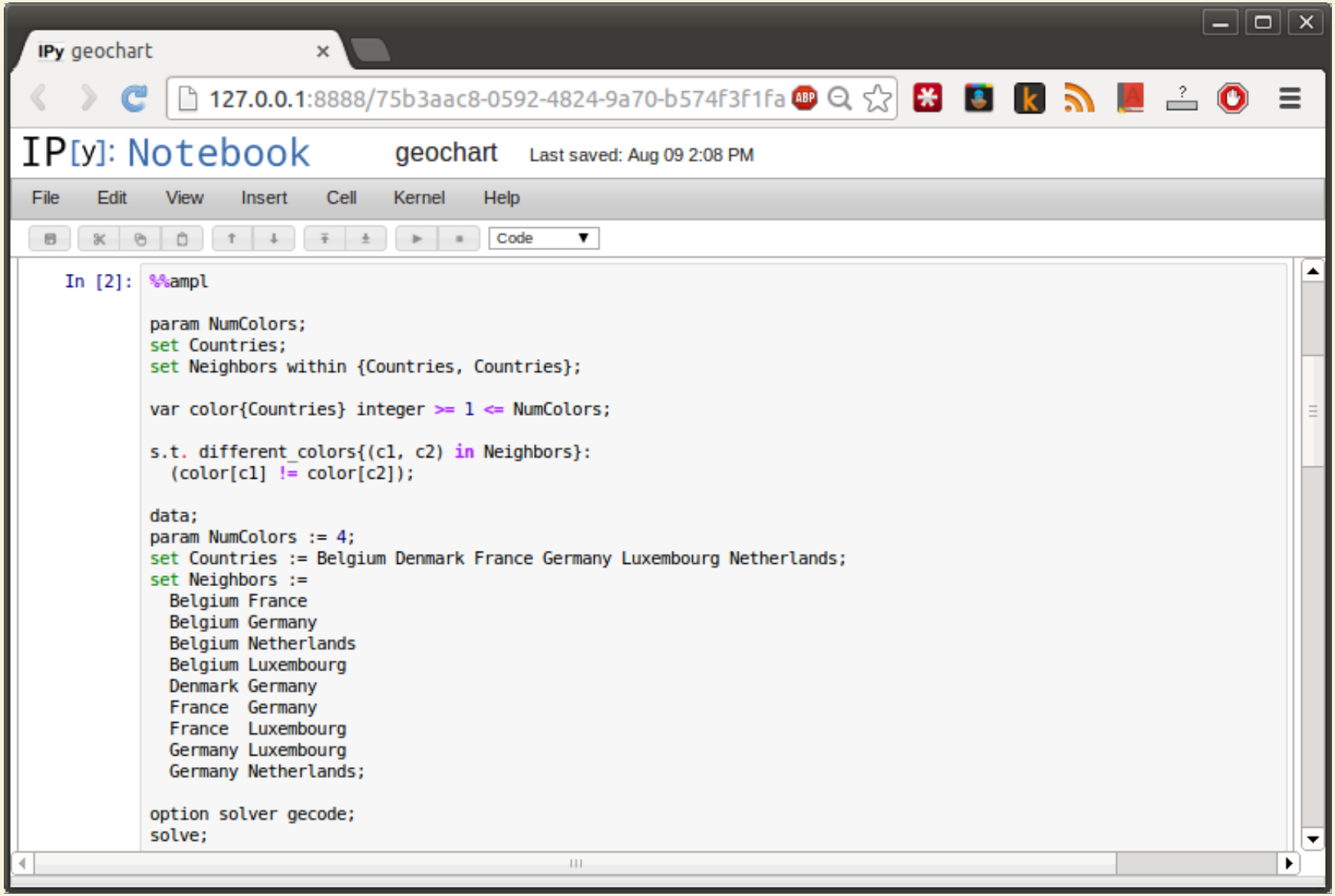
Solver Studio for Excel

- Create and edit AMPL models without leaving Excel
- Solve using local solvers or in the cloud via NEOS
- Integrated model and data editors
- Automatic data exchange with model
- Freely available from **http://solverstudio.org**

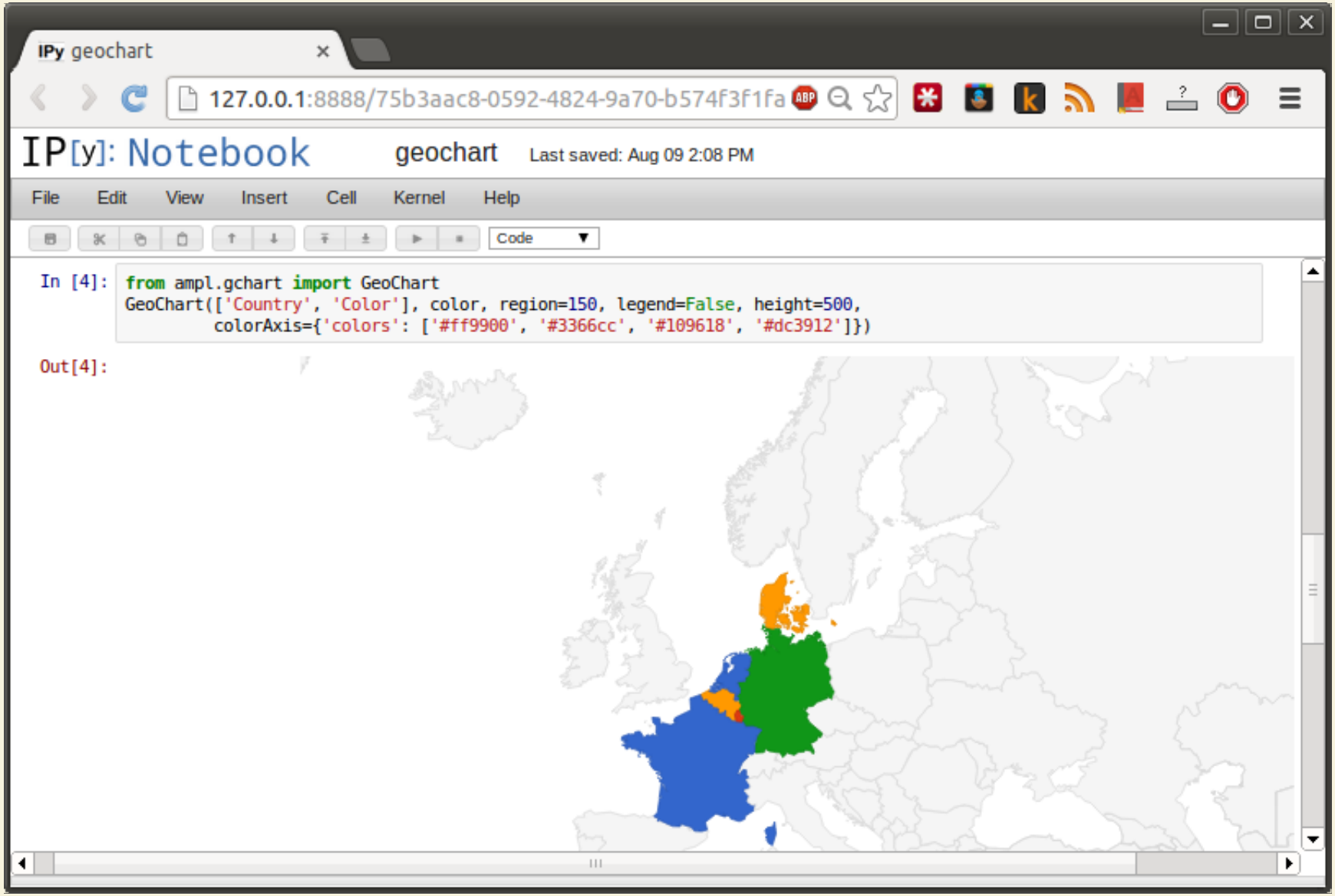
Solver Studio for Excel



AMPL IPython Plugin



AMPL IPython Plugin



Database and Spreadsheet Access

- Crucial for integration into real-world applications
- AMPL provides streamlined database access on major platforms

- Supports any database system that has an ODBC driver

History of CP Support in AMPL

- 1996: first experiments with adding logic programming features to AMPL.
- Fourer (1998). *Extending a General-Purpose Algebraic Modeling Language to Combinatorial Optimization: A Logic Programming Approach* [1]
- Fourer and Gay (2001). *Hooking a Constraint Programming Solver to an Algebraic Modeling Language*
- Fourer and Gay (2002). *Extending an Algebraic Modeling Language to Support Constraint Programming* [2]
- Initially **IBM/ILOG CP Optimizer** was connected.
- **Gecode** was connected in 2012, **JaCoP** - in early 2013.

Supported CP Constructs

- Logical operators: `and`, `or`, `not`
- Iterated logical operators: `exists`, `forall`
- Conditional operators:
  `if-then`, `if-then-else`, `==>`, `==> else`, `<==`, `<==>`
- Counting operators:
  `count`, `atmost`, `atleast`, `exactly`, `numberof`
- Pairwise operator: `alldiff`
- All kinds of arithmetic expressions and functions available in AMPL (if can be handled by a solver or reformulated)

See **http://www.ampl.com/NEW/LOGIC/** for details.

Example: Transportation Model

An example from a multicommodity transportation model **multmip3.mod**

For every origin `i` and destination `j` the total shipments `sum {p in PROD} Trans[i,j,p]` should be either zero or between `minload` and `limit[i,j]`.

MIP formulation:

```
var Trans {ORIG,DEST,PROD} >= 0;
var Use {ORIG,DEST} binary;
subject to Multi {i in ORIG, j in DEST}:
  sum {p in PROD} Trans[i,j,p] <= limit[i,j] * Use[i,j];
subject to Min_Ship {i in ORIG, j in DEST}:
  sum {p in PROD} Trans[i,j,p] >= minload * Use[i,j];
```

Transportation Example using CP

Disjunctive constraint:

```
subject to Multi_Min_Ship {i in ORIG, j in DEST}:
  sum {p in PROD} Trans[i,j,p] = 0 or
  minload <= sum {p in PROD} Trans[i,j,p] <= limit[i,j];
```

Implication:

```
subject to Multi_Min_Ship {i in ORIG, j in DEST}:
  sum {p in PROD} Trans[i,j,p] > 0 ==>
    minload <= sum {p in PROD} Trans[i,j,p] <= limit[i,j];
```

- No need for auxiliary binary variables.
- The formulation is more straightforward.

Example: Scheduling Model

The goal is to find a minimal cost assignment of jobs to machines.

MIP formulation:

```
param n integer > 0;

set JOBS := 1..n;
set MACHINES := 1..n;

param cap {MACHINES} integer >= 0;

param cost {JOBS,MACHINES} > 0;
var Assign {JOBS,MACHINES} binary;

minimize TotalCost:
   sum {j in JOBS, k in MACHINES} cost[j,k] * Assign[j,k];

subj to OneMachinePerJob {j in JOBS}:
   sum {k in MACHINES} Assign[j,k] = 1;

subj to CapacityOfMachine {k in MACHINES}:
   sum {j in JOBS} Assign[j,k] <= cap[k];
```

Scheduling Example using CP

Using the `count` operator:

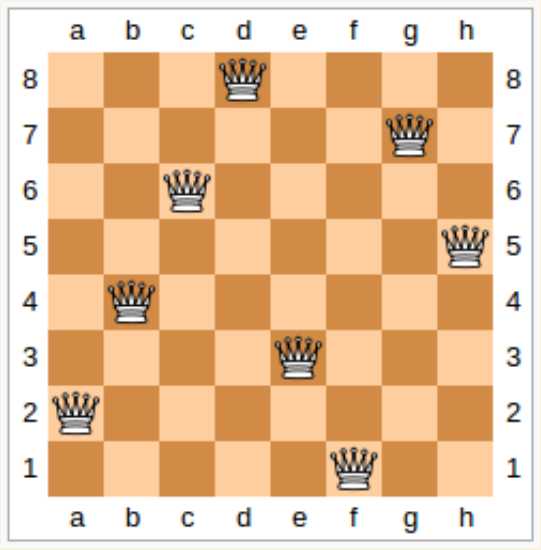
```
subj to CapacityOfMachine {k in MACHINES}:
   count {j in JOBS} (MachineForJob[j] = k) <= cap[k];
```

Using the `numberof` operator:

```
subj to CapacityOfMachine {k in MACHINES}:
   numberof k in ({j in JOBS} MachineForJob[j]) <= cap[k];
```

- No need for n^2 binary variables.
- All the `numberof` constraints can be converted into a single `IloDistribute` constraint in `ilogcp`.

N Queens Example with Alldiff




```
# Place n queens on an n by n board
# so that no two queens can attack
# each other (nqueens.mod).

param n integer > 0;
var Row {1..n} integer >= 1 <= n;

s.t. c1: alldiff ({j in 1..n} Row[j]);
s.t. c2: alldiff ({j in 1..n} Row[j]+j);
s.t. c3: alldiff ({j in 1..n} Row[j]-j);
```

More examples available at
http://www.ampl.com/NEW/LOGIC/EXAMPLES.

Work in Progress

- Variables in subscripts
- Multiple solutions
- Element constraint
- Restart functionality in the Gecode driver
- Use constraint suffixes (attributes) for fine-grained control over some of the search options, e.g. icl in Gecode.

Summary

- AMPL provides a consistent and intuitive interface to multiple constraint programming solvers.
- CP functionality in AMPL is production-ready and new features are actively added.
- New user interfaces make model development easier.
- Database access functionality facilitates integration into real-world applications.

Links

- AMPL Logic and Constraint Programming Extensions: **http://www.ampl.com/NEW/LOGIC/**
- Trial version of AMPL with IBM/ILOG CP: **http://www.ampl.com/trial.html**
- Open-source AMPL solvers and libraries including Gecode: **https://code.google.com/p/ampl/**
- AMPL models by Hakan Kjellerstrand including 100 CP models: **http://www.hakank.org/ampl/**
- Source code for ilogcp, gecode and jacop interfaces on GitHub: **https://github.com/vitaut/ampl**