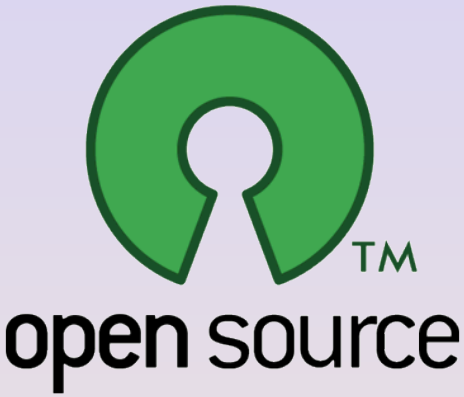
# COIN-OR and the COIN-OR Optimization Suite

Ted Ralphs






COIN fORgery: Developing Open Source Tools for OR

Institute for Mathematics and Its Applications, Minneapolis, MN

# Intro

- First, thanks to the IMA for their generous support of this workshop!
- And thank *you* for being here!!
- This will be a wide-ranging workshop with an equally wide-ranging audience.
- The approach is not like an academic conference, we're really going for engagement, active feedback, and spirited discussion.
- We have tried to focus the material for the audience, but feel free to let us know if this is not the case—there is still time to adjust.
- The schedule includes
  - Structured talks in the mornings
  - Lunch discusion groups
  - Hands-on sessions in the afternoon
  - (Mostly) informal socializing/networking in the evening

**Let's Go!**

# Goals of the Workshop

- There are several goals underlying this workshop.
  - 
  - Provide tutorials and hands-on coding sessions for developers interested in using our tools and contributing.
  - Recruit some new volunteers for a range of important tasks that need to be to move things forward.
  - Discuss how the COIN-OR Foundation itself can grow and move forward.
  - Discuss how the COIN-OR Optimization Suite and its aging code base can be effectively maintained and developed going forward.
  - Plan for the coming year of coding sprints!
- Our hope is that there will be many questions, diversions, discussions, etc.
- Please jump in at any time!
- We can even add/delete topics and adjust the schedule as appropriate.

# Outline

# The Motivation

- Many of the papers being written in OR today are computational in nature or have a computational component.
- Historically, the pace of computational research has been relatively slow and the transfer of knowledge to practitioners has been even slower.
- Results of computational research are still generally not reproducible.
- Research codes tend to be buggy, narrowly focused, and lacking robustness/generality.
- There have been few rewards for publishing software outside of archival journals.
- There has been no peer review process for software and referees of computational papers have generally had little to go on.
- Building on previous results is difficult and time-consuming.
- Interoperating with other software libraries (such as LP solvers) is difficult.
- The paradigm encouraged by archival journals does not work well for computational research.

# The Genesis of COIN-OR

- The Common Optimization Interface for Operations Research Initiative was an initiative launched by IBM at ISMP in 2000.
- IBM seeded an open source repository with four initial projects and created a Web site.
- The goal was to develop the project and then hand it over to the community.
- The project grew to be self-sustaining and was spun off as a nonprofit educational foundation in the U.S. more than a decade ago.
- The name was also changed to the Computational Infrastructure for Operations Research to reflect a broader mission.

# What is COIN-OR Today?

## The COIN-OR Foundation

- A non-profit foundation promoting the development and use of interoperable, open-source software for operations research.
- A consortium of researchers in both industry and academia dedicated to improving the state of computational research in OR.
- A venue for developing and maintaining standards.
- A forum for discussion and interaction between practitioners and researchers.

## The COIN-OR Repository

- A collection of interoperable software tools for building optimization codes, as well as a few stand alone packages.
- A venue for peer review of OR software tools.
- A development platform for open source projects, including a wide range of project management tools.

# The COIN Boards

The COIN-OR Foundation is governed by two boards.

## Strategic Leadership Board

- Robert Fourer
- Kevin Furman
- Horand (Gus) Gassmann (Treasurer)
- Bill Hart
- Alan King (Treasurer)
- Andrew Mason
- Giacomo Nannicini (Secretary)
- Ted Ralphs (TLC Rep)
- Matt Saltzman (President)

## Technical Leadership Council

- Ted Ralphs (Chair)
- Haroldo Santos
- John Siirola
- Mike Steglich
- Stefan Vigerske

- The SLB sets the overall strategic direction and manages the business operations: budgeting, fund-raising, legal, etc.
- The TLC focuses on technical issues: build system, versioning system, bug reporting, interoperability, etc.

# A Little Historical Perspective

- Early years
  - Most projects were offshoots of or integrated with the original IBM codes.
  - These codes formed the basis for what is now the Optimization Suite.
  - There were a large number of developers, including some that were full-time developers at IBM.
  - IBM provided both in-kind and monetary support.
  - Developer effort was focused mainly on low-level tools.
- Recent years
  - Shift to development of high-level tools (modeling, etc.).
  - Most active projects are stand-alone and don't use the technical infrastructure (build tools, etc.)
  - The number of active developers of the Optimization Suite has dropped.
  - We are struggling to support these tools on which many people and organizations depend.
- We would like to hear your opinion about this situation throughout the week.

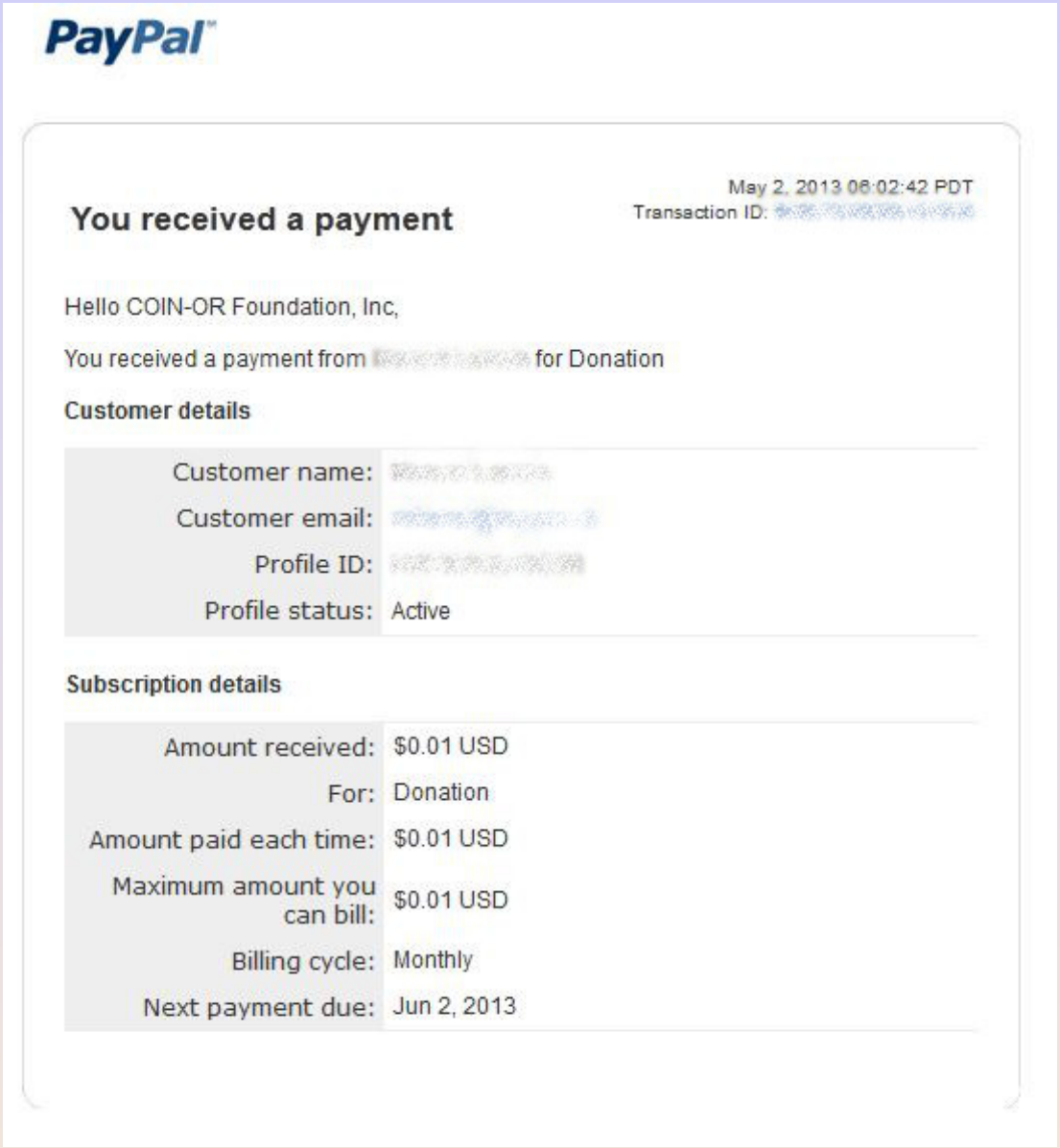
# Evolution of the Foundation's Role

- In the early years, the foundation promised to provide many free tools to developers that were not readily available on-line.
  - Centralized version control (CVS/SVN)
  - Integrated Wiki, issue tracking, source browser (TRAC)
  - Mailing lists
  - Web space
  - Continuouse integration and testing (Jenkins)
  - Distribution of binaries
- All of these things are now readily available for free and the role of the foundation is not as clear.
- Possible future roles
  - Publisher of peer-reviewed software and a promoter of the importance of software publication.
  - Educational resource for new developers and users.
  - Developer of standards, best practices, etc.
  - Focal point for combined efforts to obtain funding/support for development of open source tools?
  - Developer/maintainer of aging but still heavily used codes??

# An Evolving Discussion

- The current trends have been evident for some time.
- The future direction of COIN-OR has been an on-going topic of discussion for many years already.
- What should the future of the foundation be?
- Is there a role for supporting on-going development and maintainenance fo existing codes?
- Should we re-organize and re-focus?
- We would like to hear your opinions in the coming days.

# How is COIN-OR Supported Today?



PayPal

May 2, 2013 06:02:42 PDT
Transaction ID: [redacted]

**You received a payment**

Hello COIN-OR Foundation, Inc,

You received a payment from [redacted] for Donation

**Customer details**

| | |
|---|---|
| Customer name: | [redacted] |
| Customer email: | [redacted] |
| Profile ID: | [redacted] |
| Profile status: | Active |

**Subscription details**

| | |
|---|---|
| Amount received: | $0.01 USD |
| For: | Donation |
| Amount paid each time: | $0.01 USD |
| Maximum amount you can bill: | $0.01 USD |
| Billing cycle: | Monthly |
| Next payment due: | Jun 2, 2013 |

# Outline

# What You Can Do With COIN-OR: Low-level Tools

- We currently have 50+ projects and more are being added all the time.
- Most projects are now licensed under the EPL (very permissive).
- COIN-OR has solvers for most common optimization problem classes.
  - Linear programming
  - Nonlinear programming
  - Mixed integer linear programming
  - Mixed integer nonlinear programming (convex and nonconvex)
  - Stochastic linear programming
  - Semidefinite programming
  - Graph problems
  - Combinatorial problems (VRP, TSP, SPP, etc.)
- COIN-OR has various utilities for reading/building/manipulating/preprocessing optimization models and getting them into solvers.
- COIN-OR has overarching frameworks that support implementation of broad algorithm classes.
  - Parallel search
  - Branch and cut (and price)
  - Decomposition-based algorithms

# What You Can Do With COIN-OR: High-level Tools

One of the most exciting developments of recent years is the number of is the wide range of high-level tools available to access COIN-OR solvers.

- Python-based modeling languages
- Spreadsheet modeling (!)
- Commercial modeling languages
- Mathematica
- Matlab
- R
- Sage
- Julia
- ...

COIN-OR isn't just for breakfast anymore!

# COIN-OR Projects: Linear Optimization

- Clp: COIN LP Solver

  Project Manager: Julian Hall
- DyLP: An implementation of the dynamic simplex method

  Project Manager: Lou Hafer
- Cbc: COIN Branch and Cut

  Project Manager: Ted Ralphs
- SYMPHONY: MILP solver framework that supports shared and distributed memory parallel processing, biobjective optimization, warm starting, sensitivity analysis, application development, etc.

  Project Manager: Ted Ralphs
- BLIS: Parallel IP solver built to test the scalability of the CHiPPS framework.

  Project Manager: Ted Ralphs
- Cgl: A library of cut generators

  Project Manager: Robin Lougee

# COIN-OR Projects: Nonlinear Optimization

- Ipopt: Interior Point OPTimizer for nonlinear optimization problems.
  Project Manager: Andreas Wächter
- DFO: An algorithm for derivative free optimization.
  Project Manager: Katya Scheinberg
- CSDP: A solver for semi-definite programs
  Project Manager: Brian Borchers
- OBOE: Oracle based optimization engine
  Project Manager: Nidhi Sawhney
- FilterSD: Package for linearly constrained non-linear optimization problems.
  Project Manager: Frank Curtis
- OptiML: Optimization for machine learning, interior point, active set method.
  Project Manager: Katya Scheinberg
- qpOASES: QP solver using the active online set strategy.
  Project Manager: Joachim Ferreau

# COIN-OR Projects: Nonlinear Optimization (cont'd)

- oBB: Parallel global optimization of Hessian Lipschitz continuous functions.

  Project Manager: Jaroslav Fowkes

- RBFOpt: A global derivative-free solver. functions.

  Project Manager: Giacomo Nannicini

# COIN-OR Projects: Mixed Integer Nonlinear Opt

- Bonmin: Basic Open-source Nonlinear Mixed INteger programming is for (convex) nonlinear integer programming.

  Project Manager: Pierre Bonami
- Couenne: Solver for nonconvex nonlinear integer programming problems.

  Project Manager: Pietro Belotti
- LaGO: Lagrangian Global Optimizer, for the global optimization of nonconvex mixed-integer nonlinear programs.

  Project Manager: Stefan Vigerske
- DisCO: Discrete Conic Optimization, a solver and framework for solving mixed integer second-order conic optimization problems.

  Project Manager: Aykut Bulut
- MibS: A solver for mixed integer bilevel optimization problems.

  Project Manager: Ted Ralphs
- SHOT: A deterministic convex MINLP solver based on polyhedral outer approximation and primal heuristics.

  Project Manager: Andreas Lundell

# COIN-OR Projects: Modeling

- FLOPC++: An open-source modeling system.
  Project Manager: Tim Hultberg
- Pyomo: A repository of python-based modeling tools.
  Project Manager: Bill Hart
- PuLP: Another python-based modeling language.
  Project Manager: Stu Mitchell
- DipPy: A python-based modeling language for decomposition-based solvers.
  Project Manager: Mike O'Sullivan
- CMPL: An algebraic modeling language
  Project Manager: Mike Stieglich
- SMI: Stochastic Modeling Interface, for optimization under uncertainty.
  Project Manager: Alan King
- yaposib: Yet Another Python OSI Binding.
  Project Manager: Ted Ralphs
- CyLP: Python interface to Cbc and Clp.
  Project Manager: Ted Ralphs (?)

# COIN-OR Projects: Modeling (cont'd)

- Gravity: Scalable, memory efficient modeling language for solving mathematical models in optimization and machine learning.

  Project Manager: Hassan Hijazi

- jMarkov: Tool for Markov chain modeling: finite chains, quasi-birth-and-death processes, phase-type distributions, and Markov decision processes.

  Project Manager: Juan F. Perez

- Rehearse: An algebraic modeling library in C++.

  Project Manager: Onur Celebi

# COIN-OR Projects: Interfaces and Solver Links

- Osi: Open solver interface is a generic API for linear and mixed integer linear programs.
  Project Manager: Matthew Saltzman
- GAMSlinks: Allows you to use the GAMS algebraic modeling language and call COIN-OR solvers.
  Project Manager: Stefan Vigerske
- AIMMSlinks: Allows you to use the AIMMS modeling system and call COIN-OR solvers.
  Project Manager: Marcel Hunting
- MSFlinks: Allows you to call COIN-OR solvers through Microsoft Solver Foundation.
  Project Manager: Lou Hafer
- CoinMP: A callable library that wraps around CLP and CBC, providing an API similar to CPLEX, XPRESS, Gurobi, etc.
  Project Manager: Bjarni Kristjansson
- Optimization Services: Framework providing data interchange formats and tools for calling solvers locally and remotely through Web services.
  Project Managers: Jun Ma, Gus Gassmann, and Kipp Martin

# COIN-OR Projects: Frameworks

- ABACUS: An LP-based branch-and-cut framework.

  Project Manager: Frank Baumann, Mark Sprenger

- Bcp: A generic framework for implementing branch, cut, and price algorithms.

  Project Manager: Laci Ladanyi

- CHiPPS: A framework for developing parallel tree search algorithms.

  Project Manager: Ted Ralphs

- DIP: A framework for implementing decomposition-based algorithms for integer programming, including Dantzig-Wolfe, Lagrangian relaxation, cutting plane, and combinations.

  Project Manager: Ted Ralphs

# COIN-OR Projects: Automatic Differentiation

- ADOL-C: Package for the automatic differentiation of C and C++ programs.

  Project Manager: Andrea Walther

- CppAD: A tool for differentiation of C++ functions.

  Project Manager: Brad Bell

# COIN-OR Projects: Graphs

- GiMPy and GrUMPy: Python packages for visualizing algorithms

  Project Manager: Ted Ralphs
- Cgc: Coin graph class utilities, etc.

  Project Manager: Phil Walton
- LEMON: Library of Efficient Models and Optimization in Networks

  Project Manager: Alpar Juttner

# COIN-OR Projects: Miscellaneous

- Djinni: C++ framework with Python bindings for heuristic search
  - Project Manager: Justin Goodson
- METSlib: An object oriented metaheuristics optimization framework and toolkit in C++
  - Project Manager: Mirko Maischberger
- CoinBazaar: A collection of examples, application codes, utilities, etc.
  - Project Manager: Bill Hart
- PFunc: Parallel Functions, a lightweight and portable library that provides C and C++ APIs to express task parallelism
  - Project Manager: Prabhanjan Kambadur
- ROSE: Reformulation-Optimization Software Engine, software for performing symbolic reformulations to Mathematical Programs (MP)
  - Project Manager: David Savourey
- MOCHA: Matroid Optimization: Combinatorial Heuristics and Algorithms, heuristics and algorithms for multicriteria matroid optimization
  - Project Manager: David Hawes

# COIN-OR Projects: Miscellaneous

- Créme: Randomized thermal relaxation for finding a feasible solution of the Maximum Feasible Subsystem problem.

  Project Manager: Pietro Belotti

- jORLib: Java library that provides algorithmic implementations and frameworks for optimization problems in the area of Operations Research.

  Project Manager: Joris Kinable

- MC++: Toolkit for bounding factorable functions.

  Project Manager: Benoit Chachuat

- Paver: Python scripts to do comparisons of solver performance.

  Project Manager: Stefan Vigerske

- QAPSolver: Solver for quadratic assignment problems

  Project Manager: Peter Hahn

# Outline

# The COIN-OR Optimization Suite

- Many of the tools in the repository that are focused on solution of mathematical optimization models are inter-related.
- They are built from a common underlying set of tools in a hierarchical fashion using a common build harness.
- The COIN-OR Optimization Suite is an umbrella project that consists of compatible version of all these mutually interoperable projects.
- This suite will be the focus of the remainder of the tutorial.

# Modular Structure of the Suite

- One of the hallmarks of good open source tools is *modularity*.
- The suite is made up of building blocks with well-defined interfaces that allow construction of higher level tools.
- There have been 75 authors over time and most have never coordinated directly with each other!
- This is the open source model of development.

# Basic Building Blocks: `CoinUtils`

The `CoinUtils` project contains a wide range of low-level utilities used in almost every project in suite.

- Factorization
- File parsing
- Sparse matrix and array storage
- Presolve
- Memory management
- Model building
- Parameter parsing
- Timing
- Basic data structures

# Basic Building Blocks: Open Solver Interface (OSI)

Uniform API for a variety of solvers:

- Cbc
- Clp
- CPLEX
- DyLP
- FortMP
- Xpress
- GLPK
- Mosek
- OSL
- Soplex
- SYMPHONY
- Volume

- Read input from MPS or LP format files or construct instances using COIN-OR data structures.
- Manipulate instances and output to MPS or LP file.
- Set solver parameters.
- Calls LP solver for LP or MIP LP relaxation.
- Manages interaction with dynamic cut and column generators.
- Calls MIP solver.
- Returns solution and status information.

# Building Blocks: Cut Generator Library (CGL)

- A collection of cutting-plane generators and management utilities.
- Interacts with OSI to inspect problem instance and solution information and get violated cuts.
- Cuts include:
  - Combinatorial cuts: AllDifferent, Clique, KnapsackCover, OddHole
  - Flow cover cuts
  - Lift-and-project cuts
  - Mixed integer rounding cuts
  - General strengthening: DuplicateRows, Preprocessing, Probing, SimpleRounding

# Building Blocks: Frameworks

- CHiPPS (COIN High Performance Paralle Search) is a library hierarhcy for implementing parallel tree search.
  - ALPS (Abstract Library for Parallel Search) is a collection of abstract base classes for implementating basic (parallel) tree search.
  - BiCePS (Branch, Constrain, and Price Software) implements a range of abstract base classes needed for implementing relaxation-based branch-and-bound.
- Bcp is a low-level framework for implementing branch. cut, and price algorithms.
- Dip (Decomposition for Integer Programming) is a framework for automatic decomposition and decomposition-based algorithms (Lagrangian relaxation, Dantzig-Wolfe decomposition) built on ALPS.

# Base Solvers

- `Clp` is the LP solver on which the rest of the Optimization Suite is built.
- `Cbc` is the MILP solver built on `Clp` that underpins many other projects.
- `Ipopt` is the core NLP solver that is also
- Anecdotally, these three projects are very widely used in both goverment, academia, and industry.
  - These projects are also embedded in many other applications, such as OpenOffice,
  - They are distributed with modeling system, such as AMPL, MPL, AIMMS, etc.
  - They can be called from R, Matlab, Sage, etc.
- `SYMPHONY` and `DyLP` are experimental LP and MIP solvers, respectively.

# Higher Level Projects

- Solvers built on `CHiPPS`
  - `BLIS` (MILPs
  - `DisCO` (MISOCP)
  - `MibS` (MIBLP)
  - `Dip` (MILP)
- Solvers built on `Cbc` and `Ipopt`.
  - `Couenne` (MINLP)
  - `Bonmin` (MINLP)

# Modeling Tools and Interface

- `OS` (Optimization Services)
- `OSI` (Open Solver Interface)
- `SMI` (Stochastic Modeling Interface)
- Python interfaces
  - Pyomo
  - PuLP/DipPy
  - yaposib
  - CyLP

# Optimization Suite Dependency Graph