# COIN-OR: Open-source Software for Operations Research

## *What, Why and How*

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Robin Lougee-Heimer

# “What”

- COIN-OR is
  - A repository of source code, models, data, examples
  - Available for re-use
  - Under open-source licenses
  - Powered by volunteers

# What is “Open Source”?

- A category of software licenses
  - Rules by which code can be used, copied, modified, distributed,...
  - Freely available, usually via Internet
  - Changes typically given back
- A philosophy
  - Healthy virtual community
  - Debugs, maintains, enhances the source

# Common “Open-Source” Misconceptions

- All open-source licenses are the same
  - E.g., Viral vs. non-viral
- “Free for academic use only” is open source
  - Discrimination
- Open source is the same as freeware/shareware
  - Binary executable to end-user software
  - Restricted intellectual property rights

- COIN-OR recommends the Common Public License
  - OSI-certified open source license which permits IBM (and others) to share AND still use the code in commercial products.

# Open Source in the Software Stack


| | |
|---|---|
| **Application Software**<br>e.g., SAP, Baan | StarOffice (2000) |
| **Application Middleware**<br>e.g., DB2, CICS | mySQL |
| **System Devices**<br>e.g., directories, tools | Apache<br>Sendmail<br>dnsbind |
| **Operating Systems**<br>e.g., XP, Unix | Linux<br>FreeBSD |

Market Segments
- Web servers
- Networking infrastructure (e.g. firewalls, dns servers...)
- File / Print servers
- Universities

# “Why” for the community?

- Reuse rather than reinvent
- Fairer comparisons
- Build on the best
- Promote standards
- Foster collaboration and cross-pollination
- Outlet for software not “product destined”

# “Why” for IBM ?

- Vehicle for IBM Research working with universities
  - Alternatives
    - Awards with no strings attached
    - Employment as a “work for hire”
- Shared control enables true collaboration and invention
- Lessened IP issues
- Concept expanding to other areas of IBM interest

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# “How”?

- Companies
- Universities
- Individuals
- IBM

# “How”? Companies such as…





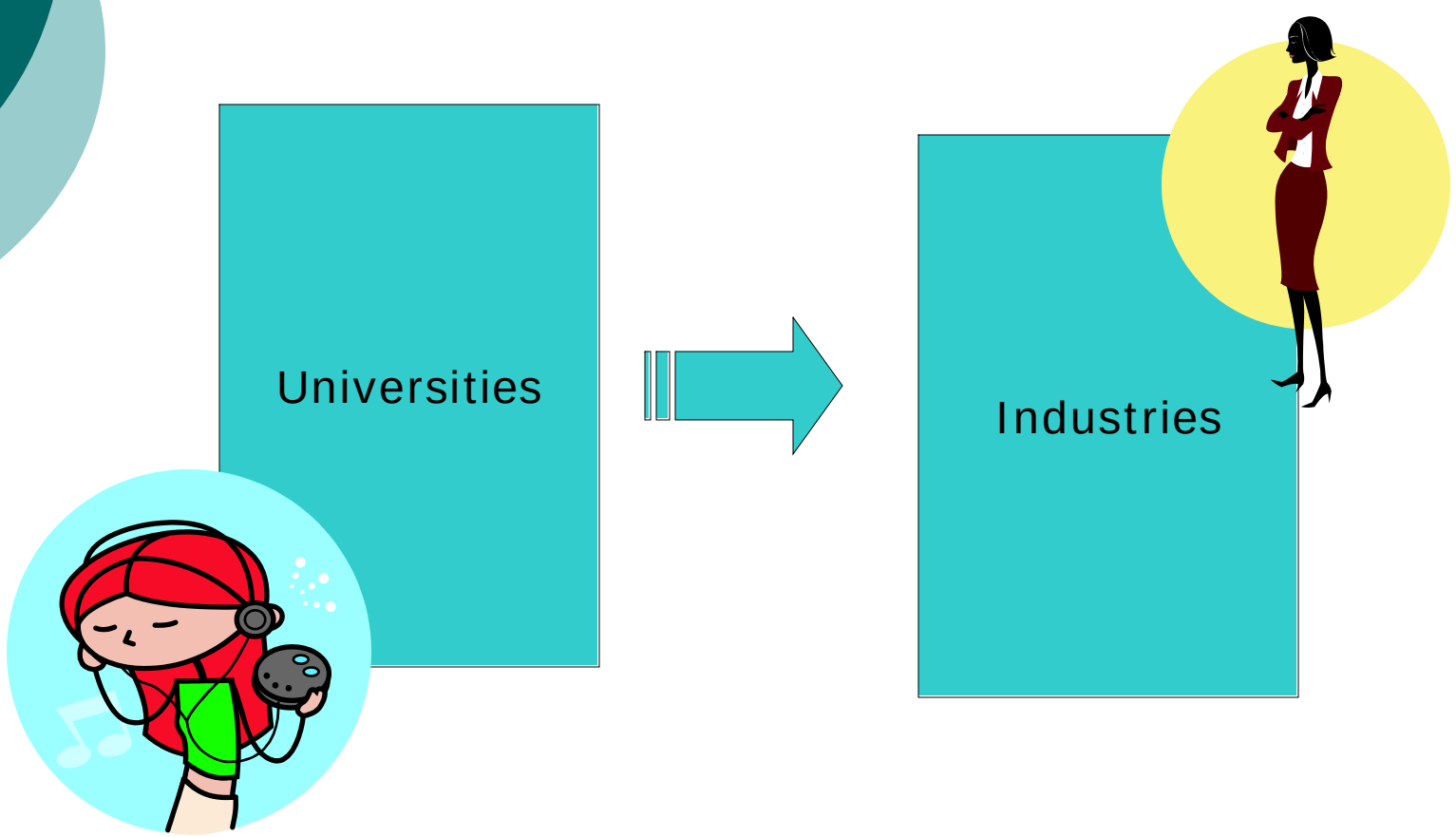



Industry accounts for 37 % of the coin-discuss mail list

# “How”? Universities including…

- Brunel
- Carl von Ossietzky University, Oldenburg
- Carnegie Mellon
- Clemson
- Cornell
- Konrad-Zuse-Zentrum für Informationstechnik Berlin
- Lehigh
- Northwestern
- Politecnico di Milano
- Rutgers
- Simon Fraser University
- Universite de Geneve
- U of Arizona
- U of Pittsburgh
- U of São Paulo
- U of Washington
- U of Waterloo

# Individuals



# “How”? IBM

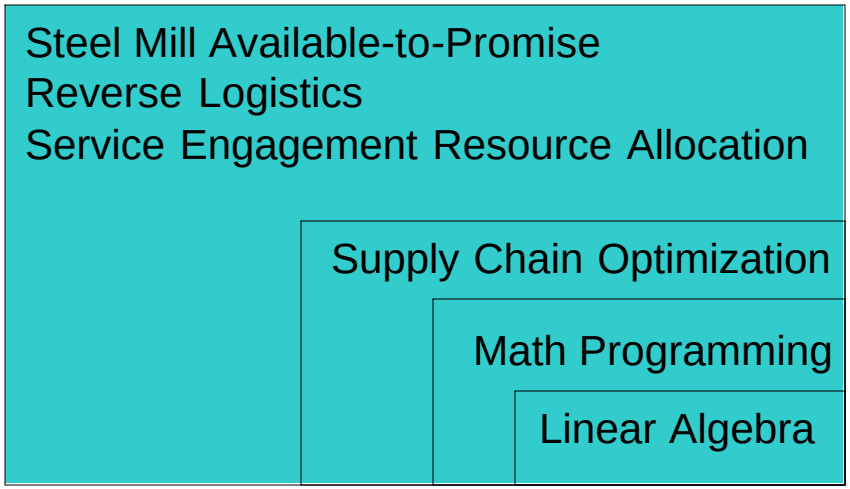
- External Consulting

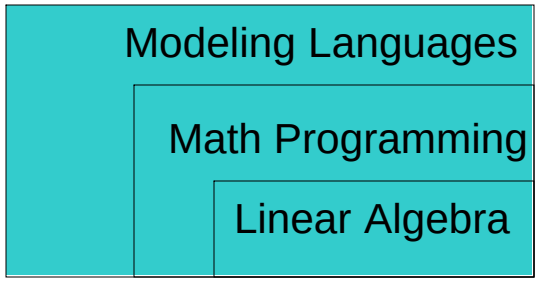
  BOSTONCOACH
  *A superior ride. Worldwide.*

  - Yield Management for a railway
  - Space allocation and payload balancing

- Service offerings
  - Watson Implosion Tool (WIT) 
  - New version of EasyModeler
- Internal Consulting
  - EinsTuner
  - The design of *every* custom microprocessor developed by IBM uses nonlinear optimization software available on COIN-OR.
- Basic Research, e.g.,
  - Simultaneously branch and price
  - Two Mixed Integer Rounding Cuts

# Layered Solvers



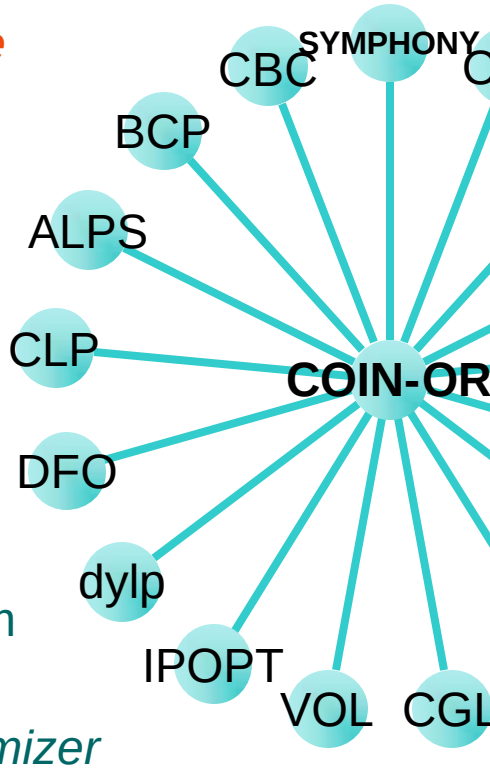

| Computer Science Approach | |
|---|---|
| Java/C++ API Layers | Population with required skills |
| Industry Vertical Solution | 100,000's |
| Supply chain network optimization | 10,000's |
| Math Programming | 1,000's |
| Linear Algebra | 100's |

| Operations Research Approach | |
|---|---|
| | Population with required skills |
| Modeling Language (AMPL, Gams, MPL) | 10,000's |
| Math Programming | 1,000's |
| Linear Algebra | 100's |

# Current Status

- COIN-OR Foundation, Inc
  - Educational non-profit corporation
  - Established 2004
  - Hosted by informs Institute for Operations Research and the Management Sciences
  - True community ownership
    - Milestone accomplishment
    - IBM is participating and supporting
    - COIN-OR is more open
      - IBM is *not* less interested

# COIN-OR Projects




***C**OIN **B**ranch and **C**ut*

***B**ranch-**C**ut-**P**rice Framework*

***A**bstract **L**ibrary For Parallel **S**earch*

***C**OIN **L**P **S**olver*

***D**erivative-Free **O**ptimization*

**Dy**namic Simplex Algorithm

***I**nterior **P**oint **OPT**imizer for General NLPs*

***VOL**ume Algorithm*

***O**pen **T**abu **S**earch*

***O**pen **S**olver **I**nterfaces*

***N**on-**L**inear **P**rogramming **API***

**S**tochastic **M**odeling **I**nterface

Manifold computation

**C++ A**utomatic **D**ifferentiation

Coin Utilities

***C**ut **G**eneration **L**ibrary*

# Frameworks

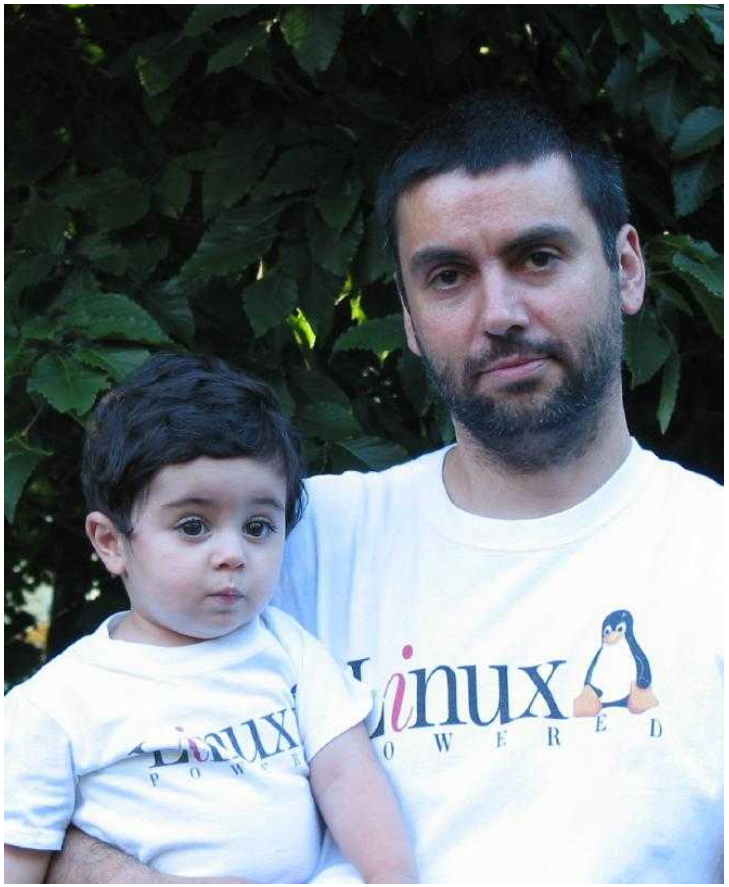
# Abstract Library for Parallel Search (ALPS)

- A scalable, high-performance tree-search engine
  - Improves on the simple master-worker scheme of BCP and SYMPHONY
- Supports general tree-search algorithms
  - Integer
  - Global optimization
  - Constraint programming
- Frees developers from worrying about implementing the tree manager
  - Parallel management

- Designed to support data-intensive problems
- Ted Ralphs, Project Manager

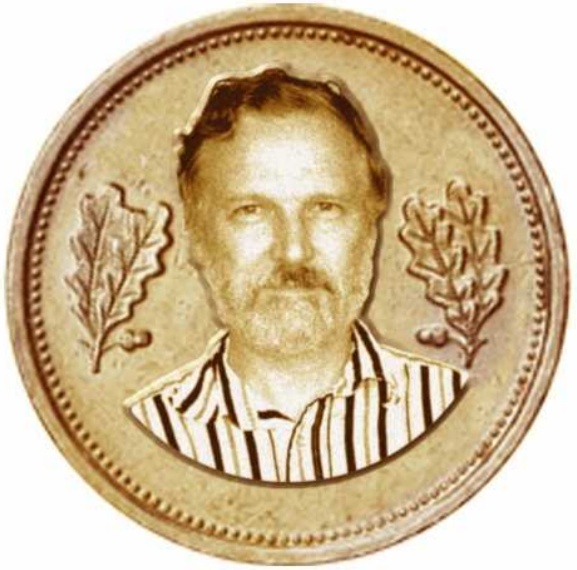
# Branch-Cut-Price Library (BCP)

- Branch-Cut-Price Library
  - Framework for creating custom LP-based branch-cut-price codes to solve Mixed Integer Programs (MIPs)
  - Parallel management
  - Any OSI-capable LP solver
  - Any cuts from CGL
- Allows development of efficient problem class specific MIP algorithms with minimal implementation effort
- Laszlo Ladanyi, Project Manager



# COIN-OR Branch & Cut (CBC)

- Branch and cut code to solve mixed-integer programs
- Designed to work with
  - Any OSI-capable solver
  - Any cuts from the CGL
- Flexibility
  - Designed to be much more flexible than commercial codes
  - Facilitates user written
    - Branching strategies
    - Node selection
    - Heuristics
    - Cutting planes
- John Forrest, Project Manger



# SYMPHONY

- User interaction
  - Black box solver for MILPs
    - MPS files
    - GMPL files
    - FLOPC++
  - Callable library
    - C API
    - C++ API (OSI)
  - Customizable framework
    - C callback functions
- Execution modes
  - Sequential
  - Shared memory parallel
  - Distributed memory parallel
- Additional functionality
  - Multicriteria MILP solver
  - Basic sensitivity analysis
  - Warm starting
- Ted Ralphs, Project Manager

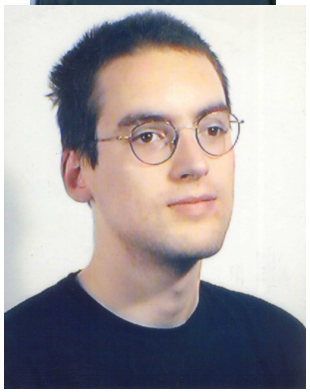
# Open Tabu Search (OTS)

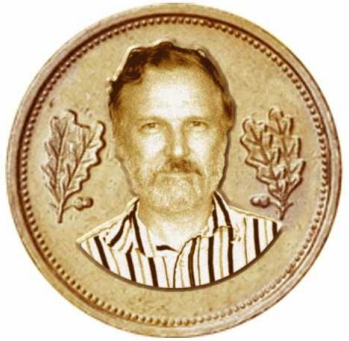
- A framework for Tabu Search
  - Clean design and class structure
    - Solution
    - Tabu List
    - Move
    - Move Manger
    - Objective Function
  - Enables quick development
    - Reactive search
    - Learning search
    - Self-expanding search
- Written in Java
  - Can exploit multi-processor systems
  - Can be embedded in Enterprise JavaBeans Framework
- Robert Harder, Project Manager

# Interfaces

# COIN-OR Open Solver Interface

- *A uniform API for calling math programming solvers*
- *Supports functions such as*
  - Creating the LP formulation;
  - Directly modifying the formulation by adding rows/columns;
  - Modifying the formulation by adding cutting planes provided by CGL;
  - Solving the formulation (and resolving after modifications);
  - Extracting solution information;
  - Invoking the underlying solver's branch-and-bound component.
- 11 OSI interfaces have been implemented
  - CLP - John Forest
  - CPLEX - Tobias Achterberg
  - dylp - Lou Hafer
  - FortMP – Patrick Valente
  - GLPK - Brady Hunsaker
  - MOSEK – Bo Jensen
  - OSL - Laszlo Ladanyi
  - SOPLEX – Tobias Achterberg
  - SYMPHONY - Menal Guzelsoy
  - VOL – Laszlo Ladanyi
  - XPRESS-MP – Matthew Saltzman
- Matt Saltzman, Meta-project Manager





# OSI CPLEX Solver Interface Author

Tobias Achterberg and latest derivative work

MOPTA 2005

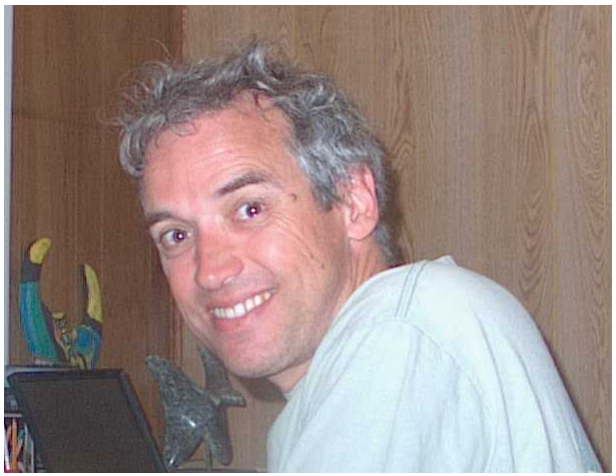
# COIN-OR NonLinear Programming API

- An API for defining and solving nonlinear programming (NLP) problems
- A set of C subroutines that create, modify and query in a data structure which represents the problem.
- Interfaces to LANCELOT and IPOPT are available

- Michael Henderson, Project Manager

# COIN-OR Stochastic Modeling Interface

- Enables communication of stochastic data and solutions between modeling environments and solvers



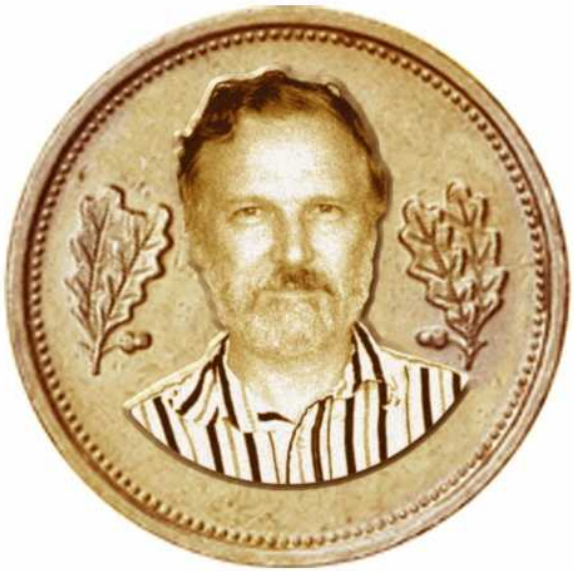
- Alan King, Project Manager
  - Christian Condevaux-Lanloy, key developer

# Solvers

# COIN-OR LP Solver (CLP)

- A high-quality open-source linear program solver
  - Simplex
  - Interior point
  - Quadratic objective
- Extensible matrix format
- Pivot-level control

- John Forrest, Project Manger



# Derivative Free Optimization (DFO)

- Solver for general nonlinear optimization problems with
  - Small (<100) number of variables
  - Expensive to evaluate functions
  - Derivatives or their estimates not available
- Katya Scheinberg, Project Manager

# DYLP

- Implementation of the Dynamic Simplex Algorithm
  - Padberg, *Linear Optimization and Extensions*
- Research code
  - Designed as a LP solver for use in an LP-based branch-cut-price MIP solver
  - Flexibility over speed
  - Copious trace output
  - Extensive consistency checks
- Lou Hafer, Project Manager

# Interior Point OPTimizer (IPOPT)

- An interior point algorithm for nonlinear, non-convex, constrained optimization problems

Opened by CMU

- Andreas Waechter, Project Manager
  - Carl Laird, C++ version

# Volume Algorithm (VOL)

- A subgradient method that produces approximate primal as well as dual solutions
  - Scales exceptionally well on large problems with combinatorial structure
  - Primal solution comes from estimating the volumes below the faces of the dual problem.
  - Small infeasibilities in the primal vector are negligible in many practical settings.
  - The original subgradient algorithm produces only dual solutions.

- Francisco Barahona, Project Manager

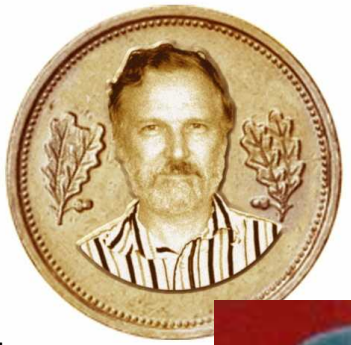
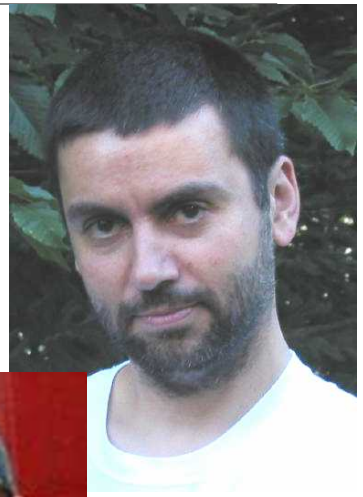
# Other Projects

# COIN-OR Cut Generation Library

- A library of cutting plane generators
- Standardized format

- More than 11 cut available
  - Cliques – Laszlo Ladanyi
  - Duplicate Row – John Forrest
  - Flow Cover – Yan Xu
  - Gomory – John Forrest
  - Knapsack Cover - Robin Lougee-Heimer
  - Lift-and-project cuts using "norm 1" - Robin Lougee-Heimer
  - Mixed-Integer Rounding – Joao Goncalves
  - Odd Hole – John Forrest
  - Probing – John Forrest
  - Simple Rounding – Robin Lougee-Heimer
  - Two mixed-integer rounding – Oktay Gunluk

- Robin Lougee-Heimer, Meta-project Manager


# COIN-OR Utilities (Coin)

- Library of utilities used by multiple projects
- Laszlo Ladanyi, Project Manager

# CppAD

- Given a C++ algorithm that computes function values, CppAD generates an algorithm that computes its derivative values
  - The step by step conversion from an algorithm that computes function values to an algorithm that computes derivative values is *Algorithmic Differentiation* (often referred to as *Automatic Differentiation*)
- Brad Bell, Project Manager

# Multifario

- A C library for finding solutions to nonlinear systems of equations with a small number of parameters.
- Uses user-supplied domain specific solver, to which Multifario presents a sequence of problems at carefully chosen parameter values.
- The resulting set of solutions covers the solution manifold in a specific part of parameter space.
- Interfaces to LOCA and AUTO packages
- Reference implementation of published algorithm

- Mike Henderson, Project Manager

# Elsewhere

- Open-Source Lab at Oregon State University
  - First of its kind at public university


- Cyberinfrastructure NSF
  - Hardware, software, data testbeds
  - Is a “service”, like the interstate
    - A lot of people want to drive on the road, not many want to lay tar.
    - Maintainable (pot holes! Road crews)
    - Accessible (entrance ramps; mgt)
    - Useable (road signs)
    - Taxes? Tolls? Billboards?
  - Examples
    - NEOS
    - COIN-OR

# Challenges

- Documentation
- Ease of use
- Recognition
- Testing
- Intellectual Property
- Maintenance

# Using COIN-OR

- www.coin-or.org
  - Tarballs and CVS
- NEOS
  - CLP
  - CBC
  - DFO
  - IPOPT


- Products
  - E.g, Frontline Systems and Knitro
- Support
  - Free
    - E.g, coin-discuss@list.coin-or.org
  - Buy

# www.coin-or.org