Global Optimization with GAMS Applications and Performance

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Introduction & History

- 2001: Start of collaboration GAMS Dev. Corp. and developers of BARON, LGO, and OQNLP to make general purpose Global Optimization (GO) solvers available to broad GAMS user base.
- Introduction of new solver technology:
  - Demand for GO solvers
  - Supply of leading general purpose GO codes BARON,LGO,OQNLP
  - GAMS company/product good platform for GO



Challenges

- Minimize risk of failing new technology by
  - Multiple Global Codes implementing different algorithmic approaches
  - Local solvers as fallback
  - Success stories from other users
  - Reproducible Quality Assurance Tests
  - Free evaluation systems

Demand for GO

- Triggered by unique benefits from GO
  - Independence of starting point
  - Global/improved solutions
  - Solution quality metrics
- From new markets/applications
  - Where only global optimum makes sense

Supply of leading GO Codes

- BARON
  - Tawarmalani & Sahinidis, *Convexification and Global Optimization in Continuous and Mixed-Integer Nonlinear Programming: Theory, Algorithms, Software, and Applications*, Kluwer, 2002.
- LGO
  - Pintér, *Global Optimization in Action,* Kluwer, 1996
  - Year 2000 INFORMS Computing Society Prize for Research Excellence
- OQNLP
  - OptQuest Scatter search library is “industry standard” for optimization of complex systems utilizing simulation

GAMS Profile

- Started as a Research Project at the World Bank in 1976
- GAMS went commercial in 1987
- Opened European Office in Cologne, Germany in 1996
- 10,000s of users in over 100 countries
- Unique position between the academic and commercial world

Supported Solver Farm

BARON	Branch-And-Reduce Optimization Navigator for proven global solutions from The Optimization Firm
BDMLP	LP solver that comes with any GAMS system
CONOPT	Large scale NLP solver from ARKI Consulting and Development
CPLEX	High-performance LP/MIP solver from Ilog
DECIS	Large scale stochastic programming solver from Stanford University
DICOPT	Framework for solving MINLP models. From Carnegie Mellon University
LGO	Lipschitz global optimizer from Pinter Consulting Services
MILES	MCP solver from University of Colorado at Boulder that comes with any GAMS system
MINOS	NLP solver from Stanford University
MOSEK	Large scale LP/MIP plus conic and convex non-linear programming system from EKA Consulting
MPSGE	Modeling Environment for CGE models from University of Colorado at Boulder
MPSWRITE	MPS file generator that comes with any GAMS System
OQNLP	Multi-start method for global optimization from Optimal Methods Inc.
OSL	High performance LP/MIP solver from IBM
OSLSE	OSL Stochastic Extension for solving stochastic models
PATH	Large scale MCP solver from University of Wisconsin at Madison
SBB	Branch-and-Bound algorithm from ARKI for solving MINLP models
SNOPT	Large scale SQP based NLP solver from Stanford University
XA	Large scale LP/MIP system from Sunset Software
XPRESS	High performance LP/MIP solver from Dash

GO and Modeling Systems

- GO Solvers benefit from Modeling System Services:
  - Variety of local NLP solvers as subsystems in GO solvers
  - Dual solution unavailable, approximate solution
    Optional cleanup up call (CONOPT) from solution found
  - Currently, no MINLP capability (LGO)
    B&B code SBB uses GAMS NLP sub-solvers
- Seamless exchange of local solvers with global solvers: For example: `Option nlp=oqnlp;`

Minimizing Risk

- Multiple Global Codes implementing different algorithmic approaches

One Solver fails: *"The solver stinks"*	All Solvers fail: *"Model is beyond today's GO capabilities"*

- Questions from clients
  - "What are the differences?"
  - "Which one is the best one?"

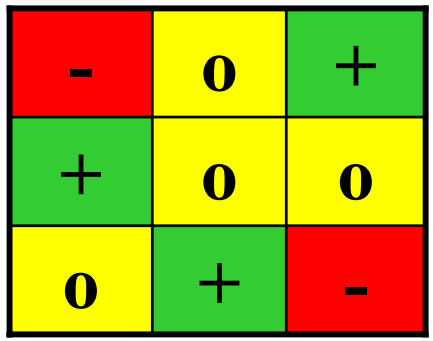
GO Solver Differences

- The three solvers differ in the methods they use. Hence, their requirements, capabilities and the results they provide are different:
- Model requirements
- Problem size
- Solution quality metrics/termination criteria

Difference Matrix

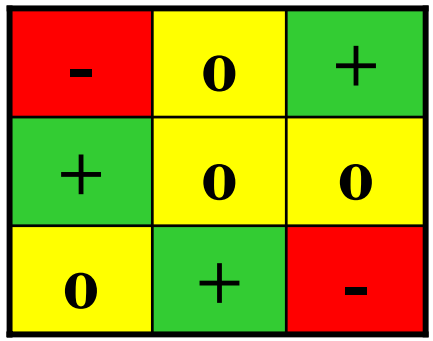
	Model requirements	Problem size	Solution metrics
BARON	**-**	**o**	**+**
LGO	**+**	**o**	**o**
OQNLP	**o**	**+**	**-**

Model Requirements



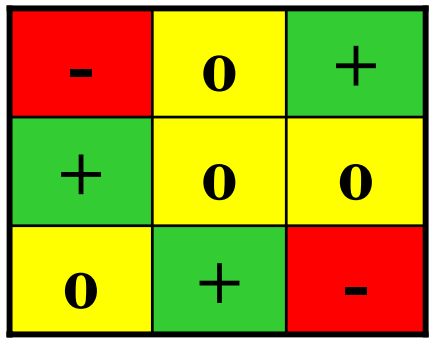
- BARON
  - Constructs convex under-estimators
  - Knowledge about model algebra
  - No black box evaluators
- LGO
  - Lipschitz-continuity of objective function
  - Black box models (external equations)
- OQNLP
  - Requirements of local solver used during search
  - Smooth problems (first [and second] order derivatives)

Problem Size



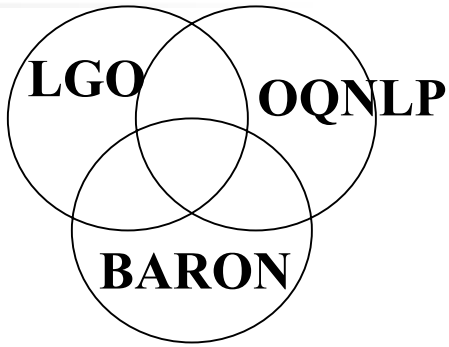
- BARON/LGO
  - Ratio of LP/MIP problem sizes = ratio of local NLP/global NLP sizes
- OQNLP
  - Size of model is limited by size limitation of the local solver

Solution Quality Metrics



- BARON
  - Deterministic lower bound
  - relative/absolute gap similar to MIP
- LGO
  - Estimated statistical or Lipschitz lower bound
  - Stochastic convergence to global optimum
- OQNLP
  - Scatter Search ensures stochastic convergence towards the global optimum

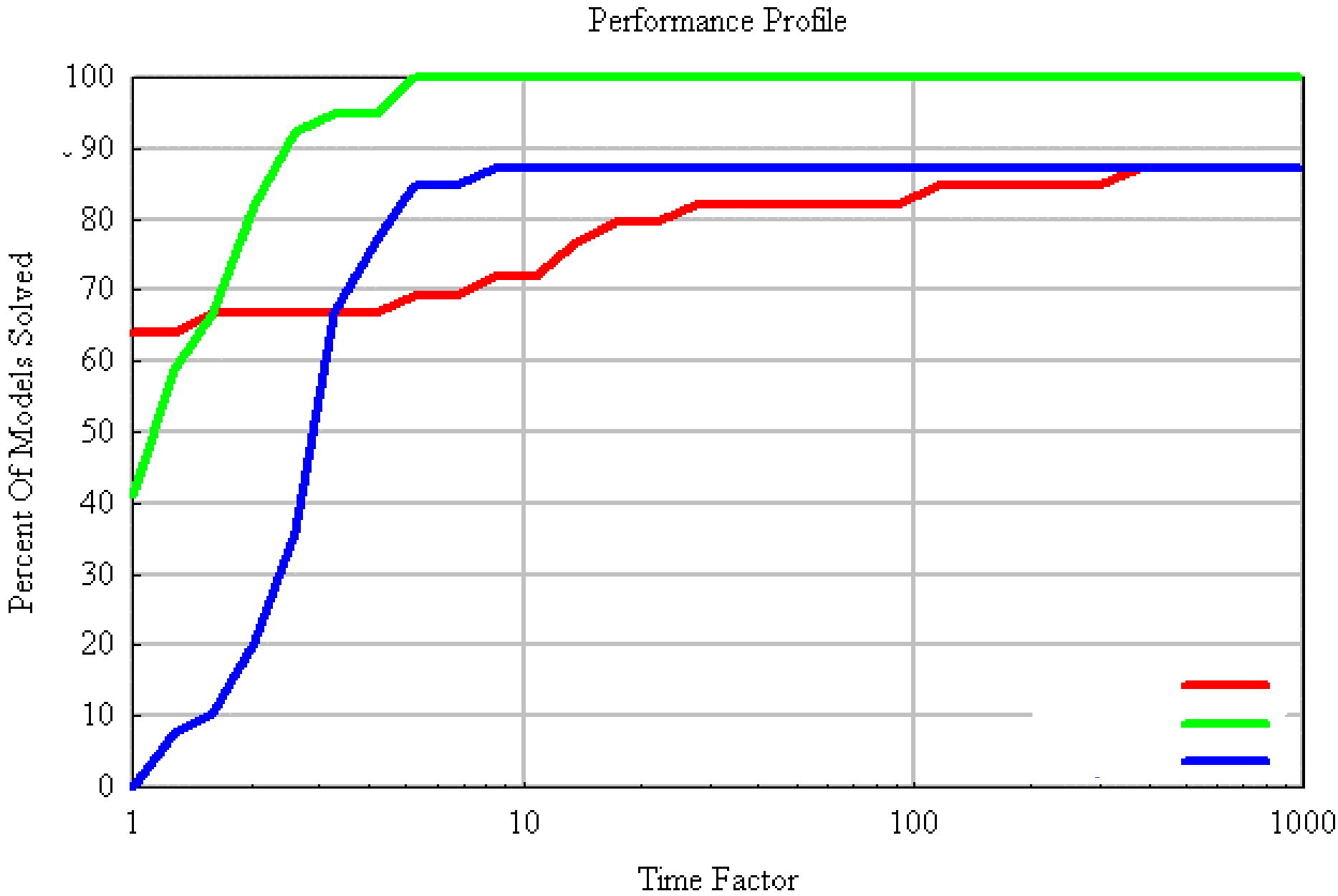
Which one is the best one?

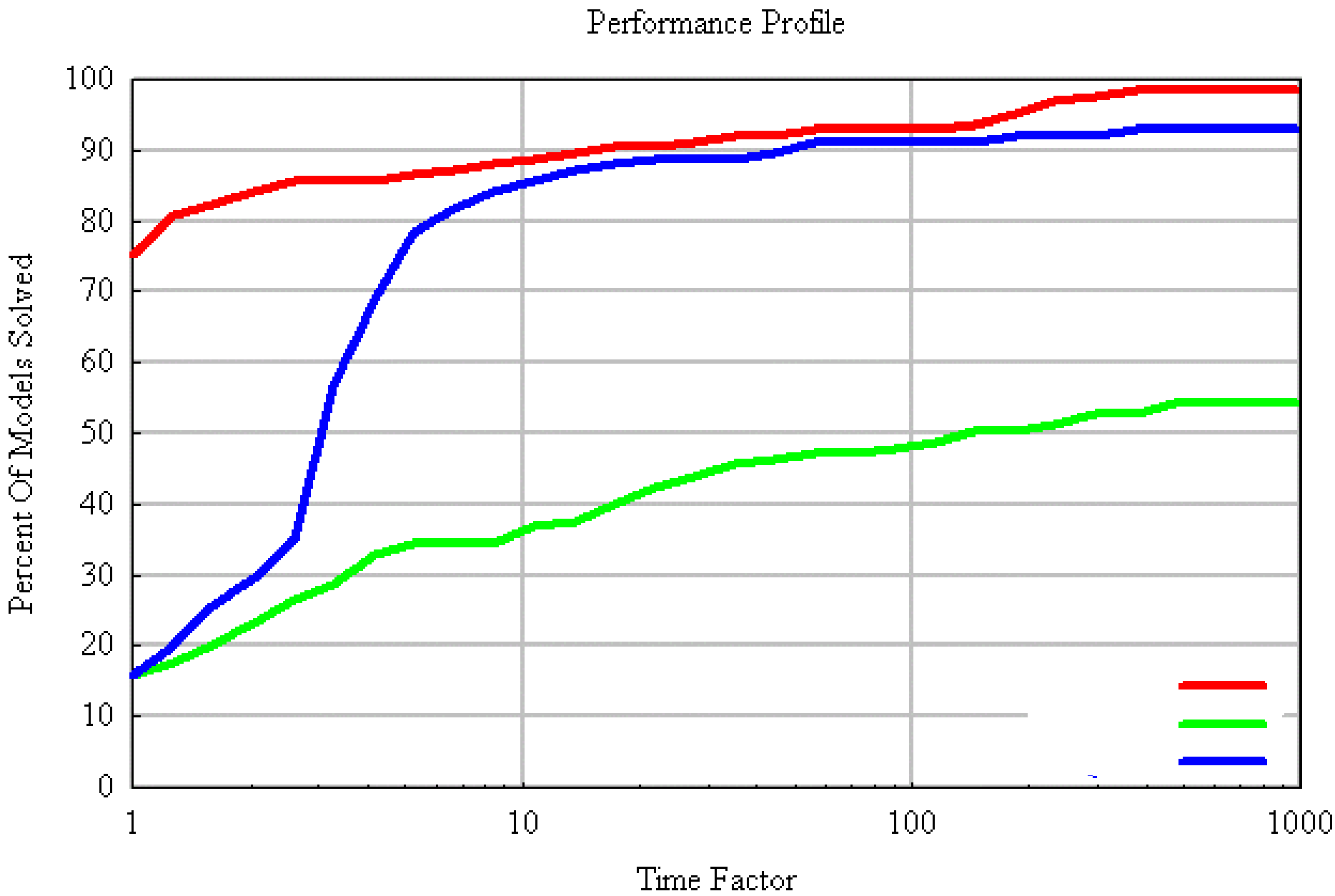


- Three answers:
  BARON, LGO, OQNLP
- Performance comparison/QA Tests
  - Test cases (GlobalLib, MINLPLib, …)
  - Data collection tools (GAMS Trace facility)
  - Data analysis tools (PAVER= **P**erformance **A**nalysis and **V**isualization for **E**ffortless **R**eproducibility)
    www.gamsworld.org/performance/paver

Performance Example

- Models from GlobalLib ($n \leq 500$, $m \leq 500$) (http://www.gamsworld.org/global)
- Performance Profiles (Dolan and More, 2002):
  - Cumulative distribution function for a performance metric
  - Performance metric: ratio of current solver time over best time of all solvers
  - Intuitively: probability of success if given τ times fastest time (τ=ratio)


Performance Profile
Percent Of Models Solved
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
Time Factor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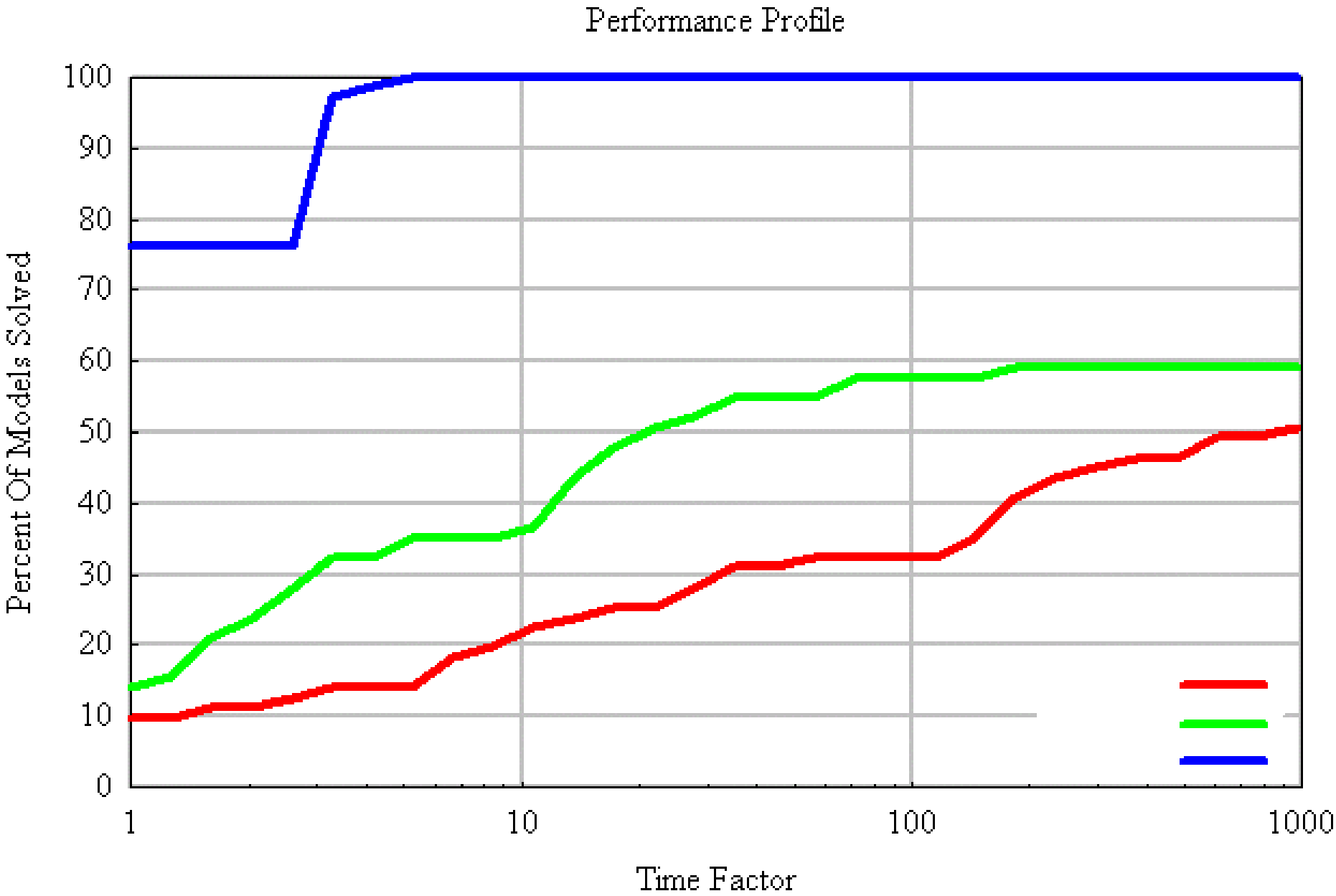
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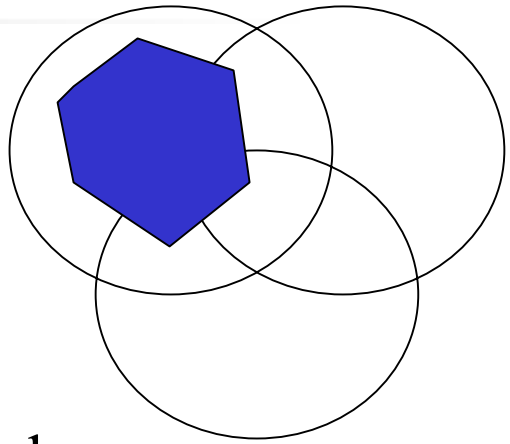
Comparison Conclusion



- Model selection decides about the “winner”
  - 309 model from GlobalLib (total)
  - Subgroups between 40 and 125 models
- Performance profiles with local solvers
- Reproducible for everyone
- Collection of models with application areas like GlobalLib demonstrate what GO solvers can do today.

Conclusions

- Introduction and addition of three leading global optimization codes into the GAMS solver portfolio.
- Prepared environment that give our users the benefit of GO at low cost and calculable risk
- Presentation will be available at **`http://www.gams.com/presentations`**