Ziena Optimization, Inc.

Experts in nonlinear optimization

www.ziena.com

Ziena Background

- Incorporated: June 2001
- Founders: 3 professors + 1 recent Ph.D.
- Product: KNITRO
  - Software to solve nonlinear optimization problems
  - Developed by professors/students at Northwestern University
  - Owned by Northwestern University
  - Exclusive and perpetual license agreement between NU and Ziena signed in February 2002

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What is optimization?

- Apply mathematical/analytic techniques to uncover the "best" solution to difficult problems involving many decision variables and constraints
- Two-stage process:
  - Model the problem mathematically
    (AMPL, GAMS, . . .)
  - Solve the mathematical problem
    (KNITRO, MINOS, SNOPT, CONOPT, . . .)

Linear vs. Nonlinear

- Linear
  - Planning & scheduling problems
  - Routing & transportation problems
  - Easier – more established
    - ILOG (CPLEX), Dash Optimization (Xpress)
- Nonlinear
  - Many engineering problems
  - Much more difficult – less established
    - Ziena (KNITRO), etc.

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Optimization software market

- Annual revenue from sales/services approaching $200 million and growing
- Bulk of the market for linear
- We specialize in nonlinear
  - Much more difficult & complex
  - No dominant developer or vendor
  - Market smaller, less defined

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Nonlinear applications

- Network design and operations
- Dynamic pricing
- Revenue management
- Mechanical engineering
- Chemical engineering
- Circuit design
- Finance/portfolio management
- Shape optimization
- Trajectory optimization

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European customers (corporate)

- Air Liquide
- Bouygues Telecom
- Busarello+Cott+Partner, Inc.
  (Swiss power systems engineering company)
- Gas du Sud (French gas company)
- Michelin
- SIAAP (French water utility)
- Tractebel S.A (Belgian energy company)

- *Distributed in Europe by Artelys, S.A. (Paris)*

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European customers (academic)

- CERT-ONERA, Control System Department (France)
- École des Mines de Paris
- ENSEEIHT (Toulouse, France)
- Fraunhofer Institute (Germany)
- Université Paul Sabatier, Faculté de Médécine Purpan (France)
- University of Coimbra, Department of Mathematics (Portugal)

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Other large customers include . . .

- ExxonMobil
- Citigroup

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Business plan — funding

- Phase I (2001-2003)
  - Founders put in some capital
  - Preliminary software sales
  - Phase I SBIR grant obtained Jan 2003
- Phase II (2004-2006)
  - Continued sales/business partnerships
  - Phase II SBIR grant obtained June 2004
- Phase III (2006-)
  - Self-sufficient from revenues

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Business plan — revenues

- KNITRO Software
  - Direct Sales
  - Maintenance contracts
  - Distributors
  - Mathematical software vendors
  - Value Added Resellers
- Consulting
- Sales of modeling software
  - AMPL

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Business partnerships

- Artelys S.A. (European distributor)
- Frontline Systems (Excel "solver")
- Tomlab (MATLAB interface)
- AMPL Optimization, LLC
- GAMS Development Corporation
- VAR Agreements:
  - Tractebel S.A.
  - Busarello+Cott+Partner, Inc.

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Long-term goals

- Run a successful/profitable small-medium size business or …
- Expand and grow and compete on a large scale or …
- Sell to one of the big linear optimization companies

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KNITRO

A software package for optimization

KNITRO

- A package for continuous optimization
- State-of-the-art optimization techniques developed over the last 10 years at Northwestern University
  - ETR 1992
  - NITRO mid 1990s
  - KNITRO 1.0 2000-2001
  - KNITRO 2.0 January 2002
  - KNITRO 3.0 April 2003
  - KNITRO 4.0 October 2004

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KNITRO Strengths

- **Robust**
- Efficient
- Flexible
- Large-scale
- Especially good for nonlinear constraints
- Supported by theory
- **Commercially supported**

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Problem types

- Unconstrained
- Bound constrained
- Equality constrained
- Nonlinear equations
- Least squares
- Linear and quadratic programs
- General nonlinear problems (large)

Problem form

- KNITRO solves problems that can be written as

$$\begin{aligned} \text{Minimize} \quad & f(x) \\ \text{Subject to} \quad & h(x) = 0 \\ & g(x) \geq 0 \end{aligned}$$

- x must be continuous
- f, h and g must be smooth
- No convexity requirement

Algorithms

- Interior-point / barrier
  - KNITRO/InteriorCG
    (handles large/dense Hessians)
  - KNITRO/InteriorDirect
    (handles ill-conditioned problems)
- Active-set SLQP (new October 2004!)
  - KNITRO/Active (good for warm starts)
- Trust-region approach
- Supported by global convergence theory

Interior algorithms: Example 1

- CVXQP2
  - n=10,000, m=2,500 + bounds
  - nnzH = 40,000
  - 99.6% of time spent factoring in Direct

Code	iters	time	time/iter
InteriorCG	11	401	36.5
InteriorDirect	14	2638	188.4

Interior algorithms: Example 2

- BQPGAUSS
  - n = 2003, bound-constrained
  - Hessian not expensive but ill-conditioned

Code	iters	time	time/iter
InteriorCG	27	1310	48.5
InteriorDirect	19	3	0.16

New algorithm

- Active-set SLQP
  - Alternates linear programs and equality-constrained quadratic programs
  - Built on top of simplex solver
- Advantages
  - Crossover techniques
  - Better active-set information
  - Warm starts

KNITRO interfaces

- C/C++/Fortran
  - Easily integrated within existing applications via callable library
- AMPL
  - Flexible and powerful syntax
  - Derivatives computed automatically
  - Focus on modeling and analysis of results
  - Ideal for prototyping
- MATLAB (through Tomlab)
- GAMS (available soon)

First derivative options

- User or modeling language provides exact derivatives
- KNITRO computes finite difference derivatives (forward or centered)
- Derivatives can be checked using finite differencing

Second derivative options

- User or modeling language provides exact derivatives
- User or modeling language provides exact Hessian-vector products (KNITRO/InteriorCG, KNITRO/Active)
- KNITRO computes Hessian-vector products via finite differencing (KNITRO/InteriorCG, KNITRO/Active)
- Dense quasi-Newton (BFGS or SR1)
- Limited-memory BFGS

Feasible Option

- By default constraints may be violated during the optimization process
- **Feasible option** enforces feasibility with respect to inequalities given initial point satisfying inequalities
- Constraints may be undefined outside feasible region
- Allows early termination with feasible solution

Solver Options comparison

	KNITRO	MINOS	SNOPT	LOQO	IPOPT	GRG
Large-scale (100,000)	x	X smrsp	X smrsp	x	x	
iterative	x		?			
direct	x	x	x	x	x	x
Exact Hessian	x			x	x	?
Quasi-Newton	x	x	x		?	x
Hessian-vector	x					
Feasible	x					?
Interior	x			x	x	
Active-set	x	x	x			x
Commercially supported	x					?

Future Developments

- Add marketing / project management staff position
- Mixed-integer nonlinear optimization

KNITRO future developments

KNITRO Optimization Package