Multiobjective Optimization with Genetic Algorithms is Now Considered Mainstream

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Evolutionary Computing in Industry Track

- As stated, track **focus** is on application of Genetic Algorithms to solve NLP and MINLP industrial problems.
- Many successful application reported in past GECCO proceedings.
- Focus of this talk is on a leading supplier of optimization tools to industry to reveal MOGA currently used and available for application by end users.
- Premise is that all suppliers offer or will soon offer similar MOGAs to remain competitive.

PIDO – Process Integration and Design Optimization

- In 2001, Daratech defined new class of IT based solutions, PIDO, to enhance benefits from digital simulation and prototyping.
- Estimated 2001 market size of $24.4 million.
- Identified leading companies to be Engineous Software (51%), LMS International (10%), Phoenix Integration (9%), MAC Software (8%), Vanderplaats (6%), Synaps (3%), …
- Forecasted strong growth to $128 million by 2005.
- In 2003, Daratech estimated market at $38.8 with 24% growth rate annually through 2007.
- In late 2003, identified Engineous Software as still owning over 50% of market.
- In early 2004, Engineous Software has made an *aggressive* move in introduction of MOGA.

Talk Structure

- What is PIDO?
- Overview of Engineous Software's iSIGHT product and its customers.
- Engineous strong support and endorsement for MOGA in its most recent release.
- Suggested improvements to MOGA for end users.

What is PIDO?

- **Automation:** Setup and manage the execution of commercial and proprietary computer analysis tools (e.g., Ansys, Excel, Nastran).
- **Optimization:** Optimize one or more features of a product to meet requirements by iteratively varying input parameters.
- **Analysis:** Provide tools to coordinate and analyze the data from the iterations and analysis tools.

Who is Engineous?

- Since 1996, develops and sells PIDO software package called iSIGHT to Automotive, Aerospace, Industrial Manufacturing, Turbo Machinery and Electronics Industries.
- **Daratech** reports over 1000 licenses with 200 customers such as:
  - *Automotive:* BMW, DaimlerChrysler, Ford, GM, Jaguar, Nissan, Saab, Toyota, Volvo.
  - *Aerospace:* Boeing, Lockheed Martin, Goodrich Corporation.
  - *Industrial Manufacturing:* Caterpillar, General Electric, Proctor & Gamble, United Technologies Research Center, Xerox Corporation.
  - *Turbo Machinery:* Hitachi, Pratt and Whitney, Rolls Royce, Siemens Westinghouse, York International.
  - *Electronics:* Computer Science Corporation, Mitsubishi, Sony, Toshiba.
- Tong presented many of his companies applications in ECI track at GECCO 2003 conference.
- Tong/Staubach presenting Pratt Whitney applications in ECI track at GECCO 2004
- In 2004, has released latest version of product that emphasizes MOGA

iSIGHT Implementation of PIDO - Automation

- Automation:
  - Non intrusive coupling of simulation codes.
  - Support workflow including sequences, loops and conditional branches among simulation programs.
  - Supports task grouping and hierarchical nesting of tasks.
  - Supports distributed tasks and analysis code execution
  - Supports parallel task execution.
  - Supports most platforms and operating systems.

iSIGHT Implementation of PIDO - Optimization

- Optimization (Prior to 2002 with iSIGHT V1.0-6.0):
  - Supported Optimization Techniques:
    - *Direct Gradient Based:* Sequential Linear Programming, Sequential Quadratic Programming, Generalized Reduced Gradient
    - *Penalty Based:* Hooke Jeeves, Exterior Penalty, Augmented Lagrangian, Directed Heuristic Search.
    - *Exploratory:* Simulated Annealing, Genetic Algorithms
  - Interdigitation: Interleaving of Optimization Techniques.
  - Parallel Evaluation
  - Support for Traditional or Classical Multiple Objective Optimization
    - Presented Tutorial on above at 2002 International iSIGHT User Conference – July 15, 2002.
    - GECCO 2002, July 9-12, had significant impact in direction of future versions of iSIGHT.

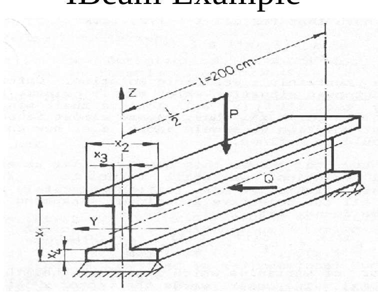
iSIGHT Implementation of PIDO - Analysis

- Analysis:
  - Simple 2D Trend Plots
  - Simple 2D Tables
  - Database storage and selection
  - Export to 3rd Party Analysis Packages

Traditional "Classical" iSIGHT Supported Techniques in July 2002

- Traditional nonlinear constrained optimization techniques calculate a single optimum point based on a single objective.
- Multiple objective problems are "cast" into a single objective problem using one of following approaches
  - Weighted Sum Method with direct GUI support
  - e-Constraint Method with Tradeoff Studies
  - Others using Tcl programming: Benson, Goal Programming, Min-Max.
- Transparently used by all optimization techniques

IBeam Example



IBeam MOOP Problem Formulation

Minimize Mass (Cross Section Area)
Minimize Static Deflection

Subject to Stress <= 16 (strength constraint)

10 <= x1 <= 80
10 <= x2 <= 50
0.9 <= x3 <= 5
0.9 <= x4 <= 5

Starting design $x_0 = [72, 45, 2, 2]$
Mass (Cross Section Area) = 332
Static Deflection = 0.0144
Stress = 5.3069

Weighted Sum Approach

Minimize $f(x) = ??\ w_m f_m(x)/sf_m$

Subject to $g_j(x) <= 0$, $j = 1,2,….,J$
$h_k(x) = 0$, $k= 1,2,….,K$

$??_{m=1}^{M} w_m = 1$

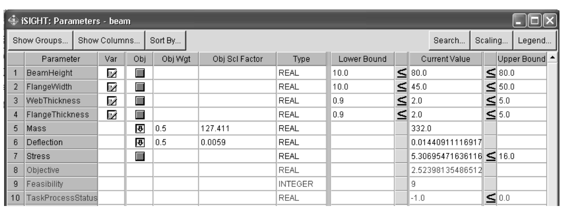
$x_i^{(L)} <= x_i <= x_i^{(U)}$, $i = 1,2, …, n$

-Need to normalize each objective for weights to be meaningful.

Pareto Optimal Theorems (Deb)

- The solution to the problem represented by Weighted Sum is Pareto optimal if the weight is positive for all objectives.
- If x* is a pareto-opimal solution of a convex multi-objective optimization problem then there exists a non-zero positive weight vector w such that x* is a solution to the problem.

iSIGHT GUI Formulation

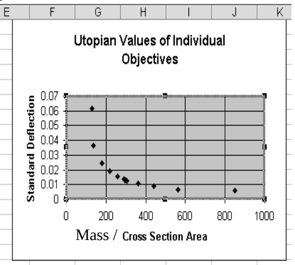

iSIGHT: Parameters - beam

Show Groups... Show Columns... Sort By... Search... Scaling... Legend...

	Parameter	Var	Obj	Obj Wgt	Obj Scl Factor	Type	Lower Bound		Current Value		Upper Bound
1	BeamHeight					REAL	10.0	≤	80.0	≤	80.0
2	FlangeWidth					REAL	10.0	≤	45.0	≤	50.0
3	WebThickness					REAL	0.9	≤	2.0	≤	5.0
4	FlangeThickness					REAL	0.9	≤	2.0	≤	5.0
5	Mass			0.5	127.411	REAL			332.0		
6	Deflection			0.5	0.0059	REAL			0.01440911116917		
7	Stress					REAL			5.30695471636116	≤	16.0
8	Objective					REAL			2.52398135486512		
9	Feasibility					INTEGER			9		
10	TaskProcessStatus					REAL			-1.0	≤	0.0

Standard Tradeoff Curve with WeightedSum

	A	B	C	D
1				
2	850	0.0059		
3	127.411	0.0614		
4	306	0.01278	p=1	MinMax
5	297	0.0132	p=2	
6	294.417	0.01338	p=5	
7	292.459	0.0134	p=10	
8	292.05	0.0135	p=100	
9	563	0.0068	w1=.1	WeightedSum
10	561.2	0.00685	w1=.2	
11	441.163	0.0089	w1=.3	
12	363.658	0.0106	w1=.4	
13	305.965	0.0127	w1=.5	
14	258.776	0.0154	w1=.6	
15	217.082	0.019	w1=.7	
16	177.57	0.0247	w1=.8	
17	135.031	0.0364	w1=.9	



Advantages and Disadvantages

- Advantage
  - Simplicity
  - Ease of implementation
- Disadvantages
  - Uniformly distributed weight vectors need not find a uniformly distributed set of Pareto-optimal solutions
  - Cannot find certain solutions in a non convex space.

e-Constraint Approach

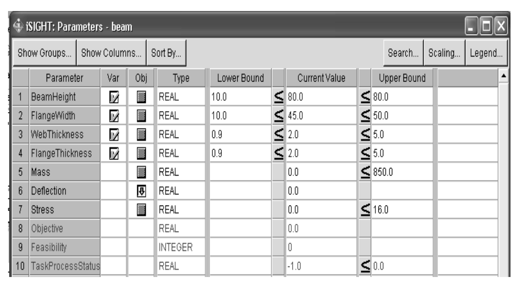
$$
\begin{aligned}
&min\{f_i(\mathbf{x})\}\\
&s.t.\ f_j \le e_j,\ j \ne i,\ j = 1...k\\
&\mathbf{x} \in S
\end{aligned}
$$

Idea is to have a single objective and make the others constraints.

e-Constraint

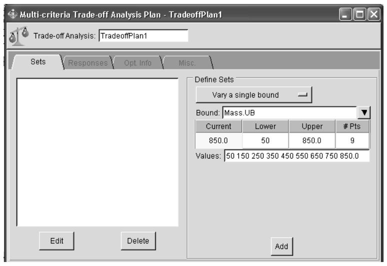
- Advantages
  - Works in convex and non convex spaces
  - Can find all points on pareto optimal front
- Disadvantage
  - Requires user to select appropriate values of constraints

Single Objective to Minimize Standard Deflection

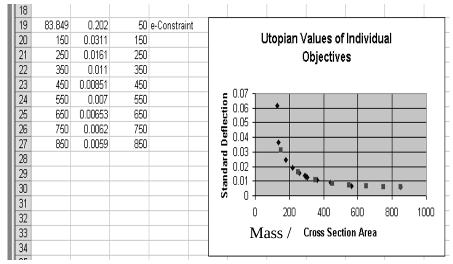


	Parameter	Var	Obj	Type	Lower Bound		Current Value		Upper Bound
1	BeamHeight	☑	■	REAL	10.0	≤	80.0	≤	80.0
2	FlangeWidth	☑	■	REAL	10.0	≤	45.0	≤	50.0
3	WebThickness	☑	■	REAL	0.9	≤	2.0	≤	5.0
4	FlangeThickness	☑	■	REAL	0.9	≤	2.0	≤	5.0
5	Mass		■	REAL			0.0	≤	850.0
6	Deflection		⇩	REAL			0.0		
7	Stress		■	REAL			0.0	≤	16.0
8	Objective			REAL			0.0		
9	Feasibility			INTEGER			0		
10	TaskProcessStatus			REAL			-1.0	≤	0.0

Tradeoff Analysis in 100 Increments for Mass / Cross Section Area



Standard Tradeoff Curve with e-Constraint



18				
19	83.849	0.202	50	e-Constraint
20	150	0.0311	150	
21	250	0.0161	250	
22	350	0.011	350	
23	450	0.00851	450	
24	550	0.007	550	
25	650	0.00653	650	
26	750	0.0062	750	
27	850	0.0059	850	
28				
29				
30				
31				
32				
33				
34				

GECCO 2002 in NYC

- Author had not attended conference since 1994.
- In 2002, MOGA had developed into a huge aspect of conference.
  - Coello Tutorial
  - Deb's book – Multiobjective Optimization using Evolutionary Algorithms.
  - NSGA-II benchmarks on test cases against other approaches.
  - Neighborhood Cultivation Genetic Algorithm
- Immediately suggested to Engineous to move in direction.
  - Fall of 2002, coupled NSGA 2 to iSIGHT for proof of concept.
  - Benchmarked NSGA-II on set of Sandgren Test Cases and presented results at GECCO 2003 (Tong and Powell)
  - Provided visualization of results with 3rd party, public domain, ggobi tool for visualization of pareto optimal set with scatterplot matrices and parallel coordinate plots.
  - Engineous engineers productized MOGA for iSIGHT V8.0 released in February 2004.

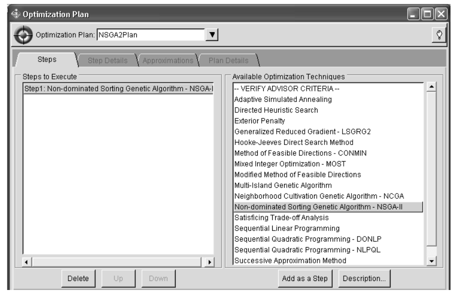
Genetic and Evolutionary Algorithms - New

- Citations per year (from Coello)
  - 1992 – 6
  - 1995 - 60
  - 1998 - 145
  - 2001 – 120
- Many interesting 2nd generational approaches PAES, SPEA, NSGA -II, micro-GA

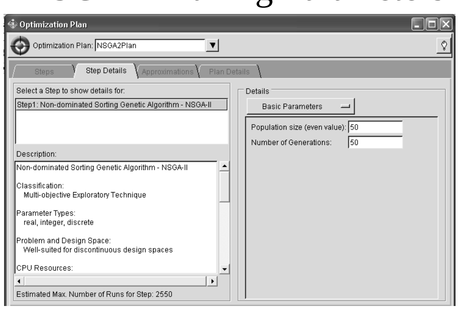
iSIGHT V8.0

- Released February 2004
- Key Features in News Release
  - MOGA (NSGA-II [real value] and NCGA [binary representation])
    - Parallel evaluation supported
    - Seeding supported
  - Engineering Data Mining Visualization Tool
    - Parallel Coordinates Display
    - Scatter plot matrices
    - Point identification linking
- All 200 customers have MOGA within a mouse click to their currently integrated codes.
- May 26, 2004 – Engineous holds first e-Course on MOGA.
- October 2004 – Engineous announces MOGA tutorial as one of two tutorials at International iSIGHT User Conference.

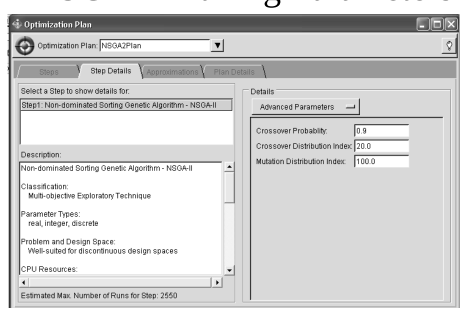
NSGA-II Technique Selection



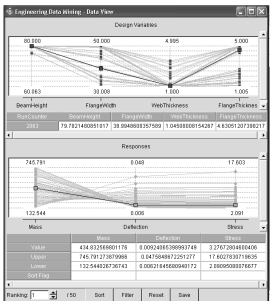
NSGA-II Tuning Parameters



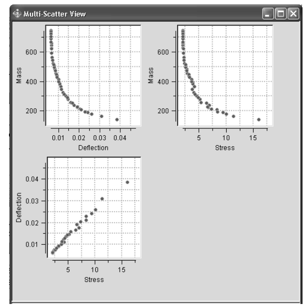
NSGA-II Tuning Parameters



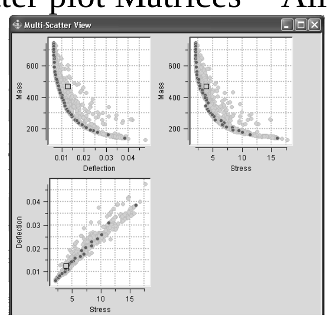
Parallel Coordinates Plot



Scatter plot Matrices – Pareto Data Only



Scatter plot Matrices – All Data



Suggested Improvements for MOGA

- Diagnostics
  - Numerical optimization techniques such as NLPQL and LSGRG have output files that output diagnostic information with each iteration. (gradients, scaling, search direction, relative improvement, termination criteria)
    - Provide rules of thumb of what to look for and what to do under certain conditions.
  - Like to see some type of diagnostics from developers of NSGA-II and NCGA that relate their best practices of how to use and tune their algorithms.