Aplicaciones de los Algoritmos Evolutivos Multiobjetivo

Carlos A. Coello Coello

CINVESTAV-IPN
Depto. de Ingeniería Eléctrica
Sección de Computación
Av. Instituto Politécnico Nacional No. 2508
Col. San Pedro Zacatenco
México, D. F. 07300, MEXICO
ccoello@cs.cinvestav.mx

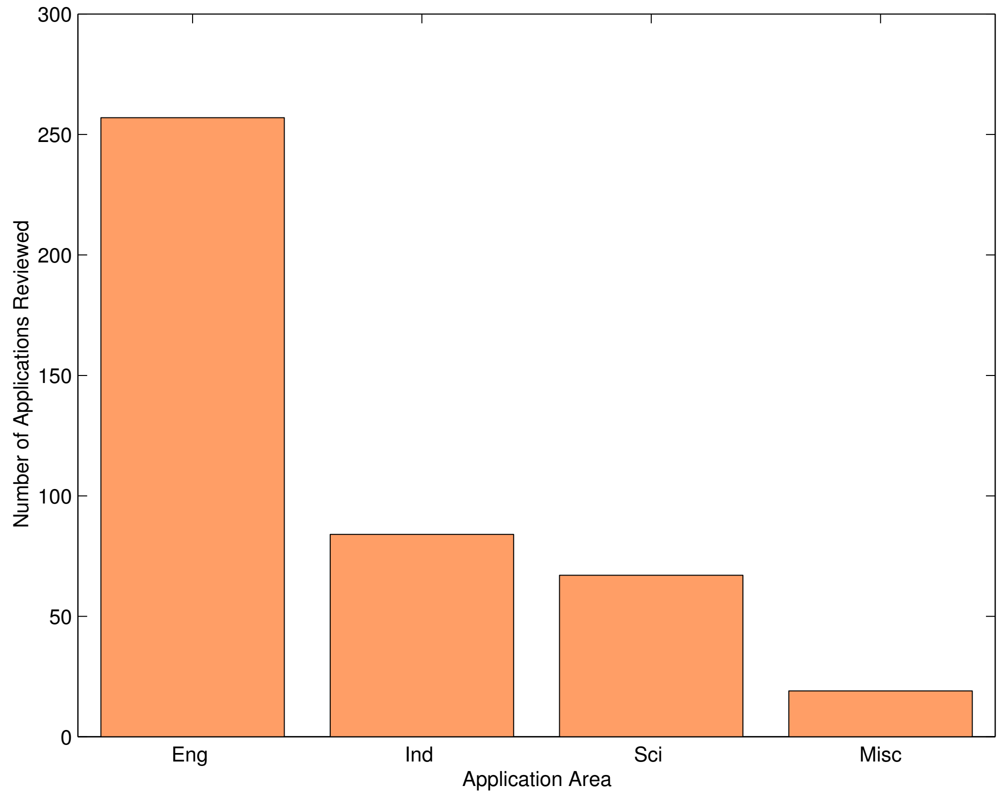
Introducción

Aunque las primeras aplicaciones prácticas de los algoritmos clásicos de optimización multiobjetivo se remonta a 1951, los algoritmos evolutivos multiobjetivo se aplicaron por primera vez hasta mediados de los 1980s (Schaffer, 1985).

Introducción

Sin embargo, las aplicaciones de los algoritmos evolutivos multiobjetivo han proliferado notablemente en los últimos años y actualmente constituyen el grueso de la literatura.

Tipos de Aplicaciones



Aplicaciones de Ingeniería

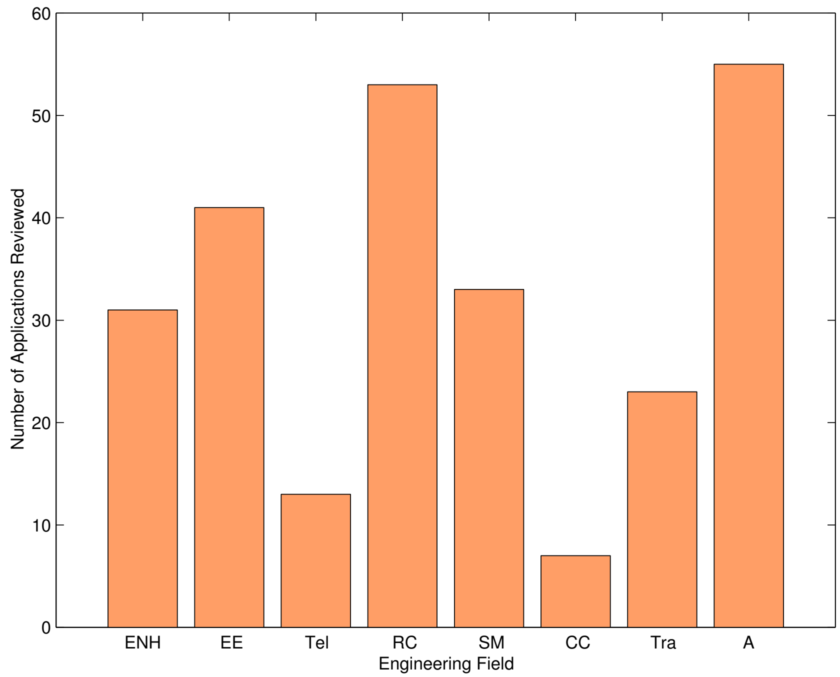


Figura 1: ENH = Environmental, Naval, and Hydraulic, EE = Electrical and Electronics, Tel = Telecommunications and Network Optimization, RC = Robotics and Control, SM = Structural & Mechanical, CC = Civil and Construction, Tra = Transport, A = Aeronautical.

Ingeniería Ambiental, Naval e Hidráulica

Specific Applications	**Reference(s)**	**Type of MOEA**
Groundwater pollution remediation	(Ritzel, 1994)	VEGA, GA with Pareto ranking
	(Cieniawski, 1995)	VEGA, GA with Pareto ranking, GA with Tchebycheff weighting method
	(Horn, 1993)	NPGA
	(Vemuri, 1995)	Multi-Niche Crowding GA
	(Erickson, 2001)	NPGA 2
	(Garrett, 1999)	GA with a linear aggregating function

Ingeniería Ambiental, Naval e Hidráulica

Specific Applications	Reference(s)	Type of MOEA
Water quality control	(Chen, 1998)	GA with a nonlinear aggregating function
	(Reed, 2001)	NSGA
	(Srigiriraju, 2000)	Noninferior Surface Tracing Evolutionary Algorithm

Ingeniería Ambiental, Naval e Hidráulica

Specific Applications	**Reference(s)**	**Type of MOEA**
Pumping scheduling	(Schwab, 1996)	GA with Pareto ranking
Water distribution network	(Halhal, 1997)	structured messy GA with Pareto ranking
Gas supply network	(Surry, 1995)	VEGA hybridized with Pareto ranking
Air quality management	(Loughlin, 1997)	GA with the Neighborhood Constraint Method

Ingeniería Ambiental, Naval e Hidráulica

Specific Applications	**Reference(s)**	**Type of MOEA**
Calibration of hydrologic models	(Yapo, 1996)	MOCOM-UA
	(Khu, 1998)	Accelerated Convergence Genetic Algorithm with a nonlinear aggregating function
Design of marine vehicles	(Thomas, 1998)	GA with Pareto ranking, MOGA and NPGA
	(Brown, 1998)	GA with Pareto ranking
	(Lee, 1997)	GA coupled with the ε-constraint method

Ingeniería Ambiental, Naval e Hidráulica

Specific Applications	Reference(s)	Type of MOEA
Planning of containership layouts	(Todd, 1997)	MOGA variant
Location of siting retail and service facilities	(Guimaraes, 1993)	GA with a linear aggregating function

Ingeniería Eléctrica y Electrónica

Specific Applications	**Reference(s)**	**Type of MOEA**
Symbolic layout compaction	(Fourman, 1985)	GA with lexicographic ordering
VLSI cell placement	(Sait, 2001)	Simulated evolution with fuzzy rules
	(Arslan, 1996)	GA with a linear aggregating function
Design of DSP systems	(Bright, 1999)	GA with Pareto ranking
Optimal planning of an electrical power distribution system	(Ramirez, 2001)	GA and evolutionary programming with Pareto ranking

Ingeniería Eléctrica y Electrónica

Specific Applications	**Reference(s)**	**Type of MOEA**
Design of a voltage reference circuit	(Nam, 1998)	Evolutionary programming with Pareto ranking
Power dispatch	(Tsoi, 1995)	Hybrid of a GA and simulated annealing with a linear aggregating function
System-level synthesis	(Blickle, 1996)	GA with a linear aggregating function
	(Dick, 1997)	MOGA
	(Dick, 1998)	Parallel recombinative simulated annealing and MOGA
	(Dick, 1999)	MOGA

Specific Applications	**Reference(s)**	**Type of MOEA**
Design of electromagnetic devices	(Weile, 1996)	NSGA
	(Weile, 1996a)	GA with Pareto ranking, NPGA, NSGA
	(Alotto, 1996)	Evolution strategy with a linear aggregating function
	(Mohammed, 1995)	GA with a linear aggregating function
	(Saludjian, 1998)	GA with a linear aggregating function
	(Borghi, 1998)	Evolution strategy with a linear aggregating function
Design of antennas	(Weile, 1996c)	NSGA

Cuadro 8: (continued)

Specific Applications	**Reference(s)**	**Type of MOEA**
	(Thompson, 2001)	MOGA, simulated annealing

Specific Applications	Reference(s)	Type of MOEA
Design of a tree-phase induction motor	(Kim, 1998)	Evolution strategy with a linear aggregating functiin
Fault tolerant system design	(Schott, 1995)	NPGA
Synthesis of CMOS operational amplifiers	(Zebulum, 1998)	GA with a target vector approach
Design of filters	(Harris, 1996)	GA with Pareto ranking
	(Zebulum, 1999)	GA with a target vector approach

Cuadro 9: (continued)

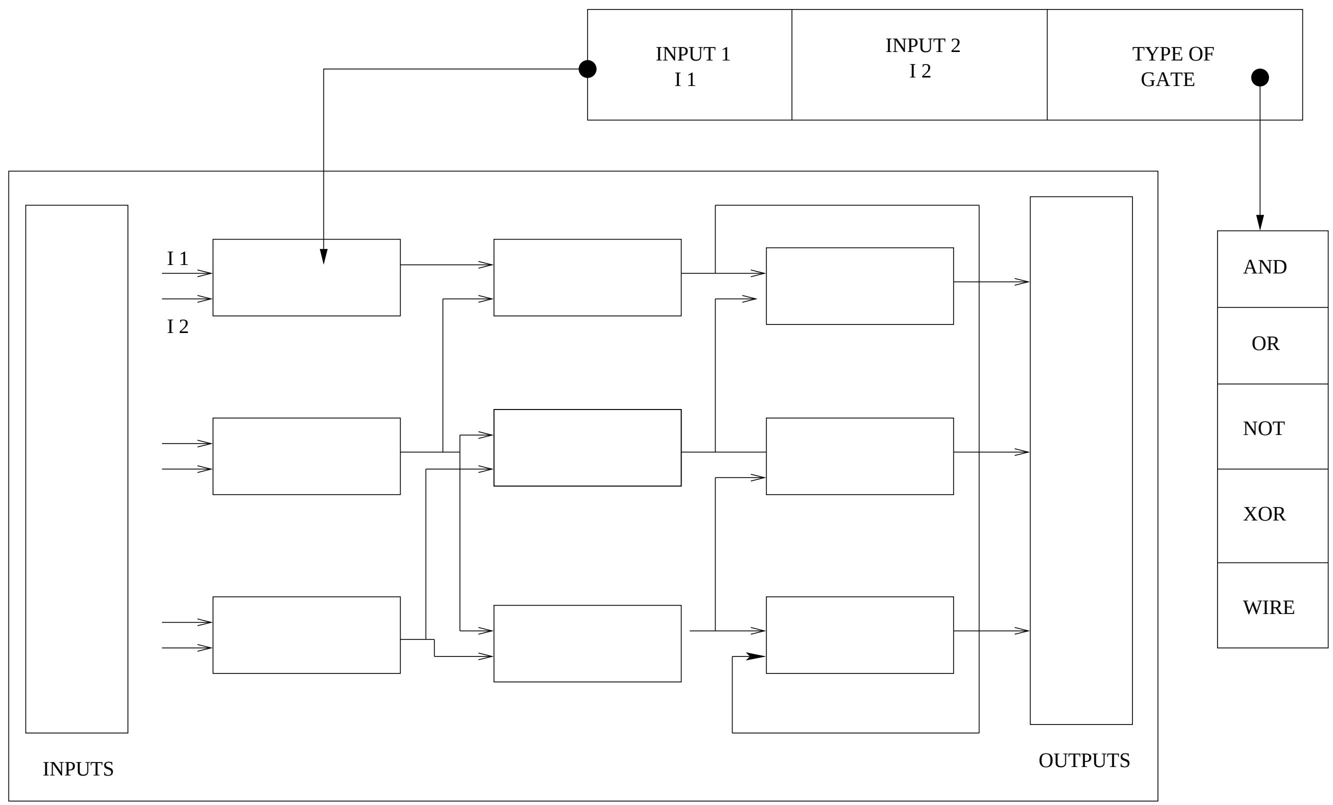
Specific Applications	**Reference(s)**	**Type of MOEA**
	(Wilson, 1993)	VEGA, a GA with goal attainment, a GA with a linear aggregating function, a GA with Pareto ranking
	(Schnier, 2001)	Evolution strategy and a dominance-based tournament selection scheme

Ingeniería Eléctrica y Electrónica

Specific Applications	**Reference(s)**	**Type of MOEA**
Design of lamps	(Eklund, 2001)	GA with an aggregating function
Microprocessor design	(Stanley, 1995)	GA with Pareto ranking
Shape design of a single-phase reactor	(DiBarba, 2001)	Nondominated sorting evolution strategy
Design of combinational circuits	(Rodriguez, 2001)	Multi-objective genetic programming
	(Coello, 2000)	VEGA

Ejemplo de Ingeniería Eléctrica

Usaré el problema de diseño de circuitos combinatorios para ilustrar una aplicación de este bloque. Para representar un circuito adoptamos la matriz que se muestra a continuación:



Ejemplo de Ingeniería Eléctrica

En este caso, las variables del problema son los tipos de entrada a cada compuerta (*gate*) y el tipo de compuerta para cada celda de la matriz.

La aptitud de un individuo se incrementa en uno por cada valor de la tabla de verdad al que acierta. Adicionalmente, si el circuito es 100 % factible, se premia una solución de acuerdo a la cantidad de WIREs que contenga.

Ejemplo de Ingeniería Eléctrica

Para hacer multiobjetivo este problema se procedió a considerar cada una de las salidas como un objetivo a satisfacerse. La función de aptitud es ahora la siguiente:

$$
\begin{array}{lll}
\textbf{if } o_j(\vec{x}) \neq t_j & \textbf{then} & \text{fitness}(\vec{x}) = 0 \\
\textbf{else if } v \neq 0 & \textbf{then} & \text{fitness}(\vec{x}) = -v \\
\textbf{else} & & \text{fitness}(\vec{x}) = f(\vec{x})
\end{array}
$$

Se usó un esquema poblacional (similar a VEGA) en el cual cada subpoblación lidia con una sola salida del circuito, usando la función de aptitud antes indicada.

Ejemplo de Ingeniería Eléctrica

Este problema se resolvería más adecuadamente si se usara programación genética. Sin embargo, en este caso, se debe controlar el *bloat*.

Hay trabajos recientes en los que se propone usar alguna esquema de selección multiobjetivo para controlar el bloat (de Jong et al., 2001; Ekárt and Németh, 2001; Luke and Panait, 2002). Esto da origen a un problema interesante en PG: minimizar el *bloat* al mismo tiempo que nos aproximamos a la zona factible.

Telecomunicaciones y Redes

Specific Applications	**Reference(s)**	**Type of MOEA**
Improve wire-antenna geometries	(Van Veldhuizen, 1998b)	GA with an aggregating function
Adaptive distributed database mangement	(Knowles, 2000)	PAES
Offline routing	(Knowles, 1999)	PAES
Production process planning	(Zhou, 1997)	Evolution strategy with an aggregating function
Minimum spanning tree problem	(Zhou, 1999)	Evolution strategy with an aggregating function

Ejemplo de Telecomunicaciones

Analizaremos el *Adaptive Distributed Database Management Problem*:

Un *distributed database service provider* (DDSP) ofrece un servicio de base de datos (p.ej., acceso a bancos de datos del genoma, o video sobre demanda) a un conjunto de clientes. Tanto la base de datos como los clientes se encuentran típicamente distribuidos de manera global. Para fines de contar con un modelo más simple del problema, se suele presuponer una red de “nodos”, donde cada nodo puede ser un servidor, un cliente o ambos.

Ejemplo de Telecomunicaciones

El DDSP necesita asegurarse de que los clientes reciban una calidad de servicio adecuada. Por tanto, se busca encontrar la mejor configuración en las conexiones cliente/servidor, dado un cierto escenario. Como parte de dicho escenario se deben tomar en cuenta los detalles de la red de comunicaciones utilizada, las velocidades de los servidores y las velocidades de acceso de cada cliente.

Ejemplo de Telecomunicaciones

La representación es muy simple, pues se usa una cadena de n genes para representar una red de n nodos. Los alelos codifican los servidores a los que es posible conectar un cliente.

Para calcular la aptitud (*fitness*) se debe considerar el desempeño (*performance*) de cada nodo, el efecto de cargar un cierto nodo con transacciones de varios clientes, el efecto de combinar descargas con actualizaciones de los clientes y la necesidad de efectuar múltiples actualizaciones y los retardos impuestos por los *overheads* en las comunicaciones inter-nodales. Existe un software de dominio público que implementa un modelo para calcular la aptitud de una red determinada.

Ejemplo de Telecomunicaciones

El número de clientes y el número de servidores oscila típicamente entre 2 y 20 y el número de servidores entre 10 varios miles.

En la versión bi-objetivo del problema se busca minimizar el peor retraso a la vez que el retraso promedio.

Knowles & Corne (2000) consideran escenarios que involucran a 10, 20 y 40 clientes y, en cada caso, se consideran 5 problemas separados. Se presupone la necesidad de una re-optimización rápida.

Robótica y Control

Specific Applications	**Reference(s)**	**Type of MOEA**
Robot path planning	(Dozier, 1998)	Fuzzy tournament selection
	(Gacôgne, 1999)	Evolution strategy with lexicographic ordering
	(Higashihara, 1998)	MOGA
Fault diagnosis	(Marcu, 1997)	MOGA
	(Marcu, 1998)	Parallel version of MOGA
	(Marcu, 1999)	MOGA
Nonlinear system identification	(Rodriguez, 1997;Arkov, 1999)	Multiobjective genetic programming

Robótica y Control

Specific Applications	**Reference(s)**	**Type of MOEA**
Controller design	(Schroder, 1997)	MOGA
	(Donha, 1997)	GA with an aggregating function
	(Herreros, 2000)	Multiobjective robust control design GA
	(Kawabe, 1999)	GA with the Pareto partitioning method
	(Istepanian, 1999)	MOGA
	(Binh, 1997)	Multiobjective evolution strategy
	(Mahfouf, 1998)	GA with a fuzzy population ranking method

Specific Applications	**Reference(s)**	**Type of MOEA**
Design of control systems	(Chipperfield, 1995)	MOGA
	(Whidborne, 1995)	MOGA
	(Tan, 1997)	Hybrid of MOGA and the NPGA
	(Tan, 2000)	Incremented multiobjective evolutionary algorithm
	(Duarte, 2000)	MOGA combined with a neural network
	(Trebi, 1997)	GA with fuzzy logic and an aggregating function
	(Dakev, 1997;Chipperfield, 1996)	MOGA

Cuadro 14: (continued)

Specific Applications	**Reference(s)**	**Type of MOEA**
	(Blumel, 2000)	NSGA

Specific Applications	**Reference(s)**	**Type of MOEA**
Robotic manipulator problems	(Khwaja, 1998)	GA with a predator fitness approach
	(Osyczka, 1999)	GA with a variation of the Pareto set distribution method
	(Jakob, 1992)	Parallel GA with an aggregating function
	(Ortmann, 2001)	Evolution strategy with an aggregating function
	(Coello, 1998)	GA with a weighted min-max approach
Generation of fuzzy rule systems	(Jin, 1999)	Evolution strategy with an aggregating function

Cuadro 15: (continued)

Specific Applications	**Reference(s)**	**Type of MOEA**
	(Jiménez, 2001)	GA with Pareto ranking

Ingeniería Estructural y Mecánica

Specific Applications	**Reference(s)**	**Type of MOEA**
Truss design	(Cheng, 1997)	GA with Pareto ranking
	(Rao, 1993;Dhingra, 1994)	GA with cooperative game theory
	(Crossley, 1998)	Two-branch tournament GA
	(Sandgren, 1994)	GA coupled with goal programming
	(Liu, 1998;Wallace, 1996)	GA with an aggregating function
	(Coello, 2000;Hajela, 1992)	GA with a weighted min-max approach
	(Narayanan, 1999;Azarm, 1999)	MOGA

Ingeniería Estructural y Mecánica

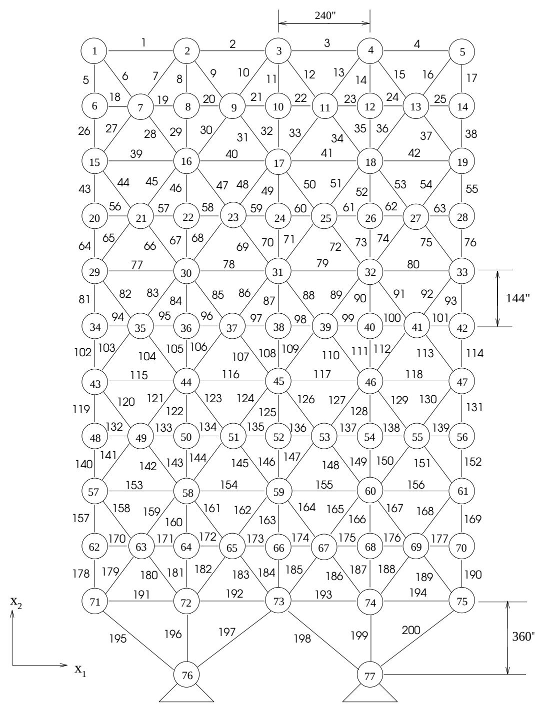
Specific Applications	**Reference(s)**	**Type of MOEA**
Beam design	(Belegundu, 1994)	GA with Pareto ranking
	(Gero, 1994)	GA with Pareto elitist-based selection
	(Osyczka, 2000)	GA with the Pareto set distribution method
	(Coello, 1999)	GA with a weighted min-max approach
	(Wu, 2001)	GA with Pareto ranking
Plate design	(Soremekun, 1997)	GA with an aggregating function

Ingeniería Estructural y Mecánica

Specific Applications	**Reference(s)**	**Type of MOEA**
Structural control systems	(Kim, 1999)	GA with an aggregating function
	(Kundu, 1996a;Osyczka, 1995)	GA with compromise programming
Packing problems	(Grignon, 1999)	Iterative GA
Gear-box design	(Kurapati, 2000)	MOGA
Micromechanical densification modeling parameters	(Reardon, 1998)	Fuzzy logic based multiobjective genetic algorithm

Ejemplo de Ingeniería Estructural y Mecánica

El ejemplo que consideraremos es el diseõ óptimo de estructuras reticulares (p.ej., armaduras, vigas, pórticos, etc.).



Ejemplo de Ingeniería Estructural y Mecánica

Este tipo de problemas se caracterizan por tener variables discretas (p.ej., una lista de elementos disponibles de un fabricante) y por requerir un enorme tiempo de procesamiento para el análisis (se debe resolver un sistema de n ecuaciones lineales simultáneas, donde n se refiere al número de grados de libertad de la estructura). Por ello, suele requerirse de procesamiento en paralelo o de supercómputo.

Ejemplo de Ingeniería Estructural y Mecánica

Los objetivos que normalmente se utilizan son:

- Minimizar el peso de la estructura.
- Minimizar los desplazamientos en cada nodo.
- Minimizar la vibración de la estructura (si se analiza dinámicamente).

Ingeniería Civil y de la Construcción

Specific Applications	**Reference(s)**	**Type of MOEA**
Building construction planning	(Feng, 1997)	GA with Pareto ranking
	(Khajehpour, 2001)	GA with a target vector approach
City planning	(Balling, 2001)	GA with a target vector approach

Ingeniería del Transporte

Specific Applications	**Reference(s)**	**Type of MOEA**
Train systems	(Chang, 1995)	GA with an aggregating function
	(Laumanns, 2001)	Unified model for multi-objective evolutionary algorithms
Road systems	(Haastrup, 1997)	NPGA with an outranking approach
	(Guimaraes, 1997)	GA with an outranking approach
	(Baita, 1995)	GA with local geographic selection
	(Anderson, 1998)	MOGA
	(Qiu, 1997)	GA with a target vector approach

Ingeniería del Transporte

Specific Applications	**Reference(s)**	**Type of MOEA**
Transportation problems	(Yang, 1994;Ida, 1997;Cheng, 2000)	GA with an aggregating function
	(Gen, 2000)	GA with fuzzy logic and an aggregating function

Ingeniería Aeronáutica

Specific Applications	**Reference(s)**	**Type of MOEA**
Constellation design	(Ely, 1998)	Two-branch tournament GA
	(Mason, 1999)	Variation of the NSGA
	(Hartmann, 1999)	Variation of the NSGA
Helicopter design	(Crossley, 1997)	GA with a Kreisselmeir-Steinhauser function
	(Crossley, 1996)	Two-branch tournament GA and Pareto ranking
	(Flynn, 1995)	GA with a modified version of Pareto ranking

Ingeniería Aeronáutica

Specific Applications	**Reference(s)**	**Type of MOEA**
Aerodynamic optimization	(Wang, 2001)	GA coupled with game theory
	(Poloni, 1997)	NPGA
	(Obayashi, 2000)	MOGA
	(Giotis, 1999)	GA with Pareto ranking
	(Mäkinen, 1996)	NSGA
	(Rogers, 2000)	VEGA

Ingeniería Aeronáutica

Specific Applications	**Reference(s)**	**Type of MOEA**
Aerodynamic optimization	(Anderson, 1996;Vicini, 1998)	GA with Pareto ranking
	(Parmee, 1999)	Co-evolutionary multiobjective GA
	(Anderson, 1995)	GA with an aggregating function
	(Quagliarella, 1998)	Virtual Subpopulation Genetic Algorithm
	(Quagliarella, 1999)	Parallel genetic algorithm

Aplicaciones Científicas

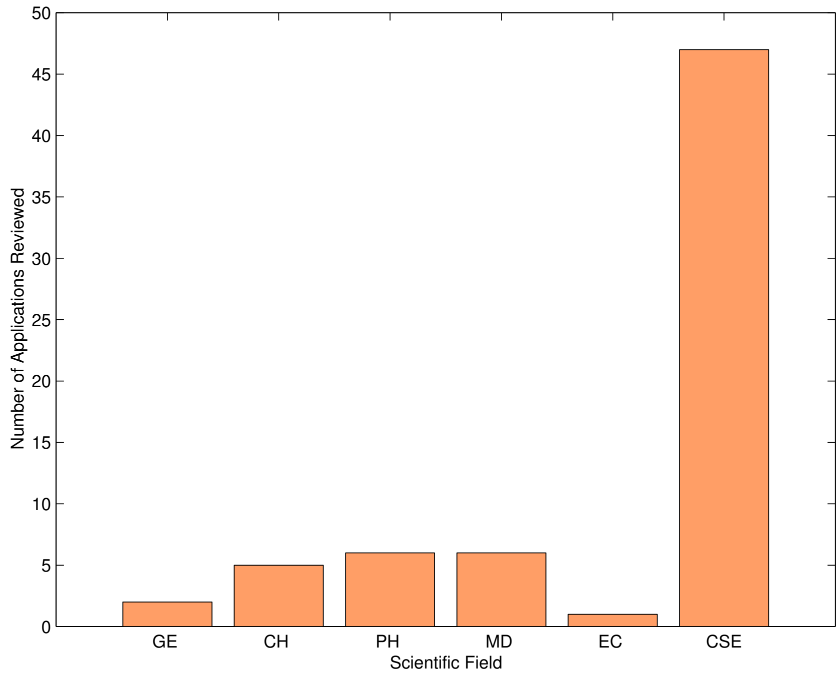


Figura 2: The following labels are used: GE = Geography, CH = Chemistry, PH = Physics, MD = Medicine, EC = Ecology, CSE = Computer Science and Computer Engineering.

Geografía

Specific Applications	**Reference(s)**	**Type of MOEA**
Environmental modelling	(Jarvis, 1996)	GA with an aggregating function
Land use planning	(Matthews, 2000)	MOGA

Química

Specific Applications	Reference(s)	Type of MOEA
Intensities of emission lines of trace elements	(Wienke, 1992)	GA coupled with goal programming
Modelling of a chemical process	(Hinchliffe, 1998)	multiobjective genetic programming
Search of molecular structures	(Jones, 1993)	GA with an aggregating function
Polymer extrusion optimization	(Cunha, 1997)	GA with the reduced Pareto set approach
	(Cunha, 1999)	NSGA and a GA with the reduced Pareto set approach

Física

Specific Applications	Reference(s)	Type of MOEA
Reflector backscattering	(Périaux, 1996)	Nash-GA
Analysis of experimental spectra	(Golovkin, 2000)	NPGA
Design of a water reactor	(Parks, 1997)	GA with Pareto ranking

Medicina

Specific Applications	**Reference(s)**	**Type of MOEA**
Treatment planning	(Yu, 1997)	GA with Pareto ranking
	(Petrovski, 2001)	SPEA
Allocation in radiological facilities	(Chen, 1996)	GA with an aggregating function
	(Lahanas, 2001)	MOGA, the NPGA and SPEA
Prognostic models	(Science, 1999)	Diffusion genetic algorithm
Left ventricle 3D reconstruction	(Aguilar, 1999)	GA with Pareto ranking

Ecología

Specific Applications	Reference(s)	Type of MOEA
Assessment of ecological models	(Reynolds, 1999)	GA with an aggregating function and a GA with Pareto ranking

Ciencias de la Computación

Specific Applications	**Reference(s)**	**Type of MOEA**
Coordination of agents	(Cardon, 1999;Galinho, 1998)	GA with an aggregating function
Exploration of software implementations for DSP algorithms	(Zitzler, 1999)	SPEA
Computer-generated animation	(Gritz, 1995)	Genetic programming with an aggregating function
	(Shibuya, 1999)	Interactive genetic algorithm with a Pareto optimal selection strategy

Ciencias de la Computación

Specific Applications	**Reference(s)**	**Type of MOEA**
Machine learning	(Kumar, 1998)	Pareto converging genetic algorithm
	(Tamaki, 1996)	GA with Pareto optimal selection
	(Schaffer, 1985)	VEGA
	(Yoshida, 1996)	Genetic programming with Pareto selection
	(Bot, 2000)	Genetic programming with Pareto ranking
	(Bernadó, 2001)	GA with Pareto ranking and an aggregating
	(Dasgupta, 2001)	GA with an aggregating function

Ciencias de la Computación

Specific Applications	**Reference(s)**	**Type of MOEA**
Image processing	(Bhanu, 1994;Aguirre, 2001)	GA with an aggregating function
	(Köppen, 1998)	Hybrid of a genetic algorithm and a multilayer backpropagation neural network
	(Aherne, 1997)	MOGA
Simulation	(Bingul, 2000)	GA with different aggregating functions
Object partition and allocation	(Choi, 1998)	NPGA
Games	(Chow, 1998)	GA with an aggregating function
Sorting networks	(Ryan, 1994)	GA with an aggregating function

Ciencias de la Computación

Specific Applications	**Reference(s)**	**Type of MOEA**
Traveling salesperson problem	(Jaszkiewicz, 2001)	GA with an aggregating function and local search
Genetic programming	(Ekart, 2001)	Tournament selection based on Pareto dominance
	(Bleuler, 2001)	SPEA2
	(DeJong, 2001)	Find only and complete undominated sets
Graph layout generation	(Barbosa, 2001)	GA with an aggregating function
Automatic programming	(Langdon, 1995)	Genetic programming with Pareto-based tournament selection

Aplicaciones Industriales

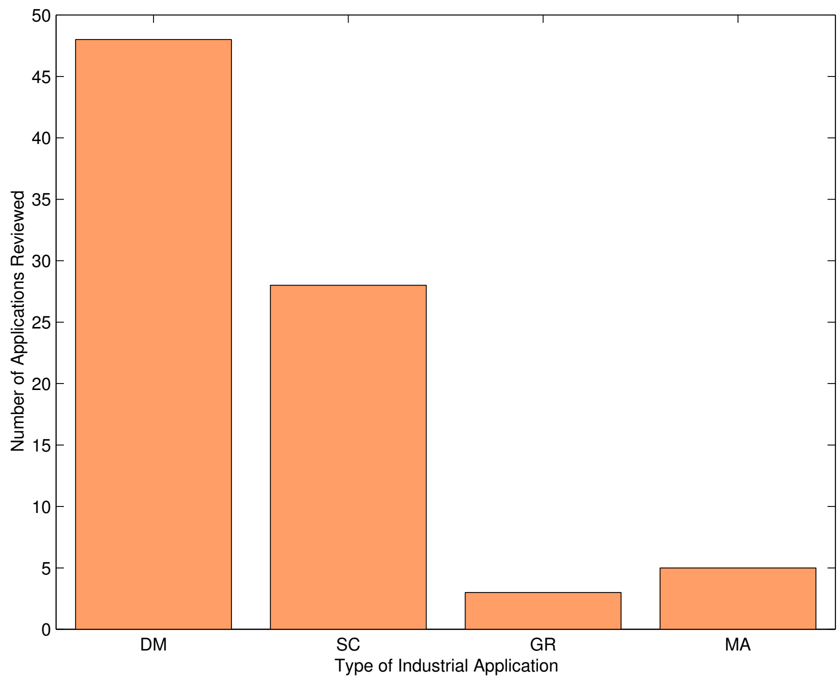


Figura 3: The following labels are used: DM = Design and Manufacture, SC = Scheduling, GR = Grouping and Packing, MA = Management.

Specific Applications	Reference(s)	Type of MOEA
Process planning	(Viennet, 1996;Massebeuf, 1999)	Hybrid of VEGA and Pareto ranking
	(Groppetti, 1997)	GA with Pareto ranking
	(Tzeng, 1995;Moon, 1998)	GA with an aggregating function
	(Sette, 1996)	GA with Pareto ranking
	(Rekiek, 2000)	Grouping genetic algorithm hybridized with PROMETHEE
	(Hyun, 1998)	PAreto stratum-niche cubicle GA

Cuadro 34: (continued)

Specific Applications	**Reference(s)**	**Type of MOEA**
	(Chen, 2001)	Generalized multi-objective evolutionary algorithm

Diseño y Manufactura

Specific Applications	**Reference(s)**	**Type of MOEA**
VLSI	(Drechsler, 1999)	GA and satisfiability classes
	(Lee, 1997)	GA with Pareto ranking
	(Esbensen, 1996;Drechsler, 1996)	GA with an aggregating function
Cellular manufacturing	(Dimopoulos, 1998;Dimopoulos, 1998)	MOGA, Pareto ranking and a GA with an aggregating function
	(Pierreval, 1998)	NPGA

Diseño y Manufactura

Specific Applications	**Reference(s)**	**Type of MOEA**
Machine design	(Fujita, 1998)	GA with Osyczka and Kundu's approach (1995)
	(Osman, 1998)	GA with an aggregating function
	(Mitra, 1998)	NSGA
	(Fonseca, 1998)	MOGA
	(Meneghetti, 1999)	GA with Pareto ranking
	(Coello, 1999)	GA with a weighted min-max approach
	(Sbalzarini, 2001;Müller, 2001)	(μ, λ)-ES with SPEA

Scheduling

Specific Applications	**Reference(s)**	**Type of MOEA**
Production	(Shaw, 1996)	MOGA
	(Santos, 1999)	GA with Pareto ranking and the NPGA
	(Tamaki, 1996)	GA with the Pareto reservation strategy
Flowshop	(Tagami, 1999)	GA with the Pareto partitioning method
	(Ishibuchi, 1998;Murata, 1997)	GA with an aggregating function
	(Brizuela, 2001)	NSGA

Scheduling

Specific Applications	**Reference(s)**	**Type of MOEA**
Flowshop	(Talbi, 2001)	NSGA, MOGA, VEGA, weighted average ranking and an elitist version of the NSGA
	(Sridhar, 1996)	GA with an aggregating function
	(Murata, 2000)	cellular multi-objective genetic local search
	(Cui, 2001)	MOGA coupled with the artificial immune system

Scheduling

Specific Applications	Reference(s)	Type of MOEA
Job shop	(Bagchi, 2001)	
	(Tamaki, 1999)	GA with the Pareto reservation strategy
	(Liang, 1994)	GA with an aggregating function
Machine	(Carlyle, 2001)	Multi-population genetic algorithm and a GA with local search and an aggregating function
	(Cochran, 2000)	Multi-population genetic algorithm
Resource	(Syswerda, 1991)	GA with an aggregating function

Scheduling

Specific Applications	**Reference(s)**	**Type of MOEA**
Time-tabling	(Paechter, 1998)	GA with a target vector approach
Personnel	(Jan, 2000)	GA with Pareto ranking
	(ElMoudani, 2001)	GA with lexicographic ordering
	(Hilliard, 1989;Liepins, 1990)	GA with Pareto ranking
	(Yoshimura, 1998)	GA with an aggregating function
Real-time	(Montana, 1998)	GA with an aggregating function

Management

Specific Applications	**Reference(s)**	**Type of MOEA**
Facility	(Broekmeulen, 1995)	GA with an aggregating function
	(Krause, 1995)	Evolution strategy with Pareto selection
Forest	(Ducheyne, 2001)	MOGA with elitism and NSGA-II
Distribution system	(Jaszkiewicz, 2001)	Multiple objective genetic local search, Pareto ranking, hybrid of Pareto ranking and local search and the multiple start local search algorithm

Grouping and Packing

Specific Applications	**Reference(s)**	**Type of MOEA**
Truck packing	(Grignon, 1996)	GA with an aggregating function
Object packing	(Ikonen, 1997)	GA with an aggregating function

Aplicaciones Misceláneas

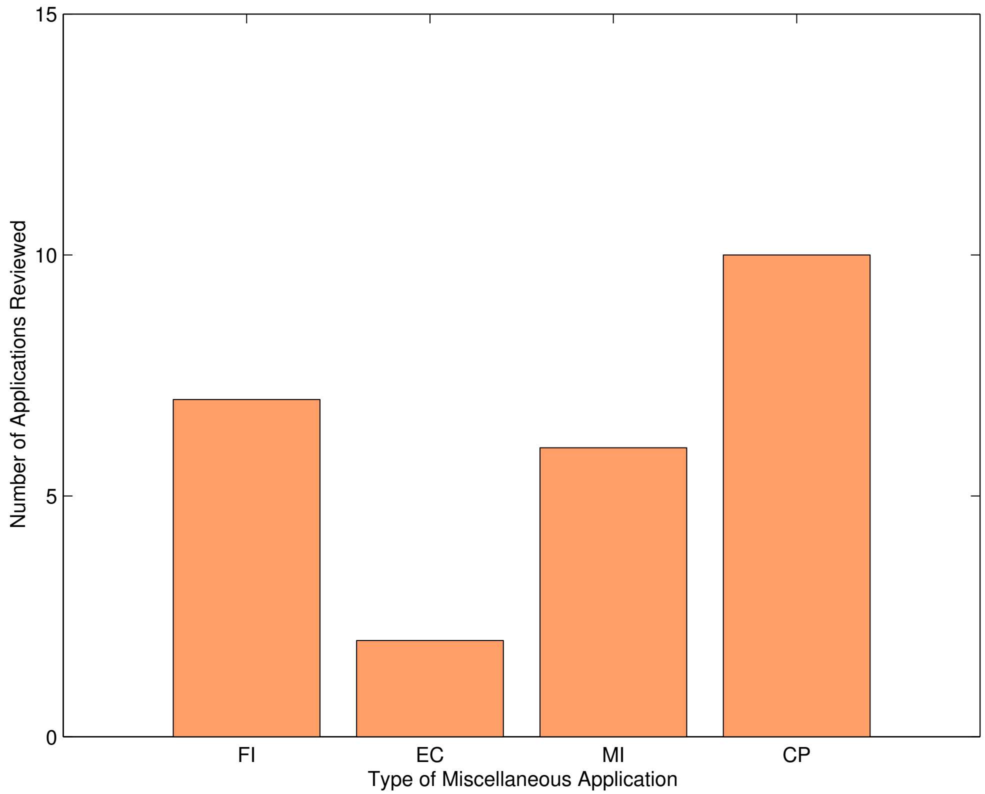


Figura 4: FI = Finance, CP = Classification and Prediction.

Economía y Finanzas

Specific Applications	Reference(s)	Type of MOEA
Investment portfolio optimization	(Vedarajan, 1997)	NSGA
	(Chang, 1998;Shoaf, 1996)	GA with an aggregating function
Financial time series	(Ruspini, 1999)	NPGA
Stock ranking	(Mullei, 1998)	GA with an aggregating function
Economic models	(Mardle, 2000)	GA coupled with a weighted goal programming approach

Clasificación y Predicción

Specific Applications	**Reference(s)**	**Type of MOEA**
Prediction problems	(Iba, 1994)	Genetic programming with an aggregating function
	(Zhang, 1996)	Genetic programming with an aggregating function
	(Kim, 2001)	Evolutionary local selection algorithm
Feature selection	(Emmanouilidis, 2000)	NPGA
	(Menczer, 2000)	Evolutionary local selection algorithm
Pattern classification	(Ishibuchi, 2000)	GA with an aggregating function
Data classification	(Emmanouilidis, 1999)	NPGA

Las Aplicaciones que Vendrán

- Coordinación de agentes.
- Visión por computadora.
- Diseño de formas.
- Control de *bloat* en programación genética.
- Más problemas de optimización combinatoria (Ehrgott & Gandibleux, 2000).