

GOSET*

For Use with MATLAB®

Manual

Version 2.2



United States
Naval Academy



Purdue University
School of Electrical and
Computer Engineering

* Genetic Optimization System Engineering Tool

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Scott D. Sudhoff
Professor of Electrical and
Computer Engineering
Purdue University

Chapter 1

Introduction

- 1.1 The Genetic Optimization System Engineering Tool (GOSET)
- 1.2 System requirements
- 1.3 Installing GOSET
- 1.4 GOSET license

1.1 The Genetic Optimization System Engineering Tool (GOSET)

The Genetic Optimization System Engineering Tool (GOSET) is a MATLAB® based code for solving optimization problems. In the course of its development, it was extensively used to solve a variety of engineering problems – particularly those related to magnetics, electric machinery, power electronics, and entire power and propulsion systems. It has been used to automatically design inductors, brushless dc motors, power supplies, and inverters and for the parameter identification of synchronous machines, induction machines, gas turbines, etc. It is meant primarily as an engineering tool, although it is quite generic in its ability to solve both single-objective and multi-objective optimization problems. Because it solves these problems using evolutionary algorithms it is very robust in its ability to seek global rather than local optimum, as well as in its ability to contend with functions that are not ‘friendly’ in that they are, for example, discontinuous. GOSET provides the means for the user to either be blissfully unaware of the algorithms and parameters used, or to become intimately involved in the exact algorithms as well as the parameters used in these algorithms. It also allows the user to either work from a text-based environment or to utilize a graphical user interface. In short, it provides the user with a powerful tool for the automation of the engineering design process.

1.2 System Requirements

GOSET runs on MATLAB Version 6.5 Release 13 and up, and you can refer to the system requirements for corresponding versions of MATLAB.

For the MATLAB 6.5.1 or later versions running on Microsoft Windows, DLL version of GOSET is also provided to improve the computational speed. If you are using MATLAB 6.5 on Microsoft Windows, you can download the following file and install this functionality.

http://www.mathworks.com/support/solutions/files/s33513/GenericDII_1p1.exe

The detailed installation procedure is provided in the following link.

<http://www.mathworks.com/support/solutions/data/1-1ABRP.html?solution=1-1ABRP>

GOSET DLL version is marked by the letter 'D' in the GOSET version. For example, DLL version of 'goset 2.0' is 'goset 2.0D'.

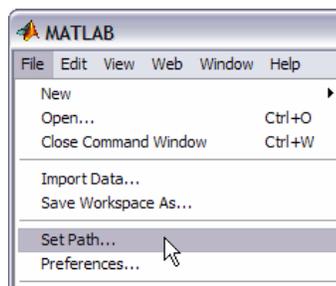
1.3 Installing GOSET

GOSET is MATLAB based toolbox and the installation is a simple process of adding the GOSET path to the MATLAB paths.

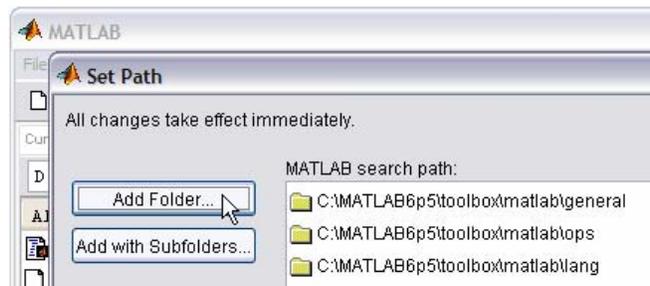
It is strongly advised not to change the default folder name of GOSET. For the GOSET provided with this manual, the default folder name is 'goset 2.x' or 'goset 2.xD' for the DLL version.

Installation Instruction

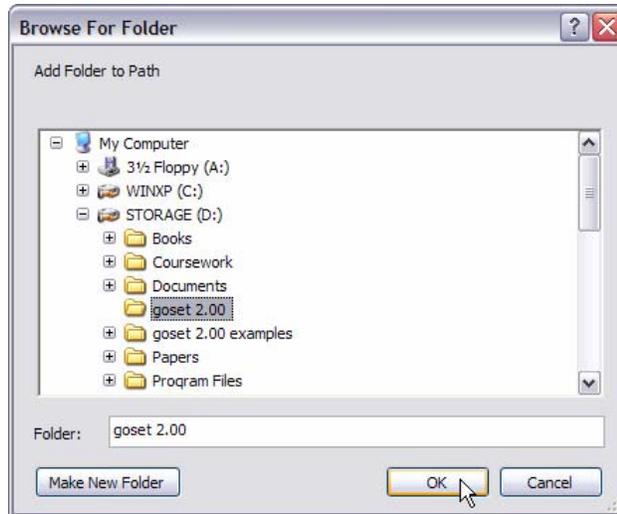
1. Copy the 'goset 2.x(D)' and 'goset 2.x examples' folders in a convenient place.
2. In MATLAB menu, go to 'File' and select 'Set Path'.



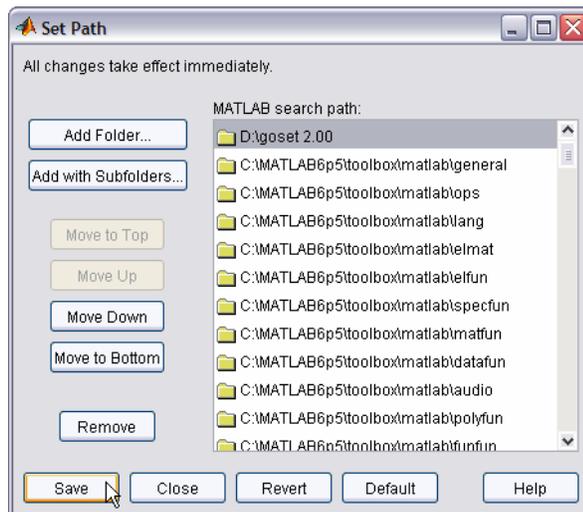
3. Then, click 'Add Folder' .



4. Locate 'goset 2.x(D)' folder and click 'OK' to add 'goset 2.x(D)' folder to the MATLAB search paths.



5. Click 'Save' and 'Close' to finish.



6. Now, you are ready to use GOSET.

1.4 GOSET License

Each version of GOSET is subject to the license control. The license of GOSET expires after certain period of time from the date of release. This is to prevent the unlawful distribution of GOSET and also to mandate the users to update their GOSET to the latest version.

When there is less than a week left in the GOSET license, you will get the following warning message:

There are only n days left in GOSET 2.x License.

Please contact the distributor for the latest version of GOSET.

Chapter 2

An Overview of Single-Objective Genetic Algorithms

This section is devoted to a brief overview of Genetic Algorithms (GAs) focused on the canonical genetic algorithm.

- 2.1 Introduction to genetic algorithms
- 2.2 Canonical genetic algorithm
- 2.3 Other genetic operators

2.1 Introduction to genetic algorithms

Genetic algorithms are optimization methods that are inspired by biological evolution. GAs operate on a population of candidate solutions and apply the principle of survival of the fittest to evolve the candidate solutions towards the desired optimal solutions.

In GAs, candidate solutions are referred to as *individuals*. The defining properties of these individuals (parameters) are encoded to chromosomes that consist of a string of genes. According to the representation rule, a gene can be a symbol from an alphabet (in a canonical GA), a binary number, integer, real-value, etc. A *population* refers to the group of individuals.

The *fitness* of an individual is a metric that tells us how good each individual is as the solution to the given problem. Using a fitness function, individuals are assigned corresponding fitness values. The individuals with better fitness values are more like to survive and reproduce.

With the representation rule and the fitness function determined for the given optimization problem, an initial population is randomly generated and fitness values are evaluated. Then a pair of *parent* chromosomes is selected from the current population. The probability of selection increases with increasing fitness. Genetic operators such as *crossover* and *mutation* are applied to these parent chromosomes to generate children. The children are used to create a new population, for which fitness values are evaluated and assigned. This process of selection, crossover, mutation, and fitness evaluation is repeated until a stopping criterion is satisfied. Each iteration of this procedure is called a generation.

From the above description of a GA, it is clear that GAs are radically different from the classical optimization approaches. Some of the most significant differences are:

- GAs operate encodings of the parameter values, not necessarily the actual parameter values
- GAs operate on a population of solutions, not a single solution
- GAs only uses the fitness values based on the objective functions and do not require derivative information or other knowledge
- GAs uses probabilistic computations, not deterministic ones
- GAs are efficient in handling problems with a discrete search space

2.2 Canonical genetic algorithm

In this section, a canonical GA is introduced to illustrate the fundamental mechanisms of GAs. A flow chart of canonical GA is shown in Figure 2.1. There in, the GA begins with an initialization step, followed by a repeated sequence of fitness evaluation, selection, crossover and mutation.

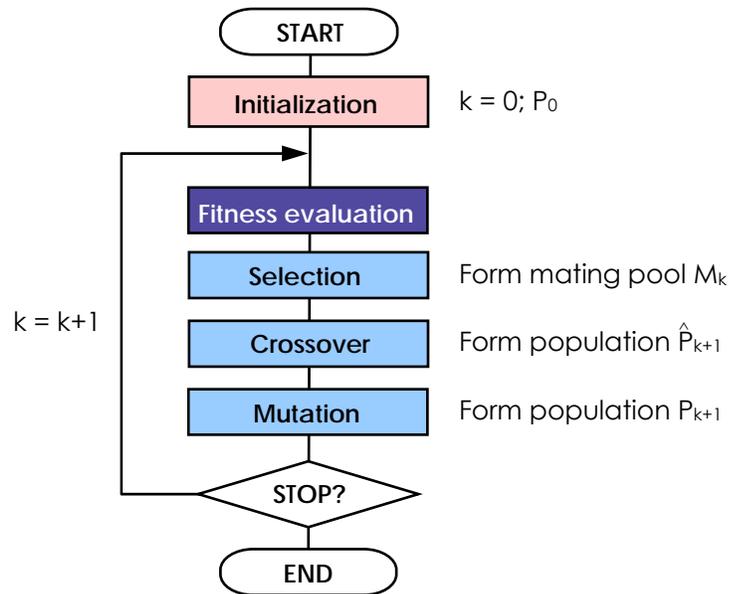


Figure 2.1 Flow chart of a typical GA

Initialization

In the initialization step, initial solutions are randomly generated and encoded into individuals according to the predefined representation rule. Binary coding is employed in canonical GAs. The generation number k is set to 0 and the initial population is denoted P_0 .

Fitness Evaluation

The fitness value is a figure of merit for an individual. In the fitness evaluation step, each individual is assigned with its fitness value. Generally, higher fitness value corresponds to a more optimal individual.

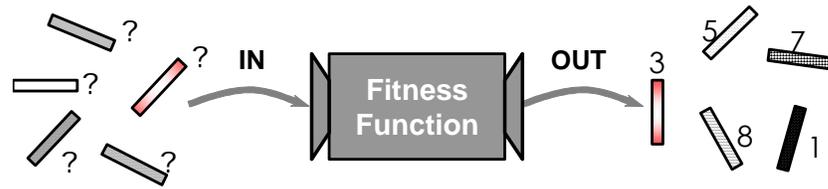


Figure 2.2 Fitness evaluation

Selection

In nature, the individuals that are better suited to the environment are more likely to survive and reproduce. The selection operator emulates this situation by ensuring that individuals with larger fitness values are more likely to survive to reproduce. Among the several different selection methods, the roulette wheel and tournament selection algorithms are commonly used to form a mating pool M_k .

a. Roulette wheel selection

Roulette wheel selection is one of the most popular selection methods. Let's assume that all the individuals are evaluated and assigned with their fitness values. Then one can imagine a roulette wheel with sections whose number is same as the number of individuals and whose areas are proportional to the fitness values of the corresponding individuals. Then the wheel is turned and a chromosome is selected and copied to the mating pool. This process is repeated until the mating pool is full.

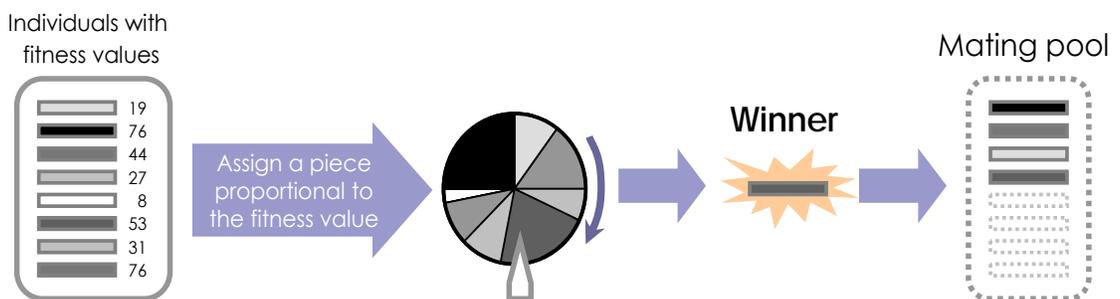


Figure 2.3 Roulette wheel selection

b. Tournament selection

As the name states, two or more individuals are randomly chosen from the population and the one with better fitness value is selected and copied in the mating pool. This method is simpler than the roulette wheel method.

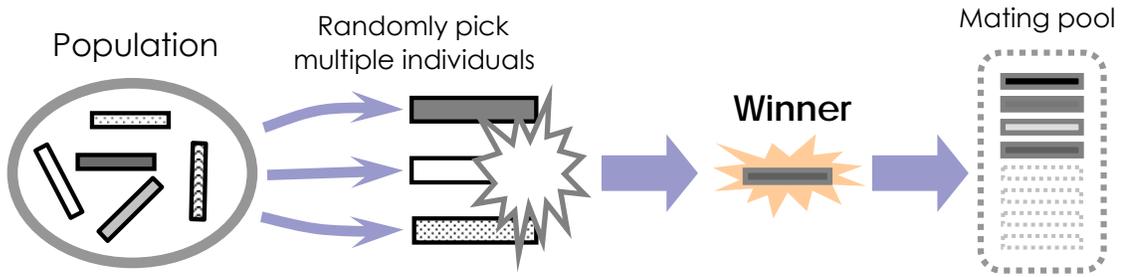


Figure 2.4 Tournament selection

Crossover

Crossover emulates the reproduction of living organs by exchanging gene among the chromosomes. Crossover generates new individuals that share the characteristics of their parents. Crossover is performed on the mating pool M_k to form population \hat{P}_{k+1} as a first step in forming the next generation P_{k+1} . The single-point crossover and the multiple-point crossover operators are list below.

a. Single-point crossover

A crossover point is randomly selected and the genes of the parents are exchanged after the crossover point as depicted in Figure 2.5.

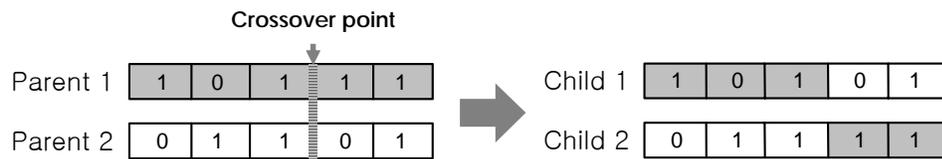


Figure 2.5 Single-point crossover

b. Multiple-point crossover

Several crossover points are randomly chosen and the genes of the parents are exchanged in between the crossover points. Figure 2.6 illustrates two point crossover.

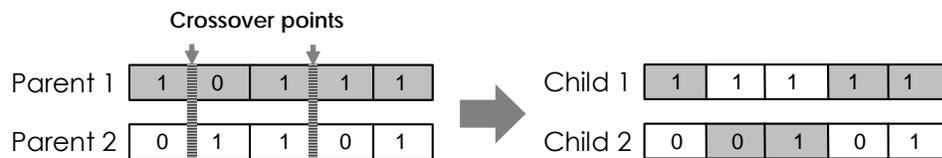


Figure 2.6 Multiple-point crossover

Mutation

In natural evolution, mutation occurs as the result of an error in copying the gene information. As an analogy to this, mutation in GA is a process of changing some genes in chromosomes randomly. The main role of mutation operator is to maintain the diversity of the population.

In the canonical GA using binary representation, mutation operator flips the selected bit value as in Figure 2.7. The mutation operator is applied to \hat{P}_{k+1} which yield P_{k+1}

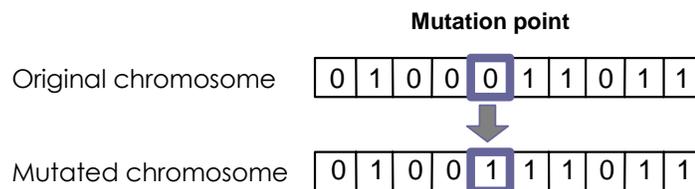


Figure 2.7 Mutation in binary-coded GAs

2.3 Other genetic operators

Selection, crossover and mutation are the primary genetic operators. However, other genetic operators have been developed to improve the performance of GAs. We introduce some of them that are employed in GOSET.

Elitism

Elitism is a mechanism to protect the best individual from being altered and lost by genetic operations. The simplest way to implement elitism is to pass the current best individual to the next population without any genetic operations. By using elitism, it is guaranteed that maximum fitness in the population will never decrease.

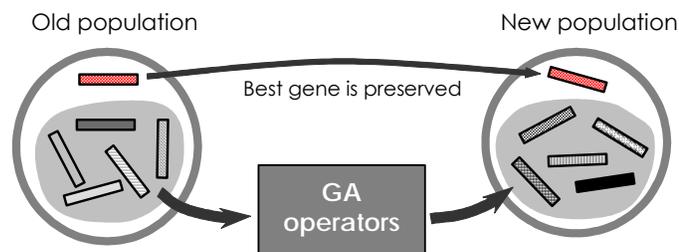


Figure 2.8 Elitism

Migration

This operator works only when multiple-region (or multiple-population) scheme is employed. By setting the number of regions, n , greater than one, the population is divided into n different populations. Generally, these populations evolve without any interaction. Periodically, some of the individuals are redistributed and move from one region to other region.

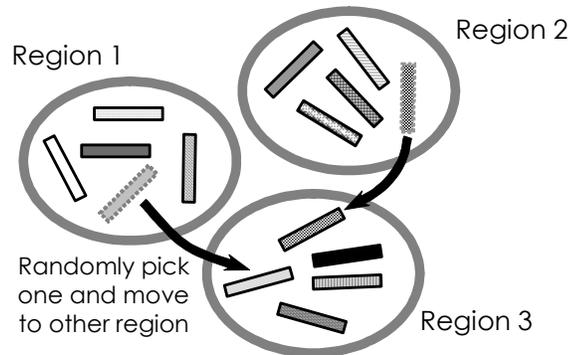


Figure 2.9 Migration operator

Using multiple populations with migration can result in a better chance of finding the global optimum with less computation.

Random search

Random search is a way to extensively explore the neighborhood of the best individual for better solution by random mutation of the best individual. It can help reduce the time for the GA to converge to the optimal solution.

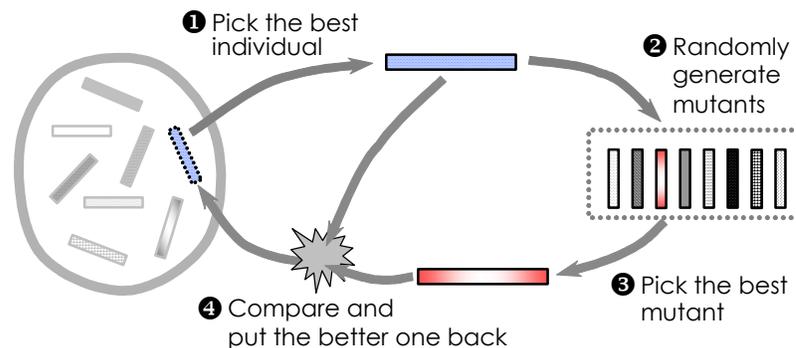


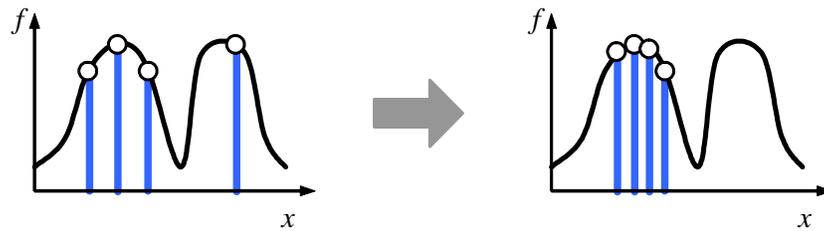
Figure 2.10 Random search

As shown in Figure 2.10, the best individual is randomly perturbed to generate mutants. Then, the fitness values of the generated individuals are evaluated. If the

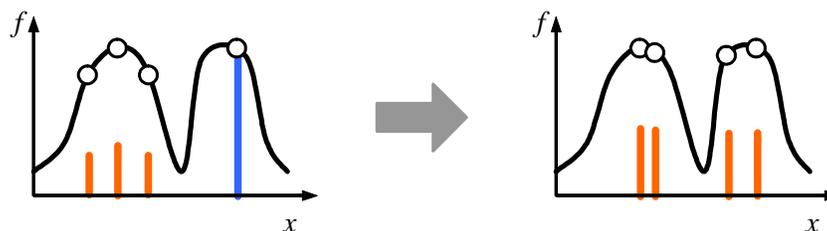
best among the mutants has better fitness value than that of the current best individual, then the current best individual is replaced by the new best individual. Otherwise, the original best individual is placed back to the population.

Diversity Control

For some optimization problems, there are multiple optimal solutions (multi-modal problems). A naive application of GAs can result in convergence of the solutions to one optimal solution. Even in the problem with single optimal solution, it is not desirable for the many solutions exploring the same region in the solution space. Therefore, the diversity control is employed. By using diversity control, the under represented solutions are emphasized and similar solutions are penalized by adjusting their fitness values.



(a) Without the diversity control



(b) With the diversity control

Figure 2.11 Diversity control

Figure 2.11 shows the effect of diversity control. Each circle on the curve represents a solution and its fitness value is shown by the vertical bar below it. Most of the solutions are close to the first optimal solution in (a). With the high probability of selecting a solution near the first optimum, it is likely to end up having all the solutions near the first optimum. However, when the diversity control is used, the fitness function values of the overrepresented solutions in the first optimum are penalized as in (b) and underrepresented solutions in the second optimum are less penalized and have better chance to survive.

Chapter 3

An Overview of Multi-Objective Optimization

GOSET has the capability to perform multi-objective optimizations. A few fundamental notions on multi-objective optimization are introduced in this chapter.

- 3.1 Multi-objective optimization problems
- 3.2 GAs for multi-objective optimization problems

3.1 Multi-objective optimization problems

Definition

Multi-objective optimization problems involve more than one objective function. Each objective function is to be minimized or maximized. The general form of multi-objective optimization problem can be formally defined as

$$\begin{array}{ll} \text{min/max} & f_m(\mathbf{x}), \quad m = 1, 2, \dots, M \\ \text{subject to} & g_j(\mathbf{x}) \geq 0, \quad j = 1, 2, \dots, J \\ & h_k(\mathbf{x}) = 0, \quad k = 1, 2, \dots, K \\ & x_i^{(L)} \leq x_i \leq x_i^{(U)}, \quad i = 1, 2, \dots, n \\ & \text{lower} \quad \quad \quad \text{upper} \\ & \text{bound} \quad \quad \quad \text{bound} \end{array}$$

The fundamental difference between single-objective optimization and multi-objective optimization is that in multi-objective optimization problem the desired result is a set of points that describe the best tradeoff between competing objectives rather than a single point representing the extrema of a single objective function.

Pareto optimal solution

In the single-objective optimization problem, the superiority of a solution over other solutions is clearly determined by comparing their objective function values. However, in multiple-objective optimization problem, the goodness of a solution has to be redefined.

For this purpose, the concept of domination is introduced. Suppose there are two solutions x_1 and x_2 . The solution x_1 is said to dominate x_2 (or x_2 is dominated by x_1), if the following two conditions are satisfied,

Dominance test conditions

1. The solution x_1 is no worse than x_2 in all objectives.
2. The solution x_1 is strictly better than x_2 in at least one objective.

As an illustration of the concept of domination, let's consider two-objective optimization problem with f_1 and f_2 . We want to maximize f_1 and minimize f_2 . Assume there are five solutions as in Figure 3.1.

First, compare the solution 1 and the solution 2. The solution 1 is better than the solution 2 for both of the objectives. Hence it is evident that the solution 1 dominates the solution 2.

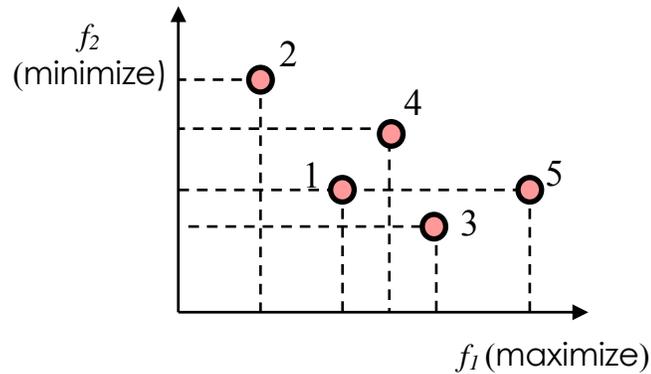


Figure 3.1 Dominance check example

Now look at the solution 1 and solution 5. They have same f_2 values, but solution 5 has bigger f_1 value than solution 1. Thus solution 5 dominates solution 1. As a final example, let's check the dominance between the solution 1 and 4. The solution 4 is better for the first objective function, but the solution 1 is better for the second objective function. As neither solution satisfies the first condition for dominance test, we cannot say that either solution dominates the other.

Given a set of solutions, the **non-dominated solution set** is a set of all the solutions that are not dominated by any members of the solution set.

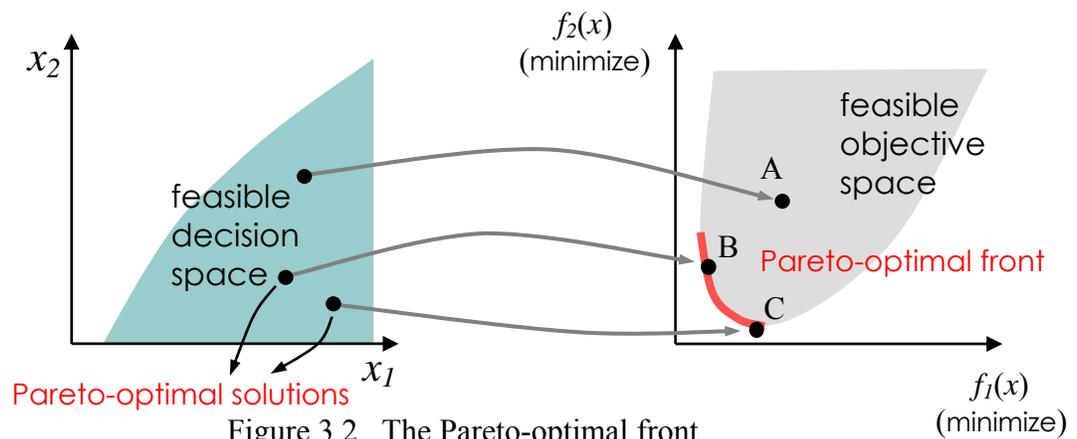


Figure 3.2 The Pareto-optimal front

Each solution in the feasible decision space can be mapped to the feasible objective space. The non-dominated set of the entire feasible search space is called the **Pareto-optimal solution set**. In Figure 3.2, a bold line in the feasible objective space is

called the **Pareto-optimal front** that is the set of all the points mapped from the Pareto optimal solution set. The Pareto-optimal front represents the best possible compromise between conflicting objectives. The Pareto-optimal front is the desired result of the multi-objective optimization.

Diversity control

There are multiple solutions for a given multi-objective optimization problem and any solution in the Pareto optimal solution set can be the best solution. Thus it is required to find not only as many Pareto-optimal solutions as possible, but also as diverse as possible solutions over the Pareto-optimal front.

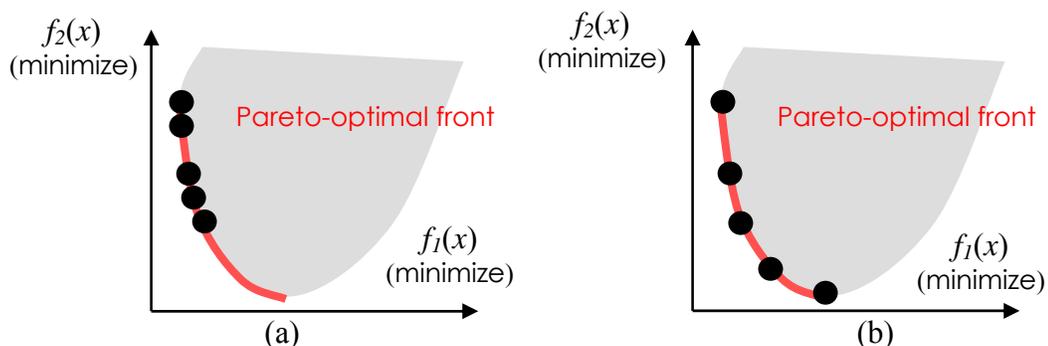


Figure 3.3 Different distributions of solutions

In the Figure 3.3, there are five points in Pareto-optimal front for each case (a) and (b). While the solutions of (a) are concentrated on a specific part of the Pareto-optimal front, those of (b) are evenly distributed over the Pareto-optimal front. There are chances that the most appropriate solution for the given problem exists in the neglected portion of the Pareto-optimal front in case (a). Thus, it is very important to have diverse solutions.

There are several different techniques used to control the diversity of solutions. The interested is referred to [Deb01] or [Car02].

3.2 Genetic algorithms for multi-objective optimization problem

Genetic algorithm utilizes a population of solution candidates. It is possible for the genetic algorithms to find out multiple optimal solutions in one execution. Meanwhile,

a series of executions is required to find out multiple solutions in the classical optimization approaches. Therefore, genetic algorithms are highly suitable for solving multi-objective optimization problems.

Schaffer [Sch84] implemented the first multi-objective genetic algorithm in 1984 to find a set of non-dominated solutions. However, it is not until mid 1990's that the researchers became actively involved in this area.

Several different multi-objective genetic algorithms have been developed over the years. The followings are some of those.

- Vector Evaluated GA (Schaffer, 1984)
- Non-Dominated Sorting GA (Goldberg, 1989)
- Niche-Pareto GA (Horn et al., 1994)
- Vector-optimized ES (Frank Kursawe, 1990)
- Multiple objective GA (Fonseca & Fleming, 1993)
- Weighted-Based GA (Hajela and Lin, 1993)
- Random Weighted GA (Murata & Ishibuchi, 1995)
- Distance-based Pareto GA (Oszczyka & Kundu., 1995)
- Strength Pareto EA (Zitzler & Thiele., 1998)
- Elitist NSGA (NSGA II) (Deb et al., 2000)
- Pareto-archived ES (Knowles & Corne., 2000)
- Rudolph's elitist MOEA (Rudolph, 2001)

Detailed description of these algorithms can be found in Deb [Deb01].

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Chapter 4

GOSET Data Structures and Algorithm Execution

- 4.1 Data structures
- 4.2 Algorithm execution flow
- 4.3 Execution of GOSET

4.1 Data Structures

A large amount of information is involved in the genetic algorithm execution. To facilitate the information in an organized fashion, GOSET categorizes the information into the following three structures:

MATLAB structure name	Contents
P	Population information
GAP	Genetic Algorithm Parameters
GAS	Genetic Algorithm Statistics

Table 4.1 Data structures

We will begin our description of these with population information structure P.

Structure: P

Structure P contains all the information related to the current population. There are 16 fields associated with this structure. Field names and their descriptions are list in the following table.

P.[Field name]	Description
P.fithandle	Handle to the fitness function
P.size	The number of individuals in the population
P.mfit	Unconditioned fitness function values ($P.nobj \times P.size$)
P.fit	Fitness function values ($1 \times P.size$)
P.eval	Fitness evaluation flag ($1 \times P.size$) 0 : fitness is not evaluated 1 : fitness is evaluated
P.age	Age of each individual of the population in generations
P.ngenes	Number of genes in all chromosomes of an individual
P.min	GAP.gd_min
P.max	GAP.gd_max
P.type	GAP.gd_type
P.chrom_id	GAP.gd_cid
P.normgene	Normalized gene values ($P.nobj \times P.size$)

P.gene	Gene values ($P.nobj \times P.size$)
P.region	Geographic region ($1 \times P.size$) of an individual
P.pen	Penalty function ($1 \times P.size$) which is used for diversity control

Table 4.2 Data structure of the population

Structure: GAP

Structure GAP has all the parameters about genetic operations. There are 67 fields associated with GAP. They are listed below with their description and default values

GAP.[Field name]	Description	Default
Fundamental parameters		
GAP.fp_ngen	Number of generations to evolve	100
GAP.fp_ipop	Number of chromosomes in initial population	100
GAP.fp_npop	Number of chromosome in normal population	100
GAP.fp_nobj	Number of objectives	Argument for gapdefault
GAP.fp_obj	Objective to optimize Note: 0 for multi-objective optimization	1: fp_nobj = 1 0: fp_nobj > 1
Diversity control parameters		
GAP.dc_act	Diversity control usage flag 0: non-active 1: active	1
GAP.dc_alg	Diversity control algorithm used in selection	4
GAP.dc_spc	Diversity control space 1: Parameter space (or solution space) 2: Fitness function space	1
GAP.dc_mnt	Minimum threshold for algorithm 1	0.02
GAP.dc_mxt	Maximum threshold for algorithm 1	0.1
GAP.dc_ntr	Number of trials for algorithm 2	3
GAP.dc_mnb	Minimum number of bins relative to population size for algorithm 2	0.5
GAP.dc_mxb	Maximum number of bins relative to population size for algorithm 2	2
GAP.dc_dc	Diversity control distance constant for algorithm 3 and 4	0.001
GAP.dc_nt	Diversity control test population size for algorithm 4	50
Selection algorithm parameters		

GAP.sl_alg	Selection algorithm 1 : Roulette wheel 2 : Tournament 3 : Custom	2
GAP.sl_nts	Number of individuals used in a tournament	4
GAP.sl_cah	Custom algorithm handle	[]
Death algorithm parameters		
GAP.dt_alg	Selection algorithm 1 : Replace parents 2 : Random replacement 3 : Tournament on fitness 4 : Tournament of age 5 : Custom 6 : Random among 1-4	2
GAP.dt_nts	Number of individuals used in a tournament	4
GAP.dt_cah	Custom algorithm handle	[]
Mating and crossover parameters		
GAP.mc_pp	Percentage of population replaced by children	0.6
GAP.mc_fc	Fraction of chromosomes involved in crossover	1
GAP.mc_alg	Crossover algorithm 1 : Single point crossover 2 : Scalar simple blend crossover 3 : Vector simple blend crossover 4 : Scalar simulated binary crossover 5 : Vector simulated binary crossover 6 : Randomly apply above algorithms	4
GAP.mc_gac	Number of generations between changing algorithms for random crossover algorithm.	3
GAP.mc_ec	Tightness of distribution (η_c) for algorithms 4 and 5	2
Mutation parameters		
GAP.mt_ptgm	Probability of a total gene mutation	0.001
GAP.mt_prgm	Probability of a relative partial gene mutation	0.002
GAP.mt_srgm	Standard deviation of relative partial gene perturbation	0.3
GAP.mt_pagm	Probability of a absolute partial gene mutation	0.002
GAP.mt_sagm	Standard deviation of absolute partial gene mutation	0.1
GAP.mt_prvm	Probability of relative vector mutation	0.002
GAP.mt_srvm	Standard deviation of relative vector mutation	0.3
GAP.mt_pavm	Probability of absolute vector mutation	0.002
GAP.mt_savm	Standard deviation of absolute vector mutation	0.1
GAP.mt_pigm	Probability of integer gene mutation	0.008
Migration parameters		
GAP.mg_nreg	Number of geographic regions the population is distributed	1
GAP.mg_tmig	Time between migrations in generations	0

GAP.mg_pmig	Probability of an individual to migrate	0
Evaluation Parameters		
GAP.ev_bev	Block evaluation flag ($1 \times P.size$) 0 : evaluate an individual at a time 1 : evaluate all the individual in a population	0
GAP.ev_are	Fitness reevaluation option 0 : evaluate the unevaluated chromosomes only 1 : always reevaluate	0
GAP.ev_ssd	Supplementary data passing 0 : pass only gene values and optional data if exist 1 : pass also age, region No. and previous fitness value	0
Scaling parameters		
GAP.sc_alg	Scaling algorithm 0 : none 1 : offset so minimum fitness is zero 2 : linear scaling (most fit individual GAP.sc_klin more likely to be selected than average fit) 3 : linear scaling (most fit individual GAP.sc_klin more likely to be selected than median fit) 4 : linear scaling (most fit individual GAP.sc_klin more likely to be selected than least fit) 5 : sigma truncation 6 : quadratic scaling	1
GAP.sc_kln	Scaling factor for linear scaling algorithms	10
GAP.sc_cst	Scaling constant for sigma truncation	2
GAP.sc_kmxq	Maximum scaling factor for quadratic scaling (most fit individual GAP.sc_kmxq more likely to be selected than median fit)	10
GAP.sc_kmnq	Minimum scaling factor for quadratic scaling (least fit individual GAP.sc_kmnq more likely to be selected than median fit)	0.01
Elitism parameters		
GAP.el_act	Elitism activation flag	1
GAP.el_fgs	Fraction of generations to pass before starting elitism	0
GAP.el_fpe	Fraction of population protected as elite state for multi-objective optimization	0.5
Random search parameters		
GAP.rs_fgs	Fraction of generations to pass before starting random search	0.5
GAP.rs_fps	Fraction of total population size used in random search	0.1
GAP.rs_srp	Standard deviation used in relative perturbation	0.3
GAP.rs_sap	Standard deviation used in absolute perturbation	0.1
GAP.rs_frp	Fraction of the time that relative random perturbations are used. Absolute random perturbation is used for the rest of the time.	0.7

GAP.rs_fea	Fraction of generations on which to execute the algorithm	0.2
Reporting parameters		
GAP.rp_lvl	Reporting level -1 : no reporting 0 : text reporting only 1 : plots and text reporting	1
GAP.rp_gbr	Generation between reports	5
GAP.rp_crh	Custom reporting function handle	[]
Objective plot parameters		
GAP.op_list	List of objectives to make objective plots for	[1]
GAP.op_style	Style for each objective 0 : logarithmic 1 : linear	[1 1 ... 1]
GAP.op_sign	Sign of fitness for each objective -1 : negative 1 : positive/mixed	[1 1 ... 1]
Pareto plot parameters		
GAP.pp_list	List of 2 or 3 objectives to be used in Pareto plot	[]
GAP.pp_xl	x-axis label	'Objective 1'
GAP.pp_yl	y-axis label	'Objective 2'
GAP.pp_title	Pareto plot title	'Solution Space'
GAP.pp_style	Style for each objective 0 : logarithmic 1 : linear	[1 1 ... 1]
GAP.pp_sign	Sign of fitness for each objective -1 : negative 1 : positive/mixed	[1 1 ... 1]
GAP.pp_axis	Axis limits for Pareto plot	[]
Distribution plot parameters		
GAP.dp_type	Distribution plot type 1 : plot individuals 2 : plot histograms	2
GAP.dp_np	Maximum no. of individuals to plot for type 1	100
GAP.dp_res	Number of bins in distribution plot for type 2	20
Gene definition parameters		
GAP.gd_min	Minimum value of gene ($P.ngenes \times 1$)	These fields must be defined by the user
GAP.gd_max	Maximum value of gene ($P.ngenes \times 1$)	
GAP.gd_type	Types of genes ($P.ngenes \times 1$) 1 : integer 2 : linear 3 : logarithmic	
GAP.gd_cid	Chromosome ID of gene ($P.ngenes \times 1$) Used for multiple chromosome case	

Table 4.3 Data structure of GAP

Default values for GAP are defined in `gapdefault.m`. Thus the user can load the `gapdefault` and then redefine only the required fields, instead of defining all the fields. In the multi-objective optimization problems, default values for GAP can be initialized by using the number of objectives as the argument of GAP. For example, if there are 4 objectives, using `gapdefault(4)` returns the appropriate GAP.

Structure: GAS

The best fitness values, median fitness values, average fitness values, and best chromosomes over the generations are stored in GAS. Current generation number and the number of total objective function evaluations are also stored.

GAS.[Field name]	Description
<code>GAS.cg</code>	Current generation number
<code>GAS.medianfit</code>	The median fitness values of each objective (No. of objectives × No. of generations)
<code>GAS.meanfit</code>	The average fitness values of each objective (No. of objectives × No. of generations)
<code>GAS.bestfit</code>	The best fitness values of each objective (No. of objectives × No. of generations)
<code>GAS.bestgenes</code>	The best gene values for each objective over the generations (No. of genes × No. of generations × No. of objectives)
<code>GAS.ne</code>	The number of the total objective function evaluations

Table 4.4 Data structure of GAS

4.2 Algorithm Execution flow

The algorithm execution flow of GOSET is depicted in Figure 4.1. Together with the short description of each step, the related GOSET function names are listed.

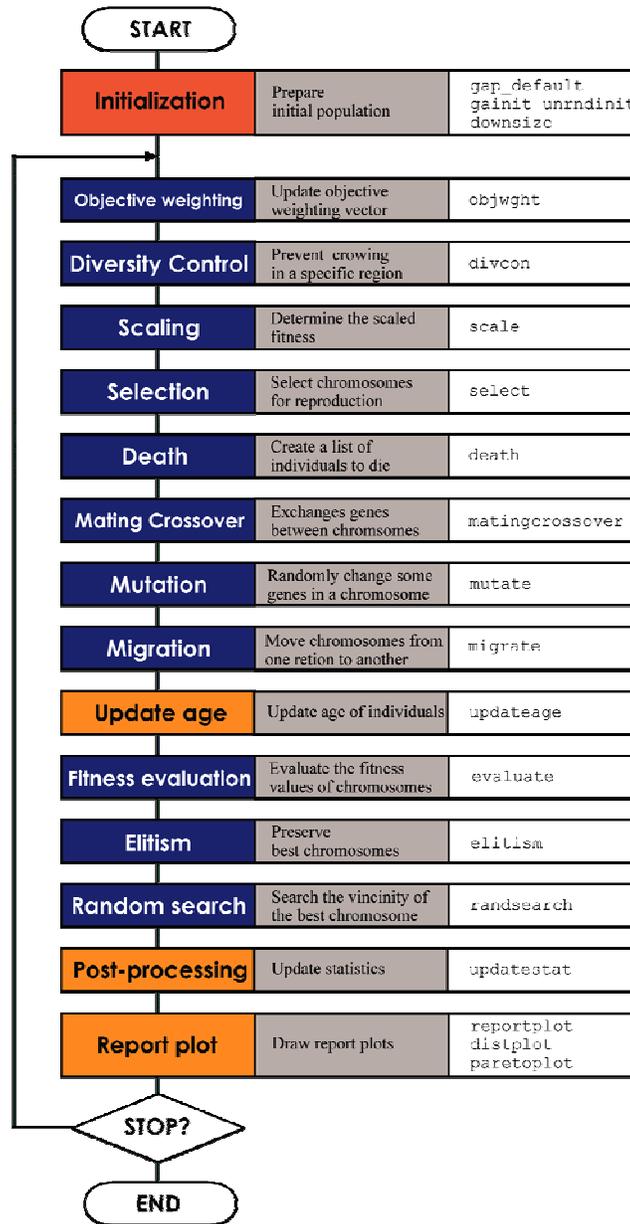


Figure 4.1 Algorithm execution of GOSSET

Initialization

In this step, the initial population is randomly generated and data structures P , GAP , and GAS are initialized. When the population does not exist, the initial population of size $GAP.ipop$ is randomly generated. Then the fitness value for each individual is evaluated. The other data structures are also initialized accordingly. If the steady-state

population size `GAP.npop` is smaller than the initial population size `GAP.ipop`, then the population size is reduced to `GAP.npop` by discarding inferior chromosomes.

Genetic operators

Various genetic operators act on the current population to generate new population. The detailed descriptions on these operators are in Chapter 5.

Post-processing

Once the new population has been generated, the best fitness value, the average fitness value, and the gene values of the best individual are stored in the data structure `GAS`.

Report plot

At the completion of the genetic operations, GOSET reports the information on the new population in the gene distribution plot and/or the Pareto plot. In the gene distribution plot, the normalized gene values of the individuals are plotted and also the best fitness value, the average fitness value, the average fitness value, and the worst fitness value over the generations are plotted. In the Pareto plot, the population is plotted in objective function space.

4.3 Execution of GOSET

When using GOSET from a MATLAB script, GOSET is initiated by `gaoptimize.m` that has the following syntax.

```
[fP,GAS]=gaoptimize(objhandle,GAP,D,GAS,iP,GUIhdl)
```

There are 12 arguments for `gaoptimize.m` which needs to be defined before executing GOSET.

objhandle `objhandle` is the handle of the m-file for the fitness function.

GAP	GAP is the structure of genetic algorithm parameters.
D	D is the optional data for the fitness function.
GAS	GAS is the structure of genetic algorithm statistics. If this does not yet exist, pass an empty matrix '[]'
iP	iP is the initial population (a structure). If not used, pass an empty matrix '[]'
GUIhdl	GUIhdl is the handle used for GUI. When GUI is not used, pass an empty matrix '[]'.

The outputs of `gaoptimize.m` are `Pout` and `GAS`.

fP	fP is the final population (a structure).
GAS	GAS is the structure of genetic algorithm statistics.

The source code for `gaoptimize.m` is given in Figure 4.2. It is easy to verify that `gaoptimize.m` follows the algorithm execution flow given in Figure 4.1. As the `gaoptimize.m` has a simple modularized structure, it can be modified easily so that the users can experiment with their own routine.

```

function [fP,GAS]= gaoptimize(objhandle,GAP,D,GAS,iP,GUIhdl)

global simflag
simflag = 1;

% initialization
[GAP,GAS,P] = gainit(nargin,objhandle,D,GAP,GAS,iP,GUIhdl);
initgen = GAS.cg;

% let the population evolve
for j=initgen:GAP.fp_ngen,

    GAS.cg = j; % Update current population number

    GAP.owv = objwght(GAP); % Objective Weighting Vector
    P.pen = divcon(P,GAP); % Diversity Control
    P.fit = scale(P,GAP); % Determine the Scaled Fitness
    [P_list,PL_size] = select(P,GAP); % Select Mating Pool / Parent List
    D_list = death(P,P_list,GAP); % Select Individuals to Die
    P2 = matingcrossover(P, ... % Mating and Crossover
        P_list,PL_size,D_list,GAP,GAS);
    P3 = mutate(P2,GAP); % Mutation
    P4 = migrate(P3,GAP,GAS.cg); % Migration
    P4.age = updateage(P4); % Update age
    [P4.mfit,P4.eval,GAS.ne(j)] = evaluate(P4,GAP,GAS.ne(j-1),D); % Evaluate
    P5 = elitism(P4,P,GAP,GAS); % Elitism
    [P,GAS] = randsearch(P5,GAP,GAS,D); % Random Search
    [GAS] = updatestat(GAP,GAS,P); % Update statistics
    reportplot(GAP,GAS,P,GUIhdl); % Update report plot

    if simflag == 0 break; end % STOP flag check
end

fP = P; % Final population

```

Figure 4.2 gaoptimize.m

For the detailed description about running GOSET, refer to Chapter 7 that contains step-by-step illustrations of using GOSET in the command line mode and the GUI mode for several different optimization problems.

Chapter 5

GOSET genetic operators

In this section, the genetic operators used in GOSET are explained in detail.

- 5.1 Objective Weighting
- 5.2 Diversity control
- 5.3 Scaling
- 5.4 Selection
- 5.5 Death
- 5.6 Mating and crossover
- 5.7 Mutation
- 5.8 Migration
- 5.9 Fitness evaluation
- 5.10 Elitism
- 5.11 Random search

5.1 Objective weighting

In the multi-objective optimization problem, there are more than one fitness values for each individual. `objwght.m` randomly generates a normalized weighting vector to be used for scalarization of the objective function values.

In the multi-objective optimization problem (`P.nobj > 1`), it is possible to use only one objective function value for fitness evaluation. If the objective function number to be used is specified in `GAP.fp_obj`, then the output weight vector `owv` has all zero values except for the element corresponding to the objective function specified by `GAP.fp_obj`.

5.2 Diversity control

Four different diversity control algorithms are available to maintain the diversity of the solutions in GOSET. These routines generate a fitness weight value for each individual. These fitness weight values constitute the fitness penalty vector (`P.pen`) that is used for determining an aggregated fitness `P.fit` in the scaling process. Individuals with many other individuals close to them are assigned a small fitness weight value (thereby reducing the effective fitness) and those with small number of neighboring individuals are assigned with fitness weight value near unity (thus, penalizing the fitness less).

The diversity control can be applied to either the parameter (or decision) space or the fitness function (or objective) space. For the diversity control in the parameter space, use `GAP.dc_spc = 1` and `GAP.dc_spc = 2` is for the diversity control in the fitness function space.

a. Diversity control algorithm 1 (`GAP.dc_alg = 1`)

In this approach, the number of neighboring individuals of each individual is counted. The neighboring individuals are those within the threshold distance which is determined as

$$\text{Threshold distance} = (\text{mean distance between points}) \times \alpha ,$$

where $\alpha = (\text{GAP.dc_mnt} + \text{rand} \times (\text{GAP.dc_mxt} - \text{GAP.dc_mnt}))$.

Then the fitness weight of an individual is the reciprocal of the counted number of individuals. Figure 5.1 illustrates this method with three examples.

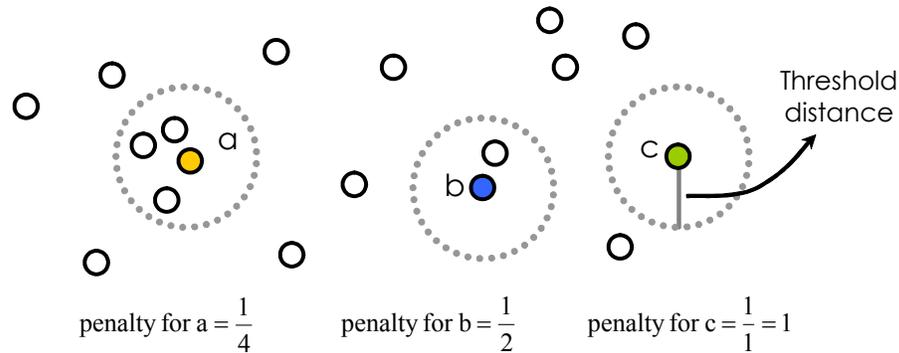


Figure 5.1 Illustration of diversity control method 1 in 2D space.

While very systematic, one major drawback of this approach is the necessity of evaluating the distance between all the individuals which requires a computation time proportional to the square of the population.

b. Diversity control algorithm 2 (`GAP.dc_alg = 2`)

This approach is based on the idea that individuals with similar gene values have similar weighted sum of their gene values for any weight vector. In this method, first an integer weight vector is generated at random, where the element value come from the integer set $\{1, 2, \dots, P.ngenes\}$. Then the weighted sum of the normalized genes for each individual is evaluated. Individuals with similar weighted sum values are grouped and put into bins based on the weighted sum. The total number of bins are randomly chosen from $\{(GAP.dc_mnb \times GAP.fp_npop), \dots, (GAP.dc_mxb \times GAP.fp_npop)\}$. For the individuals in a specific bin, their fitness penalty weights become the reciprocal of the number of individuals in that bin.

Since it is possible that two individuals with drastically different gene values have similar weighted sum for some weight vector, this procedure is repeated `GAP.dc_ntr` times and the largest fitness penalty weight is chosen as the final fitness penalty weight for each individual. This reduces the chance of assigning an individual a smaller fitness penalty weight than appropriate.

Figure 5.2 shows an illustration of the diversity control algorithm mentioned above. For example, if we look at the bin No. 1, there are two individuals. So the penalty value for the individuals in bin No. 1 is $\frac{1}{2}$, and likewise, the penalty value of the individual in bin No. 5 is $\frac{1}{4}$.

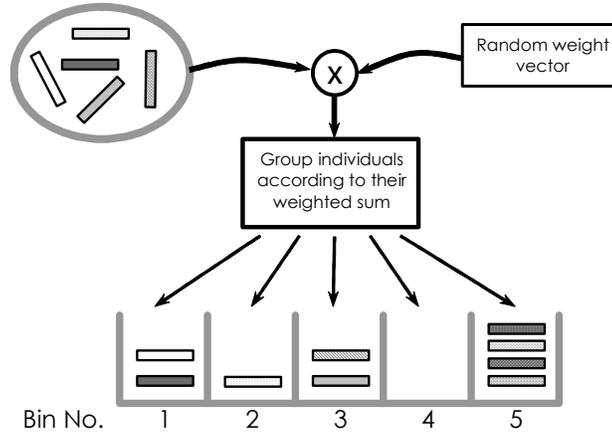


Figure 5.2 Illustration of diversity control method 2.

Although this approach is not as systematic as the first approach, the computation time is proportional to the population size, not the square of the size.

c. Diversity control algorithm 3 (GAP.dc_alg = 3)

The idea of this diversity control algorithm is similar to the diversity algorithm 1. Instead of using the count of solutions in a neighborhood, the sum of infinity norm between a solution and all the other solutions is used to determine the penalty value. The fitness penalty weight for k 'th individual is express as

$$P_{pen}^k = \frac{1}{\sum_{i=1} \exp\left(-\frac{d_{i,k}}{d_c}\right)},$$

where $d_{i,k}$ is the infinity norm between k 'th and i 'th individual, that is, the maximum absolute gene difference between k 'th and i 'th individual and d_c is the distance constant (GAP.dc_dc) which controls the size of the neighborhood. If a small d_c is used, then the effective size of the neighborhood is also small. Thus only the solutions with many neighboring solutions that are very close to them are penalized severely and most of other solutions are not penalized. As the d_c increases, the effective size of the neighborhood increases and the penalty level also increases.

The fitness penalty weight in the algorithm 3 can take continuous value rather than discrete value as in the algorithm 1. As with the algorithm 1, the distance evaluation

between all the individuals requires a computation time proportional to the square of the population.

d. Diversity control algorithm 4 ($GAP.dc_alg = 4$)

This approach is identical to the diversity control algorithm 3. However, only $GAP.dc_nt$ individuals among the population are randomly selected for the distance evaluation. The random selection of the individuals is performed for each different individual. This reduces the computational load at the cost of some inaccuracy in the distance measurement. The fitness penalty weight for k 'th individual is express as

$$P_{pen}^k = \frac{1}{1 + \frac{\text{Number of population in the region}}{GAP.dc_nt} \sum_{i=1}^{GAP.dc_nt} \exp\left(-\frac{d_{i,k}}{d_c}\right)},$$

where $d_{i,k}$ is the infinity norm between k 'th and i 'th individual, d_c is the distance constant ($GAP.dc_dc$)

5.3 Scaling

In the early stage of the evolution, if there are few individuals with very large fitness values, then these strong individuals will dominate the entire population very quickly which can lead to convergence to some local optimum without thorough exploration of the search space. This is called as premature convergence. Towards the end of the evolution, when the population is almost converged with most of the individuals sharing similar fitness values, then the competition among individuals is weak and the evolution process slows down. As a remedy to both these problems, scaling can be employed to maintain the appropriate evolution pressure throughout the evolution process. Scaling is also useful in the multi-objective optimization problems that have different scales in the objective functions.

As the first step in the scaling operation, the fitness values are scaled using one of the six scaling methods. After scaling, all negative fitness values are clipped to zero, and then the objective function weight vector ($GAP.ovw$) is applied to scalarize the fitness values ($P.mfit$) in the multi-objective optimization. Finally, the penalty vector ($P.pen$) is applied and the scalarized the fitness values are penalized to yield the aggregated fitness values ($P.fit$) that are used in the selection operation.

Several different scaling methods are available in GOSET. Options include no-scaling, offset scaling, standard linear scaling, modified linear scaling, mapped linear scaling, sigma truncation, and quadratic scaling. These methods are described below.

a. No scaling (`GAP.sc_alg = 0`)

Scaling is not applied and the actual fitness value is used as shown in Figure 5.3. This option is primarily intended for fitness functions that have been carefully constructed so that no scaling is necessary.

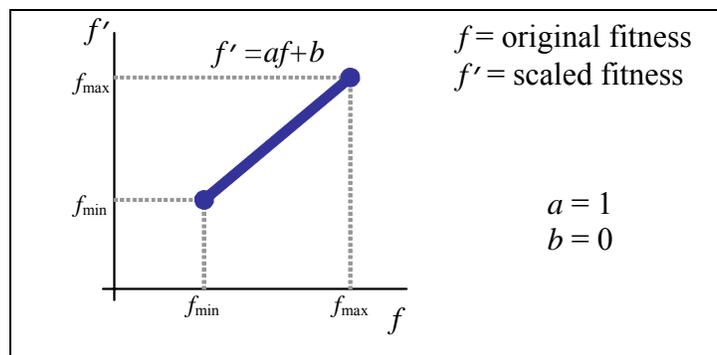


Figure 5.3 No scaling

b. Offset scaling (`GAP.sc_alg = 1`)

In this method, fitness values are mapped linearly such that the minimum fitness value is mapped to 0 and the maximum value is mapped to $f_{\max} - f_{\min}$.

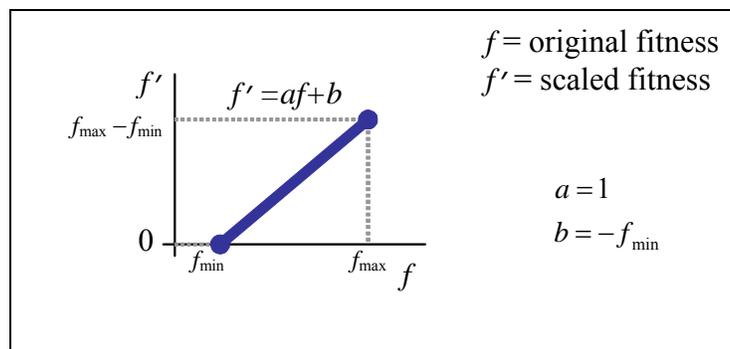


Figure 5.4 Offset scaling

c. Standard linear scaling ($GAP.sc_alg = 2$)

In this method, a linear scaling is used in such a way that the average fitness is not modified and the maximum fitness is $GAP.sc_kln$ times the average fitness value.

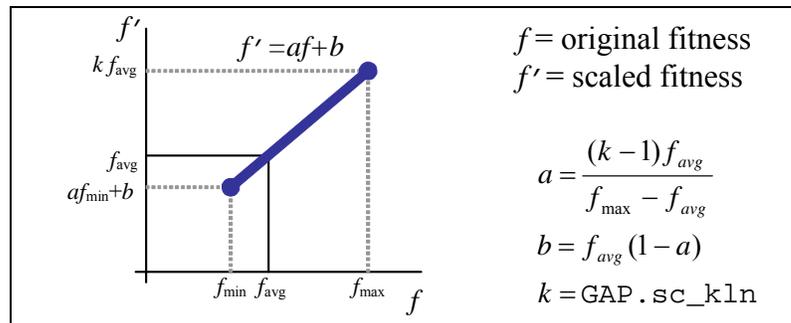


Figure 5.5 Standard linear scaling

d. Modified linear scaling ($GAP.sc_alg = 3$)

In this method, a linear scaling is applied in such a way that the median fitness is not modified and the maximum fitness is $GAP.sc_kln$ times the median fitness value.

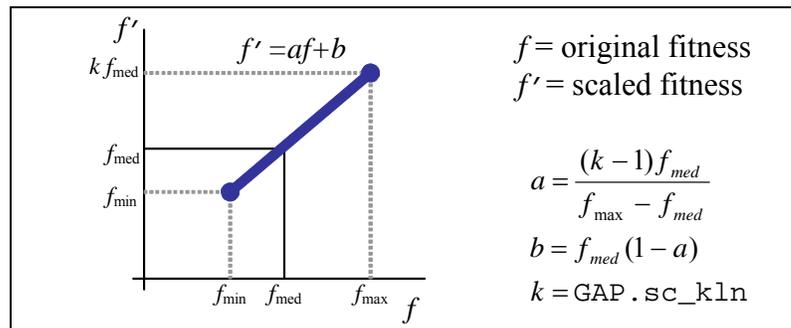


Figure 5.6 Modified scaling

e. Mapped linear scaling ($GAP.sc_alg = 4$)

This method is another linear scaling that maps the maximum fitness to $GAP.sc_kln$ and the minimum fitness to 1.

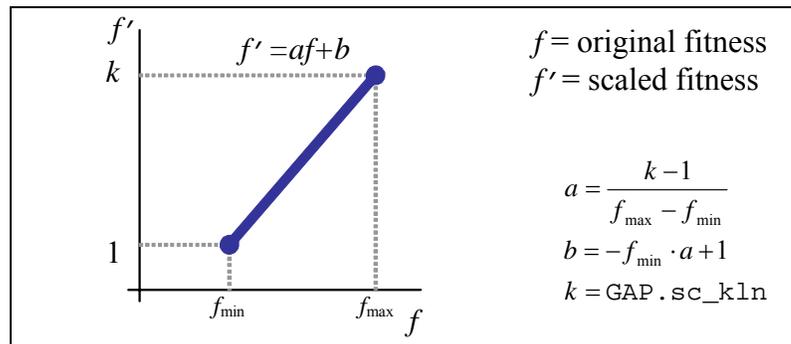


Figure 5.7 Mapped linear scaling

f. **Sigma truncation** (`GAP.sc_alg = 5`)

In the sigma truncation method, all the fitness values smaller than $(f_{\text{avg}} + \text{GAP.sc_cst} \times f_{\text{std}})$, where f_{avg} is the average fitness value and the f_{std} is the standard deviation of the fitness values, are mapped to negative values and therefore disregarded later by clipping to zeros. It is useful when there are a few individuals with very small fitness value and most individuals have large fitness values.

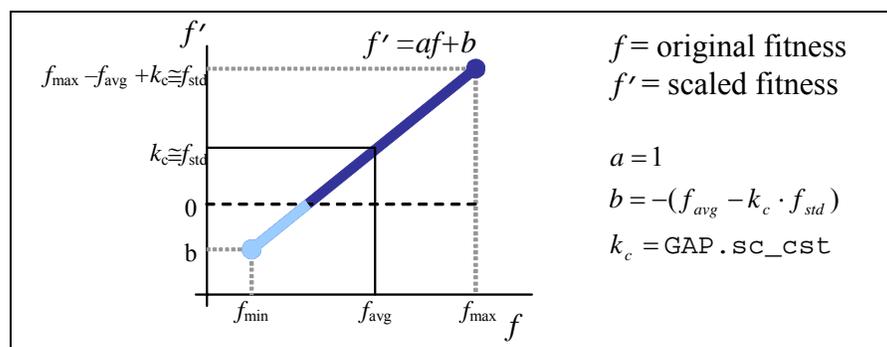


Figure 5.8 Sigma truncation scaling

g. **Quadratic scaling** (`GAP.sc_alg = 6`)

This algorithm emphasizes the large fitness value and deemphasizes the small fitness value. The maximum fitness value is mapped to `GAP.sc_kmxq`, the average fitness value to 1, and the minimum fitness value to `GAP.sc_kmnq`. The quadratic scaling is the only nonlinear scaling method in GOSET.

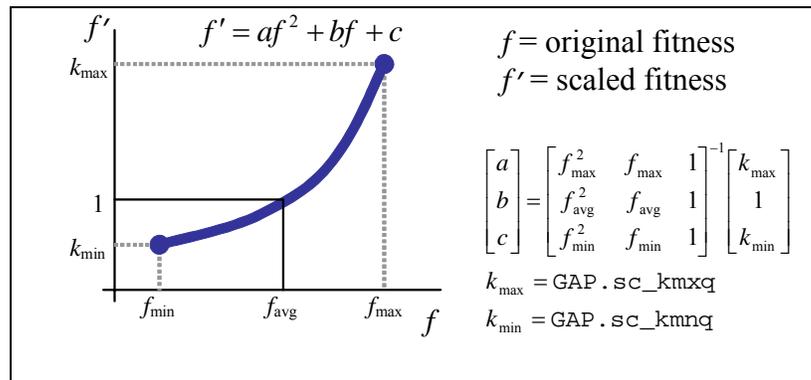


Figure 5.9 Quadratic scaling

5.4 Selection

The selection operators choose individuals from the population to constitute a mating pool for reproduction. When the multiple regions are used, selection operations are confined to each region. For each region, the selection operator picks same number of chromosomes as those in the current region and moves them to the mating pool for that region.

There are two pre-defined selection operators that the user can choose from. They are roulette wheel selection and tournament selection.

a. Roulette wheel selection

Each individual is assigned with the selection probability that is proportional to the aggregate fitness value ($P.f\text{it}$). Then individuals are chosen based on the selection probability. It is more likely that the better individual is chosen and copied to the mating pool which mimics principle of the survival of the fittest.

b. Tournament selection

$\text{GAP} . \text{sl_nts}$ number of individuals are randomly chosen from the population and their aggregate fitness values ($P.f\text{it}$) are compared. Then the individual with the best fitness value is selected to be in the mating pool.

Illustrations of these selection operators are in the section 2.2.

Custom algorithm

In the case that the user wants to use his/her own selection algorithm, the custom algorithm handle `GAP.sl_cah` can be defined as long as the algorithm follows certain format. The details regarding the custom algorithm can be found in the Appendix B.

5.5 Death

Death operator determines which individual is to die and replaced by the children. The followings are possible options for the death operators.

a. Replacing parents

Parents are replaced by their own children.

b. Random selection

The parents to be replaced are randomly chosen.

c. Tournament on fitness

The parent to be replaces is determined via the tournament based on the aggregate fitness value. `GAP.dt_nts` number of parents are randomly chosen for a tournament and the one with worst aggregate fitness value is marked for death.

d. Tournament on age

The parent to be replaces is determined via the tournament based on the age. Among the randomly chosen `GAP.dt_nts` number of parents, the oldest one is marked for death.

e. Custom algorithm

User defined custom death algorithm is used. The custom function handle is assigned to `GAP.dt_cah`. Refer to the Appendix B for the details on the format of the custom algorithm.

f. Random algorithm

If this option is selected, the death algorithm is randomly chosen among the first four death algorithms at each generation.

5.6 Mating and crossover

There are three different crossover operators in GOSET. All the crossover operation is performed on the normalized gene values and the actual gene values are updated based on the crossovered normalized gene values.

These crossover operations have correction routine for illegal genes. That is, if a gene value lies outside of the allowed range $[0, 1]$ after the crossover operation, that gene value is automatically fixed using the *ring-mapping*. Ring-mapping maps a value to the modulus after division by 1. For example, if a resultant gene value is 1.2, it is adjusted to 0.2, and if it is -2.1, it is adjusted to 0.9.

a. Single point crossover

This crossover operator is similar to the crossover operator in binary-coded GAs. In multiple chromosome setting, single point crossover occurs in each chromosome. The following example shows a single point crossover operation on individuals with two chromosomes.



Figure 5.10 Single point crossover with two chromosomes

b. Simple blend crossover

In the simple blend crossover, the children are generated from the weighted sum of their parents. It is implemented so that the gene values of the two children have same distance from the average value of the gene values of the parents. Figure 5.11 illustrates how simple blend crossover works. Filled circles represent the gene values of parents positioned at p and q respectively, and white circles represent those of children. The gene values of children can take any values between $(3p-q)/2$ and $(3q-p)/2$ and they are equally distanced from the center of p and q .

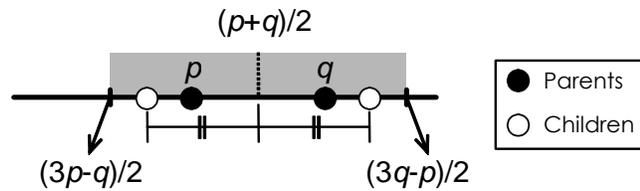


Figure 5.11

Depending on whether the each gene value in a chromosome is blended using same ratio or each gene value is blended independently, there are scalar simple blend crossover and vector simple blend crossover.

Scalar simple blend crossover

In the scalar simple blend crossover operation, each gene position has different ratio of blending. For example, two parents

$$\text{Parent 1} = [0 \quad 0.8 \quad 0.3] \text{ and Parent 2} = [1 \quad 0.2 \quad 0.5]$$

can generate

$$\text{Child 1} = [0.25 \quad 0.95 \quad 0.4] \text{ and Child 2} = [0.75 \quad 0.05 \quad 0.4]$$

via scalar simple blend crossover. The first gene values moved 25% of their distance towards the average value of them. The second gene, -25%. And the third gene, 50%.

Vector simple blend crossover

In the vector simple blend crossover operation, all the genes are blended using same ratio. For example, two parents

$$\text{Parent 1} = [0 \quad 0.8 \quad 0.3] \text{ and Parent 2} = [1 \quad 0.2 \quad 0.5]$$

can generate

$$\text{Child 1} = [0.25 \quad 0.65 \quad 0.35] \text{ and Child 2} = [0.75 \quad 0.35 \quad 0.45]$$

For all three genes, the parent gene values are blended in such a way that they moved 25% of the distance between them towards their average values.

c. Simulated binary crossover

As the name suggests, the simulated binary crossover operator mimics the behavior of the single-point crossover operator in binary-coded genetic algorithm. Detailed description of the simulated binary crossover operator is beyond the scope of this manual and only the basic concepts are introduced here. Interested readers are referred to [p109, Deb01]

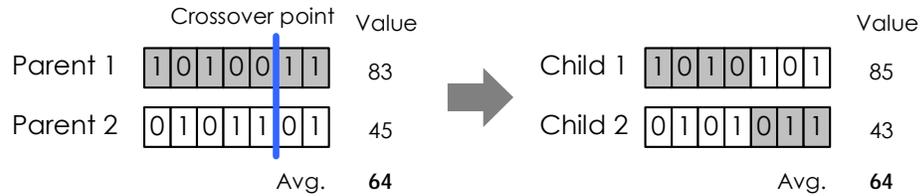


Figure 5.12 Single point crossover example

Figure 5.12 illustrates an example of the single point crossover operation on the binary chromosomes. Note that the average values are same before and after the crossover operation. Hence, the amount of increase in one chromosome is same as the decrease in another chromosome and the children are equally distanced from the center point of the parents.

Each point of the chromosome has the same probability to be selected as a crossover point. And the crossover in the lower bit results in children closer to the parents point. Thus the values of children are more like to be near the values of parents. With these investigations, the single point crossover can be simulated in real-coded genetic algorithms by using the probability density for the children as in Figure 5.13.

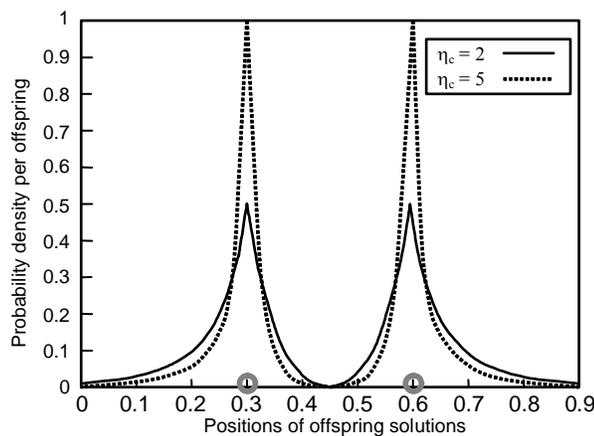


Figure 5.13 Simulated binary crossover

In Figure 5.13, it is assumed that the parents are positioned at 0.3 and 0.6. The distribution index η_c is a non-negative real number that controls the spread of the

children. If the distribution index η_c is large, the probability of generating children that are closer to the parents are higher. As the distribution index η_c becomes smaller, it is allowed to create solutions that are far from the parents.

As in the simple blend crossover, there are *scalar simulated binary crossover* and *vector simulated binary crossover* depending on whether the each gene value is crossed over using same ratio or each gene value is crossed over independently.

d. Random crossover

When `GAP.mc_alg` is set to 6, GOSET chooses a mating crossover algorithm randomly among the five methods described above. They are

- Single point crossover
- Scalar simple blend crossover
- Vector simple blend crossover
- Scalar simulated binary crossover
- Vector simulated binary crossover.

For every `GAP.mc_gac` generation, the crossover algorithm changes randomly.

5.7 Mutation

The mutation operators of GOSET can be categorized into three types as described in this section. All the mutation operations are applied to the normalized gene value and the actual gene values are updated based on the mutated normalized gene values.

a. Total mutation

With the probability of `GAP.mt_ptgm`, each gene value can be replaced by a new randomly generated gene value within the prescribed range that is defined by `P.max` and `P.min`. For the integer type gene, the gene value takes any integer value within the allowed range.

In the following figure, let us assume that the real-typed third gene is mutated. As the mutation is applied to the normalized gene values, each gene has a value between 0 and 1.

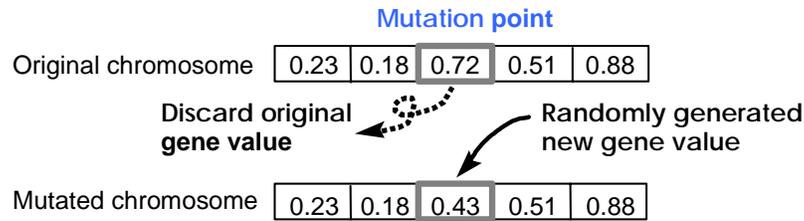


Figure 5.14 Total mutation

b. Partial mutation

Two types of partial mutations are employed. They are the relative partial mutation and the absolute partial mutation. Integer genes are not involved in the partial mutations.

These mutation operations have correction routine for illegal genes. That is, if the mutated gene value lies outside of the allowed range, i.e. $[0, 1]$, the mutated gene value is automatically ring-mapped. Ring-mapping maps a value to the modulus after division by 1. For example, if the resultant gene value is 1.7, it is adjusted to 0.7, and if it is -0.6, it is adjusted to 0.4.

Relative partial mutation

With the probability of `GAP.mt_prgm`, each gene value is perturbed by certain fraction of the current gene value. The amount of perturbation is obtained using a Gaussian random variable with standard deviation of σ_{rgm} (`GAP.mt_srgm`).

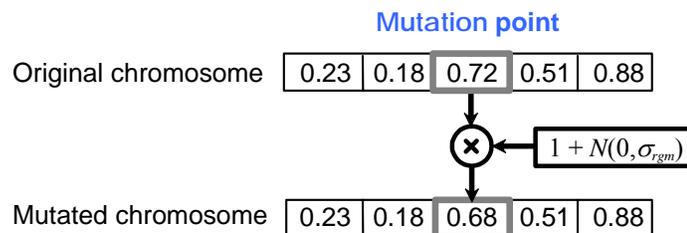


Figure 5.15 Relative partial mutation

The figure 5.15 illustrates a relative partial mutation on the third gene, when the Gaussian random variable $N(0, \sigma_{rgm})$ has a value -0.055.

Absolute partial mutation

With the probability of `GAP.mt_pagm`, each gene value is added with a Gaussian random variable with zero mean and standard deviation of $\sigma_{agm}(\text{GAP.mt_sagm})$.

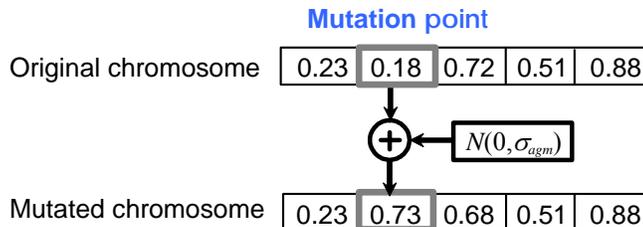


Figure 5.16 Absolute partial mutation

The figure 5.16 illustrates a relative partial mutation on the third gene, when the Gaussian random variable $N(0, \sigma_{agm})$ has a value 0.55.

c. Vector mutation

Vector mutation is very similar to the partial mutation. However, the vector mutation changes the each and every gene of the individual undergoing mutation. Integer genes do not participate in the vector mutations.

These mutation operations also have ring-map correction routine for illegal genes as in the partial mutation.

Relative vector mutation

Each individual undergoes relative vector mutation with the probability of `GAP.mt_prvm`. Every gene value of the individual is perturbed by certain fraction of the current gene value. The amount of perturbation is obtained using

$$\text{Random vector} = v_{dir} \cdot N(0, \sigma_{rvm})$$

where v_{dir} is a normalized random vector ($P_{genes} \times 1$) specifying the direction of perturbation and $N(0, \sigma_{rvm})$ is a Gaussian random variable with mean 0 and standard deviation `GAP.mt_srvm`.

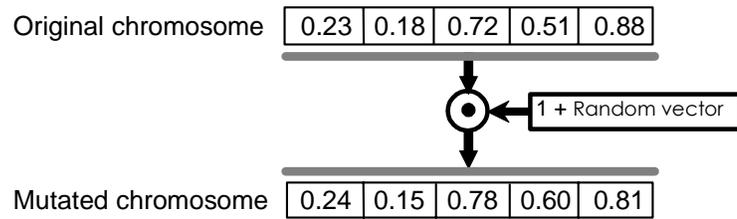


Figure 5.17 Relative vector mutation

The figure 5.17 illustrates a relative vector mutation when the random vector is given as

$$[0.03 \quad -0.15 \quad -0.08 \quad 0.18 \quad -0.08].$$

Absolute vector mutation

Each individual undergoes absolute vector mutation with the probability of $GAP.mt_pavm$. If an individual mutates, each and every gene value of the individual is added with a random vector

$$\text{Random vector} = v_{dir} \cdot N(0, GAP.mt_savm),$$

where v_{dir} is a normalized random vector ($P_{genes} \times 1$) specifying the direction of perturbation and $N(0, \sigma_{avm})$ is a Gaussian random variable with mean 0 and standard deviation $GAP.mt_savm$.

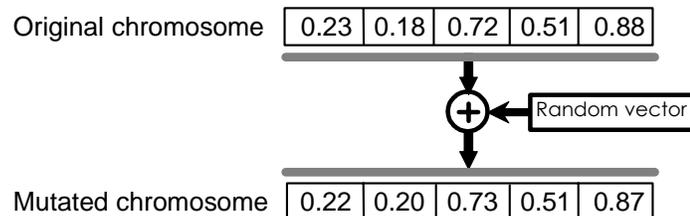


Figure 5.18 Absolute vector mutation

The figure 5.18 illustrates an absolute vector mutation with the random vector

$$[-0.01 \quad 0.02 \quad 0.01 \quad 0.0 \quad -0.01].$$

d. Integer mutation

Integer mutation is applied only to integer genes. Each gene is mutated to a randomly generated integer within the allowed range with the probability of $GAP.mt_igm$.

5.8 Migration

Migration is meaningful only when there are multiple regions defined, that is, $GAP.mg_nreg > 1$. This operator selects some individuals in the population and moves them to different regions. Each individual is migrated with the probability of $GAP.mg_pmig$. The parameter $GAP.mg_tmig$ determines the frequency of applying the migration operator and the migration interval is randomly chosen between $0.5 \times GAP.mg_tmig$ and $1.5 \times GAP.mg_tmig$. For example, if $GAP.mg_tmig$ is set to 4, then the possible migration intervals are 2, 3, 4, 5, and 6 generations.

5.9 Fitness evaluation

In this step, the fitness values of all individuals are evaluated. $GAP.ev_bev$ determines whether to evaluate the fitness of an individual at a time ($GAP.ev_bev = 0$) or to evaluate the fitness of the entire population at once ($GAP.ev_bev = 1$).

When an individual is moved from the previous generation without any change, the fitness value of the individual does not change and there is no need to evaluate the fitness again. In this case, GOSET can evaluate only the unevaluated individuals by setting $GAP.ev_are = 0$. Setting $GAP.ev_are = 1$ will force GOSET evaluate all individuals.

Evaluation of the fitness usually requires only the gene values of the individual ($P.gene$). If the optional data D is specified for the `gaoptimize` function call, then the optional data is also passed to the fitness function. On top of this, other information like age ($P.age$), previous fitness function values ($P.mfit$), and region ($P.region$) can be send to the fitness function by setting $GAP.ev_ssd = 1$. The order of the information passed to the fitness function is $P.gene$, $P.age$, $P.mfit$, $P.region$, and D .

There are many different ways to define a valid fitness function for a given optimization problem. One fundamental rule is that the better gene should have more positive fitness function value than those of inferior genes.

As an example, let's look at the minimization problem of Powell function. The Powell function [CHO96] is described as

$$f(x_1, x_2, x_3, x_4) = (x_1 + 10x_2)^2 + 5(x_3 - x_4)^2 + (x_2 - 2x_3)^4 + 10(x_1 - x_4)^4.$$

It is the minimization problem and the smaller function value is better. Hence, we can simply take the negative of $f(\mathbf{x})$ as the fitness function. The following is the fitness evaluation routine in m-file for the problem of minimizing Powell function with $-f(\mathbf{x})$ as the fitness function.

```
function fv = powell(x)
x1 = x(1);
x2 = x(2);
x3 = x(3);
x4 = x(4);

f = (x1 + 10*x2)^2 + 5*(x3 - x4)^2 + (x2 - 2*x3)^4 + 10*(x1-x4)^4;
fv = -f;
```

The Powell function always takes the nonnegative value, and thus the inverse of $f(\mathbf{x})$ can be another valid fitness function. A small positive value is added to the denominator to avoid the possible singularity at the optimum point. In this case, the last line of above m-file is replaced by the following line.

```
fv = 1/(0.001+f);
```

5.10 Elitism

Elitism is a device to insure that the fittest individual in a population is preserved unless a better fit individual is found.

Single-objective optimization case

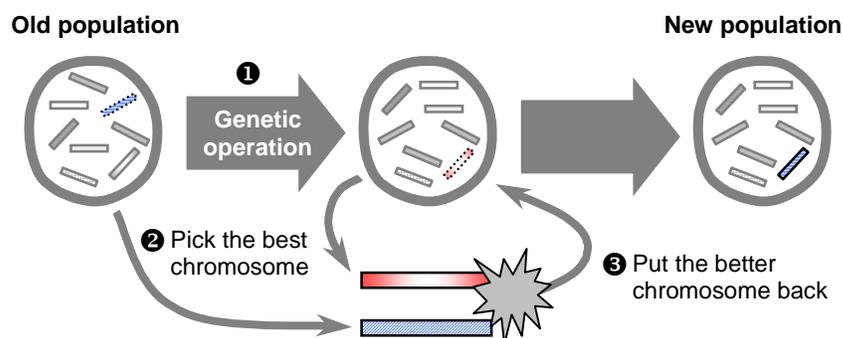


Figure 5.19 Elitism for the single-objective optimization

Elitism in the single objective optimization is straightforward. The best individual of the population P_k and the best individual of the population after the genetic operations performed are compared. The better of the two becomes a member of the next population. As this operation is confined within a region, the best one of each region is preserved for the multi-region case.

Even in the multi-objective optimization case, there are cases that it is desirable to use only one specific fitness function value for elitism. This can be done by setting `GAP.fp_obj` to the number indicating a specific objective function. The elitism, then, performs in the same way as with the single-objective optimization using only one objective function value.

Multi-objective optimization case

In the multi-objective optimization case, the objective of elitism is to preserve non-dominated solutions. Thus, it is necessary to retain multiple individuals.

First, the old population and the modified population in the same region are combined, and the non-dominating solutions are found.

As the number of non-dominated solution can increase, the number of non-dominated solutions is limited to

$$\text{Maximum No. of non-dominated solutions} = \text{GAP.e1}_{fpe} \times (\text{No. of individuals in the region}).$$

If the reserved space for the non-dominating solutions is enough for the non-dominating solutions just found, then some individuals corresponding to dominated solutions are randomly removed from the population and replaced by non-dominated solutions. If the reserved space cannot accommodate all the non-dominated solutions, then the appropriate number of non-dominated solutions are chosen using a diversity control algorithm and placed in the population for the next generation.

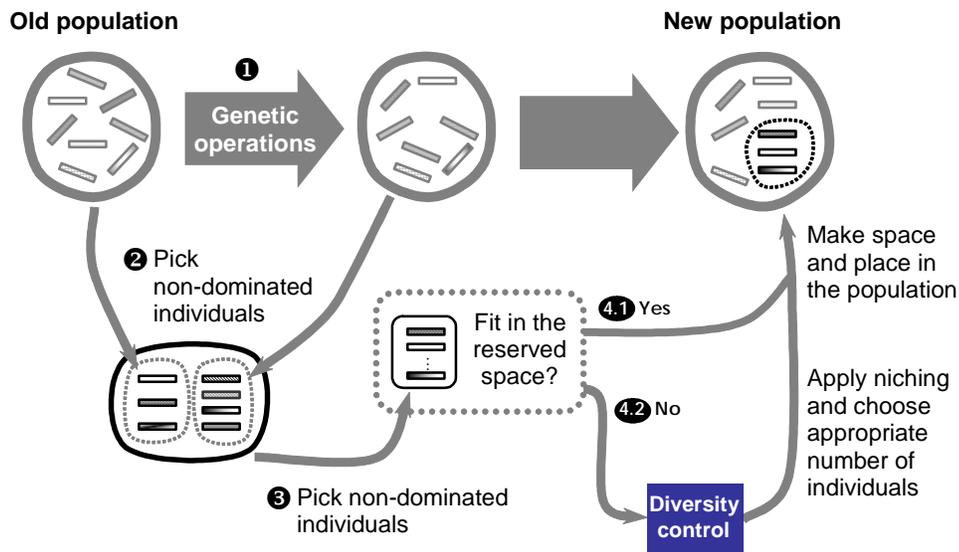


Figure 5.20 Elitism for the multi-objective optimization

5.11 Random search

Random search operator is specialized for a local search. It can reduce the convergence time significantly near the optimum point. In the initial stage of the evolution when the active exploration is desirable, it is unnecessary to apply random search. The parameter `GAP.rs_fgs` specifies the point of starting the random search. If `GAP.rs_srp = 0.2`, then the random search is inactive for the first 20 percent of entire generation. At each generation with the active random search, the random search occurs with the probability given by `GAP.rs_fea`.

Given the best solution, random search operator generates mutants of the best chromosome. Mutants are generated in the same way as the relative vector mutation based on `GAP.rs_srp` and the absolute vector mutation with `GAP.rs_sap`. The relative vector mutation is chosen with the probability of `GAP.rs_frp` and the absolute vector mutation is chosen with the probability of $(1 - \text{GAP.rs_srp})$. The number of the generated mutants is determined by the parameter `GAP.rs_fps` that specifies the fraction of the total population size, that is

$$\text{The number of mutants} = \text{GAP.rs_fps} \times \text{Size of the population.}$$

Then the best solution among the mutants is found and this solution replaces the existing best only if this solution is better than the existing best solution.

References

- [CHO96] E. K. P. Chong and S. H. Żak, *An Introduction to optimization*, Wiley-Interscience, 1996
- [Deb01] K. Deb, *Multi-Objective Optimization using Evolutionary Algorithms*, John Wiley & Sons, Inc., 2001

Chapter 6

GOSET Graphical User Interface (GUI)

In this section, the GOSET GUI is introduced. GOSET GUI provides an intuitive and convenient method to use GOSET.

- 6.1 GOSET GUI
- 6.2 Main Window
- 6.3 Menu bar
- 6.4 Evolution status, output report
and start/stop/continue buttons
- 6.5 Main menu

6.1 GOSET GUI

GOSET has the built-in graphic user interface (GUI) that provides an intuitive interface for the user. With the GOSET GUI, the user has total control over GOSET without having to remember parameter names or consult the documentation.

GOSET GUI also provides extra features that help the user to utilize GOSET more efficiently. Some of them are listed below.

Stop & Continue:

GOSET can be stopped at any time of the evolution process. The user may want to change some parameters, check the best chromosome value, or manipulate with the current population. The evolution process also can be resumed from the point it was stopped.

Project save & load:

The current population and all the parameters can be saved for later use. When the saved project is loaded, the evolution process can be resumed as if it is continued from the moment the project was saved.

View & save setting:

Current parameter settings for GA operators, gene definitions and fitness function information can be viewed. It is also possible to save these information in a text file.

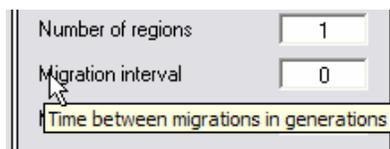
Best chromosome value display:

The actual values of the best chromosome together with the gene description can be viewed.

Mouse-on help:

For the most GUI objects, mouse-on help is provided for efficient documentation.

Example



Flexibility in the optional data for the fitness function:

For the optional fitness function data, a vector with actual numerical elements, a variable name in the workspace or a '.mat' file name containing the appropriate data can be used.

6.2 Main window

The GOSET GUI can be initiated by typing 'goset' in the MATLAB command window. If the GOSET GUI does not start, refer to Section 1.3 to check if the GOSET is properly installed.



Figure 6.1 Main window of GOSET GUI

The main window of GOSET GUI is shown in Figure 6.1. There are five sections in the main window:

- Menu bar
- Evolution status display
- Output report option
- Start/Stop/Continue buttons
- Main menu

We will look at each part of the GOSET GUI in the following sections.

6.3 Menu bar

The menu bar, shown below, is located at the top of the main GOSET GUI window.

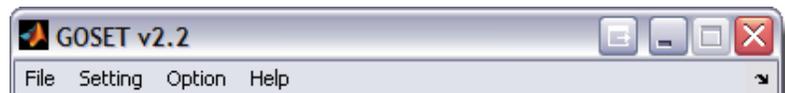


Figure 6.2 Menu bar of the GOSET GUI

The menu bar has the following menus.

- File
- Setting
- Option
- Help

a. File menu

File menu has submenu as in Figure 6.3.

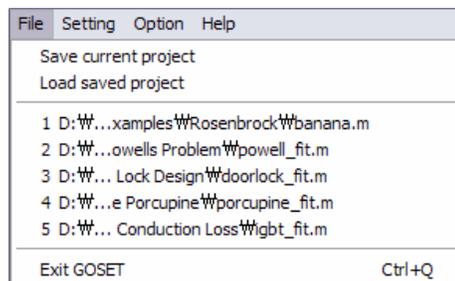


Figure 6.3 File menu of GOSET GUI

Save current project: Store all the information of current generation including the population information and the parameters of genetic operators.

Load saved project: Load a previously saved project.

Recent files: Five most recently accessed fitness function files are listed. They can be loaded directly by clicking them.

Exit GOSET: Close GOSET GUI. The shortcut key is Ctrl+Q.

b. Setting menu

Parameter settings of the current project can be viewed and the default settings can be loaded. Figure 6.4 shows the setting menu.

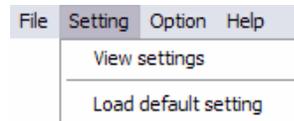


Figure 6.4 Setting menu of GOSET GUI

View setting: Display the fitness function information, gene parameters, parameters of GA operators as in the following figure.

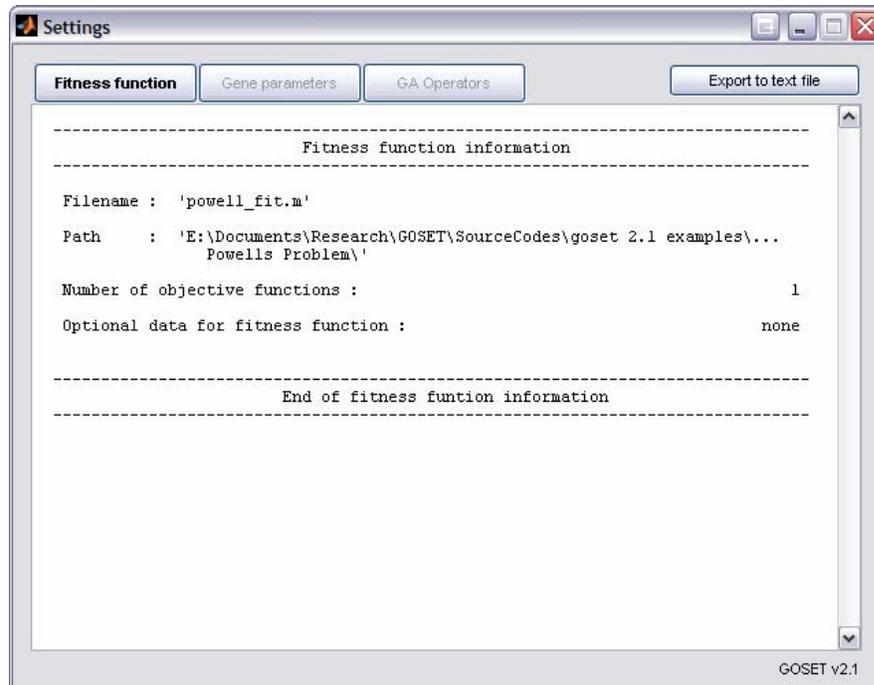


Figure 6.5 Setting Viewer

Selecting 'Fitness function', 'Gene parameters', and 'GA operators' will display corresponding information.

‘Export to text file’ button on the upper right corner of the setting window saves all these information to a text file.

Load default setting: Load default setting for GA operators. The fitness function, gene parameters are unchanged.

c. Option menu

Currently, the option menu has only one submenu ‘Extra user routine’ as in Figure 6.6.

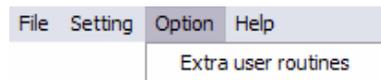


Figure 6.6 Option menu

Extra user routines: Define M-files to be executed before and after the GA.

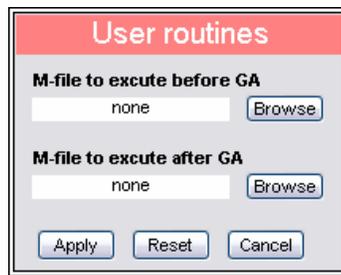


Figure 6.7 User routine input box

d. Help menu

There is one submenu ‘About GOSET’ in Help menu as shown in Figure 6.8.



Figure 6.8 Help menu

About GOSET: Display information on GOSET.

Forced Exit: Forcefully terminate GOSET GUI when the exit does not working.

6.4 Evolution status, output report, and start/stop/continue buttons

a. Evolution status display section

Evolution status display section shows the current generation number, the best fitness value, and the average fitness value. It also has a progress bar visualizing the evolution process with the completion percentage.

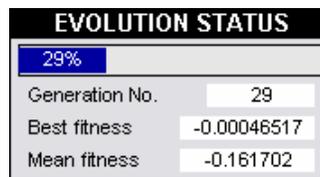


Figure 6.9 Evolution status

b. Output report option

The level of output report, the report interval and the computation time report flag can be set according to the need of the user. The plot of current generation and gene value of the best individual can be displayed.

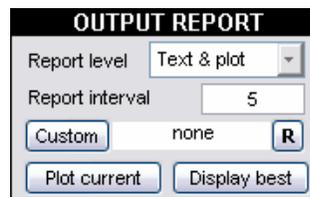


Figure 6.10 Output report option

Report level: Define the output report level. There are three options in the report level.

None: output report is not given.

Text only: Text report of the generation number, the best fitness value, average fitness value, median fitness value, and the number of evaluations in the MATLAB main window.

Example

```
Statistics for generation 46
Best fitness = -0.12645
Mean fitness = -3.0653
Median fitness = -1.6876
Number of evaluations = 2928
```

Text and plot: Together with text report in the MATLAB main window, the plot is displayed and updated every generation as defined by the plotting parameters.

Report interval: Set the number of generations between reports.

Report computation time: When checked, the time spent on each GA operation is displayed. If the report level is set to 'None', the computation time is not reported.

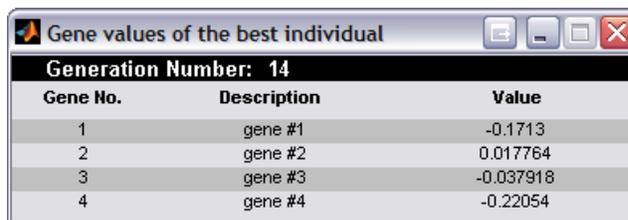
Example

```
Absolute computation times for generation 56
OWV: 0.00e+000 DC: 3.20e-002 SCALE: 0.00e+000
SELECT: 0.00e+000 MC: 3.10e-002 MUT: 0.00e+000
MIGRATE: 0.00e+000 EVAL: 1.50e-002 ELITE: 0.00e+000
RS: 0.00e+000 STAT: 0.00e+000 REPORT: 4.70e-002
```

```
Relative computation times for generation 56
OWV: 0.00 DC: 25.60 SCALE: 0.00
SELECT: 0.00 MC: 24.80 MUT: 0.00
MIGRATE: 0.00 EVAL: 12.00 ELITE: 0.00
RS: 0.00 STAT: 0.00 REPORT: 37.60
```

Plot current: Display the plot of current generation as defined in the plotting parameters.

Display best: Show the gene number, its description and the actual value of it as in Figure 6.11.



Gene No.	Description	Value
1	gene #1	-0.1713
2	gene #2	0.017764
3	gene #3	-0.037918
4	gene #4	-0.22054

Figure 6.11 Gene values of the best chromosome

c. Start/stop/continue buttons

Start, stop and continue buttons are enabled and disabled depending on the situation, as shown in Figure 6.12.

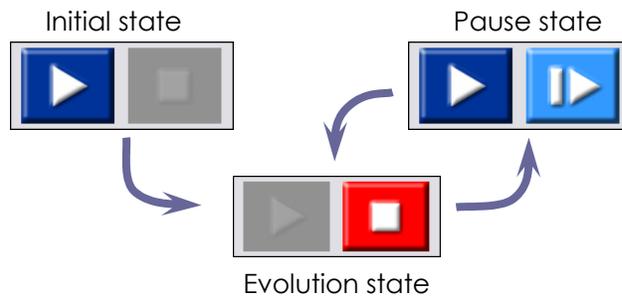


Figure 6.12 Status of buttons

For example, when the GOSET is stopped before reaching the last generation, the start and the continue buttons are enabled. If the continue button is pressed, the evolution process is resumed from where it is stopped. If the start button is pressed, all the evolution result accumulated up to that point will be discarded and the GA starts from the generation number 1.

6.5 Main menu

The fitness function information, the definition of the genes, plotting parameters and all the genetic operator parameters are defined in the main menu.

There are 14 buttons in the main menu section. When each button is pressed, the corresponding parameter input box will appear. In most case, it is clear what to do with these input fields. Therefore, we will look at only a part of the main menu section.

a. Fitness function button

The fitness function button and the fitness function name field are shown in Figure 6.13.



Mode of optimization

Figure 6.13 Fitness function button

Fitness function button: Open the fitness function parameter input box shown below.

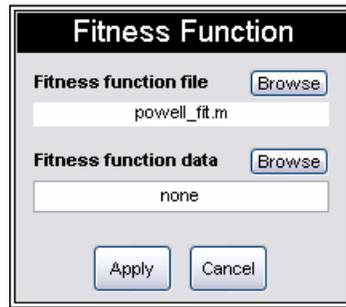


Figure 6.14 Fitness function input box

Fitness function file and the optional data for the fitness function are defined.

Optional fitness function data field can take a vector with numerical elements, a variable name in the MATLAB workspace, or the '.mat' file name that has the data vector.

Mode of optimization: For the single objective optimization problem, 'S' is displayed. And 'M' is shown for the multi-objective optimization problem.

Fitness function name: Display current fitness function file name.

b. Gene parameters

The total number of genes and their descriptions, maximum values, minimum values, gene types, and the chromosome number are defined.

The dialog box titled "Gene parameters" contains the following fields and controls:

- Total number of genes: 4
- Select the gene number to edit: A slider control.
- Parameters for gene No. 1:
 - Gene description: gene #1
 - Minimum gene value: -2
 - Maximum gene value: 2
 - Gene type: Linear (dropdown menu)
 - Chromosome ID number: 1
- Buttons: Apply, Cancel

Figure 6.15 Gene parameters input box

When a gene number is selected using the slide bar, its gene description, minimum and maximum values, type and chromosome ID are shown in the following fields. Gene description can be used to specify what each gene is representing.

c. Fundamental parameters

The total number of generations for evolution, the initial population size, the regular population size, the number of objective functions and the objective function number to be used in the optimization are defined.

The dialog box titled "Fundamental parameters" contains the following fields and controls:

- Total generation No.: 100
- Init. population size: 100
- Population size: 100
- No. of objective func.: 1
- Obj. func. to optimize: 1
- Buttons: Apply, Cancel

Figure 6.16 Fundamental parameters input box

For multi-objective optimization, use value 0 in the objective function to optimize. Even if there are multiple objectives, a specific objective function can be used for the optimization, in which case, it becomes single-objective optimization problem.

d. Diversity control

Diversity control has ON/OFF toggle switch and the user can decide whether to use the diversity control operator or not.



Figure 6.17 Diversity control ON/OFF button

In the parameter input box, the diversity algorithm and other parameters are defined. The diversity control can be applied to either the parameter space or the fitness function space.

A dialog box titled "Diversity Control" with a black header. It contains several input fields and buttons. The fields are: "Diversity control alg." with a dropdown menu showing "4"; "Apply to" with a dropdown menu showing "Parameter space"; "Minimum threshold" with a text box containing "0.02"; "Maximum threshold" with a text box containing "0.1"; "Minimum No. of bins" with a text box containing "0.5"; "Maximum No. of Bins" with a text box containing "2"; "No. of trials for Alg. 2" with a text box containing "3"; "Local population const." with a text box containing "0.001"; and "Test population size" with a text box containing "50". At the bottom are "Apply" and "Cancel" buttons.

Figure 6.18 Diversity control input box

e. Elitism

Elitism has the ON/OFF toggle switch to activate or deactivate it as in the diversity control.



Figure 6.19 Elitism ON/OFF button

Chapter 7

Tutorial Lessons

In this section, some optimization problems are considered with step-by-step guidance to familiarize the users with GOSET. Each problem is solved using both the command line approach and the GUI approach.

- 7.1 Rosenbrock's banana function
- 7.2 Tanaka problem
- 7.3 Power diode curve fitting
- 7.4 Transfer function fit

7.1 Rosenbrock's banana function

Problem description

Rosenbrock's function [p.55, CHO96] is a real-valued function given in the following:

$$f(x_1, x_2) = 100(x_2 - x_1^2)^2 + (1 - x_1)^2$$

We want to find the minimizer of the function $f(x_1, x_2)$. Rosenbrock's function and its level sets are depicted in Fig. 7.1. Due to the shape of level sets that resemble bananas, it is also referred to as the banana function. The global optimizer of Rosenbrock's function is at $(1, 1)$ where the function has its value 0.

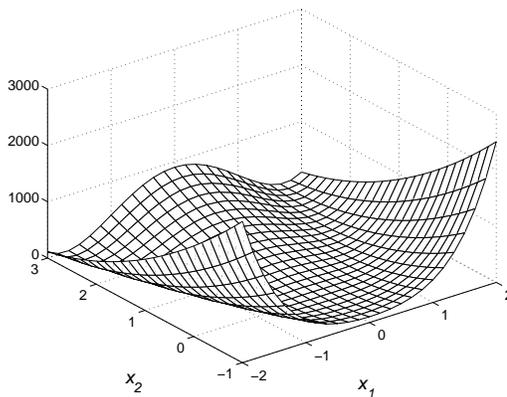


Figure 7.1 Rosenbrock's function

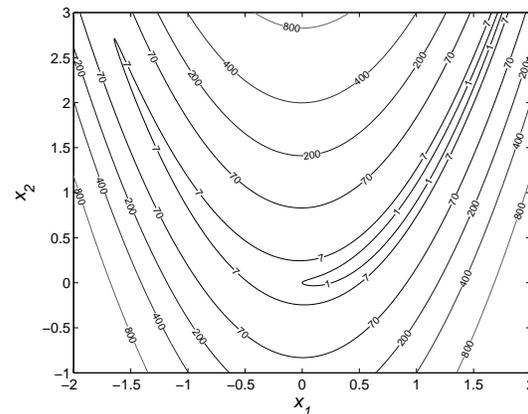


Figure 7.2 Level sets

Before using GOSET, the fitness function for the given problem needs to be defined as an mfile. There are many different ways to define a valid fitness function. As it is a minimization problem and the Rosenbrock's function value is non-negative, one simple way is to take the inverse as the fitness function. A small positive value is added to the denominator to prevent the singularity of the fitness function value at the minimizer. The following mfile `banana.m` defines a fitness function for Rosenbrock's function.

```

% BANANA.M
% Rosenbrock's Banana Function

function f = banana(x)

f1 = 100*(x(2) - x(1)^2)^2 + 5*(1 - x(1))^2;
f = 1/(0.001 + f1);

```

The above mfile is located in the folder 'Rosenbrock' under 'goset 1.0x examples' folder.

a. Command line approach

With the fitness function defined, we are now ready to use GOSET to find the minimizer of the Rosenbrock's function.

First of all, GAP and other parameters related to the population need to be determined.

```

GAP = gapdefault;
GAP.fp_ngen = 200;      % Total generation number
GAP.fp_ipop = 100;     % Initial population size
GAP.fp_npop = 100;     % Population size
GAP.op_style = 0;      % Logarithmic scale for objective plot

```

gapdefault is used to define GAP and only some parameters are redefined. For the detailed information regarding the default setting of GAP, refer to gapdefault.m.

The values of x_1 and x_2 become the gene values, and their minimum, maximum values are defined as

```

GAP.gd_min  = [ -2  -1  ];
GAP.gd_max  = [  2   3  ];

```

The types of the genes are given in the vector,

```

GAP.gd_type = [  2   2  ];

```

And employing only one chromosome for all the genes results in the following chromosome ID vector

```

GAP.gd_cid = [  1   1  ];

```

All the parameters are defined in the MATLAB workspace, and thus we can execute GOSET by

```
[P,GAS]= gaoptimize(@banana,GAP,[],[],[],[]);
```

All the above commands are in the script file 'runme.m' located in the same folder as 'banana.m', so type 'runme' in the main window to start GOSET.

Observe that the fitness function handle name is '@banana.'

As the default value for the report level is set to `GAP.rp_lvl = 1`, a plot will appear to show the normalized objective function values and the fitness function values as the GOSET evolves over the generations. Figure 7.3 is the report plot after 200 generations.

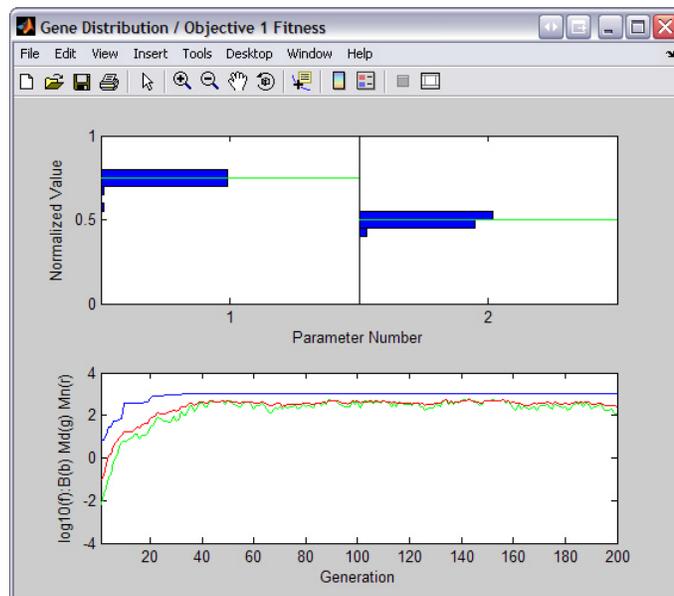


Figure 7.3 Report plot for Rosenbrock's function

There is also the text report displayed in the MATLAB main window. For this example the text report is:

```
Statistics for generation 1
Best fitness = 16.3028
Mean fitness = 0.19982
Median fitness = 0.0074076
Number of evaluations = 100
.
.
.
```

```
Statistics for generation 200
Best fitness = 999.9466
Mean fitness = 304.7056
Median fitness = 199.2891
Number of evaluations = 12687
```

The generation number and the best, mean, and median fitness values together with the number of evaluations are reported.

The best gene values can be found by checking the last element of `GAS.bestgenes`.

```
>> GAS.bestgenes(:,200)

ans =

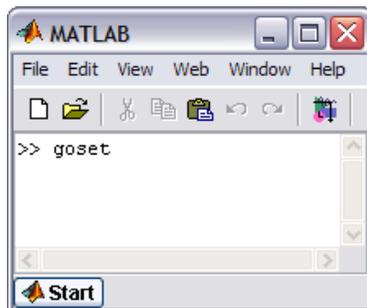
    1.0003
    1.0005
```

The resultant minimizer found by GOSET turned out to be very close to the actual minimizer (1, 1).

b. GUI approach

The procedure for GUI approach is very similar to that of command line approach. The main difference is that the parameters are defined in the GUI window, not in the MATLAB command window or a script M-file.

To start the GOSET GUI, type 'goset' in the MATLAB command window.



Then the GOSET GUI window will appear.



Fitness function selection

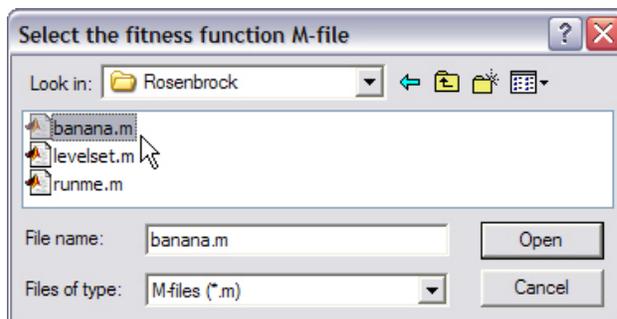
The first step is choosing the fitness function. Click 'Fitness function' button in the main menu.



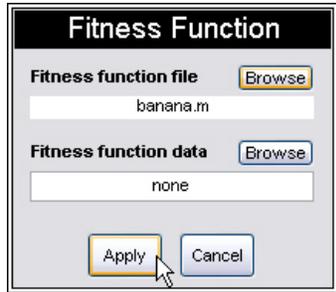
Then, click browse button.



After locating the fitness function 'banana.m', select it and click 'open.'



Click 'Apply' button to finish selecting the fitness function.

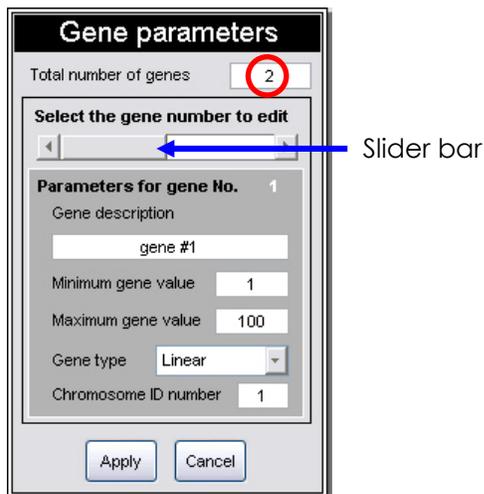


Parameter input

Once the fitness function is chosen, we are ready to define gene parameters. Select gene parameters button.



The default value for the gene number is 3. There are 2 gene values in this problem, so change the gene number to 2.



Then, for each gene, the minimum, maximum, gene type, and chromosome ID number need to be defined. Gene description can also be assigned if necessary. For the first gene, move the slider bar to so the number at the right of 'Parameters of the gene #' is 1 and type information as in the following figure

For the second gene, use the slider bar again to select 2nd gene and enter the appropriate information as in the following figure and click apply.

Then select fundamental parameters button in the main menu.

Fundamental parameters

In the input fields, insert parameter values as in the following and click apply.

Fundamental parameters	
Total generation No.	200
Init. population size	100
Population size	100
No. of objective func.	1
Obj. func. to optimize	1
<input type="button" value="Apply"/> <input type="button" value="Cancel"/>	

The last parameters to be adjusted are the plotting parameters, so click it.

Set the plot scale for the objective plot to 0 (logarithmic scale), select 'Gene value' for the distribution plot type and click apply.

Plotting parameters	
Gene dist. & history plot	
Obj. for plot	[1]
Plot scale	[0]
Sign of fit.	[1]
Distribution plot type	Gene value
No. of ind. to plot (Type 1)	100
No. of bins (Type 2)	20
Pareto plot parameters	
Obj. for plot	[]
Plot scale	[1]
Sign of fit.	[1]
X label	Objective 1
Y label	Objective 2
Title	Solution Space
Axis	Auto
<input type="button" value="Apply"/> <input type="button" value="Cancel"/>	

For the plotting and text report, select the report level to 'Text and plot.'

OUTPUT REPORT	
Report level	Text & plot
Report interval	5
Custom	none <input type="checkbox"/> R
<input type="button" value="Plot current"/> <input type="button" value="Display best"/>	

Starting GOSET

Now, we are ready to start the GOSET and click the start button.



As in the command line approach, the report plot and text will be shown and refreshed in every `GAP.rp_gbr` generation. The evolution status section in the GUI window also shows the current generation number, best fitness value, average fitness value and the progress bar.

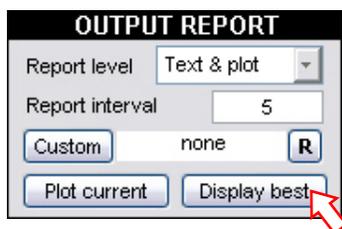
EVOLUTION STATUS	
50%	
Generation No.	100
Best fitness	999.681
Mean fitness	379.166

GOSET can be stopped at any time by clicking stop button. Try it.



The simulation is now stopped and the user can do all kinds of things with the data structures generated in the Matlab workspace. You can change parameters for genetic operators. or check the actual value of the best gene in the current generation by clicking 'Display best' button in the output report section.

Let's try and click 'Display best' button.



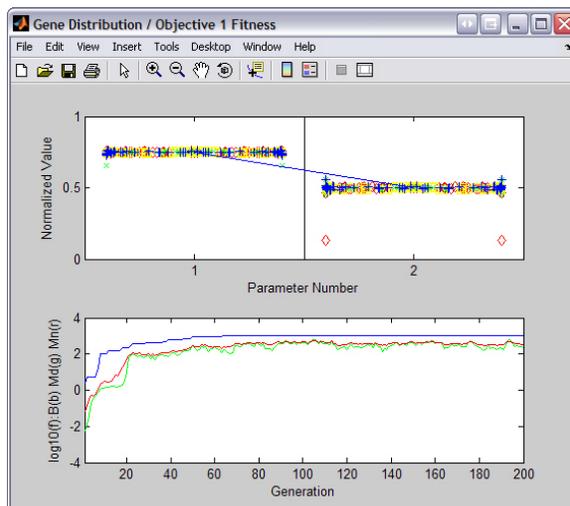
Then the following window will pop up to list the gene numbers, gene descriptions and their actual values.

Gene No.	Description	Value
1	x1	0.99984
2	x2	0.99969

GOSET can resume the optimization process using the continue button.



The following is the final report plot after 200 generations.



The best chromosome at the last generation has the gene values that are very close to the actual optimum point (1, 1).

Gene No.	Description	Value
1	x1	1.0001
2	x2	1.0002

7.2 Tanaka Problem

Problem description

One of the most important features of GOSET is the capability to handle multi-objective optimization problems. As a multi-objective optimization problem, Tanaka problem [TAN95] is considered in this section. The Tanaka problem is a constrained optimization problem with two objectives to be minimized:

$$\begin{aligned} \min f_1(x_1, x_2) &= x_1 \\ \min f_2(x_1, x_2) &= x_2 \\ \text{subject to } C_1(x_1, x_2) &= x_1^2 + x_2^2 - 1 - 0.1 \cos\left(16 \arctan \frac{x_1}{x_2}\right) \geq 0, \\ C_2(x_1, x_2) &= (x_1 - 0.5)^2 + (x_2 - 0.5)^2 \leq 0.5, \\ 0 &\leq x_1 \leq \pi, \\ 0 &\leq x_2 \leq \pi. \end{aligned}$$

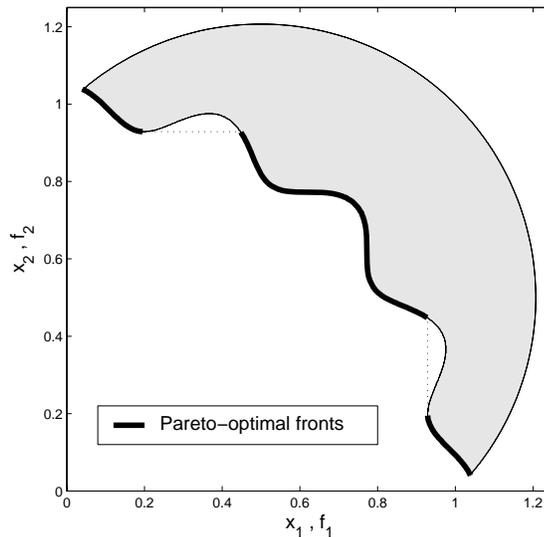


Figure 7.4 The feasible objective space and the Pareto-optimal fronts of Tanaka problem.

In this problem, the variable space is also the objective space. The feasible objective space and the Pareto-optimal front are shown in Figure 7.4.

In the first step, the fitness function for the given problem needs to be defined in a m-file. There are two objectives to be minimized and they all have positive values. And the fitness function values are defined to be the negative of the objective function values. Infeasible

solutions are assigned with the value -10 to reduce the chance of surviving in the population. The following mfile `tanaka.m` defines a fitness function for Tanaka problem.

```
% Tanaka problem (1995)

function [f] = tanaka(x)

C1 = x(1)^2+x(2)^2-1-0.1*cos(16*atan(x(1)/x(2))) >= 0;
C2 = (x(1)-0.5)^2+(x(2)-0.5)^2 <= 0.5;

if C1 & C2
    f(1,1) = -x(1);
    f(2,1) = -x(2);
else
    f(1,1) = -10;
    f(2,1) = -10;
end
```

a. Command line approach

First of all, GAP and other parameters related to the population need to be defined as in the following,

```
GAP = gapdefault(2); % default setting for two objectives
GAP.fp_nngen = 200; % Total generation number
GAP.fp_ipop = 200; % Initial population size
GAP.fp_npop = 200; % Population size
GAP.fp_obj = 0; % Multi-objective problem
GAP.sc_alg = 6; % Quadratic scaling
GAP.op_list = []; % Do not show distribution plot
GAP.pp_list = [1, 2]; % List of parameters for Pareto plot
GAP.pp_sign = [-1,-1]; % Sign of fitness for each objective
GAP.pp_axis = [0 1.25 0 1.25] % axis limits for Pareto plot
GAP.dp_np = 200; % Max no. of population to plot for type 1

GAP.gd_min = [ 0 0 ];
GAP.gd_max = [ pi pi ];
GAP.gd_type = [ 2 2 ];
GAP.gd_cid = [ 1 1 ];
```

where the `gapdefault(2)` is used to define default GAP for the problem with two objectives and the maximum number of population for plotting `GAP.dp_np` is set to 200 to display all the individuals in the population.

Then `gaoptimize` is called to perform optimization:

```
[P,GAS]= gaoptimize(@tanaka,GAP,[],[],[],[]);
```

The fitness function handle is '@tanaka.'

The script file 'runme.m' in the folder 'Tanaka' has all the above commands and executing 'runme' will start the evolution to solve Tanaka problem.

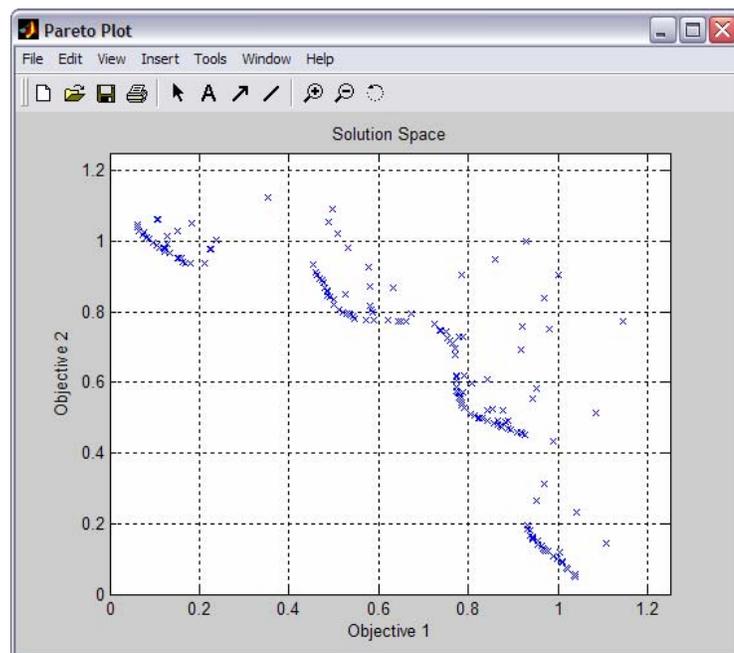


Figure 7.5 Pareto plot for Tanaka problem

The distribution plot is turned off by using null matrix '[]' for `GAP.op_list`, and only the Pareto plot is displayed as in Figure 7.5.

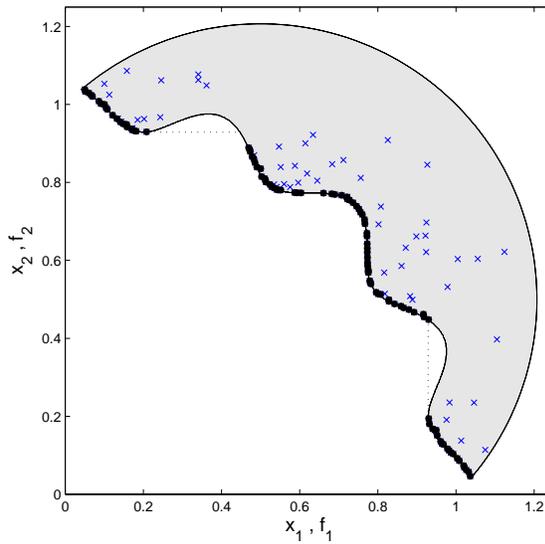


Figure 7.6 Final population plot with the non-dominated solutions in black circles

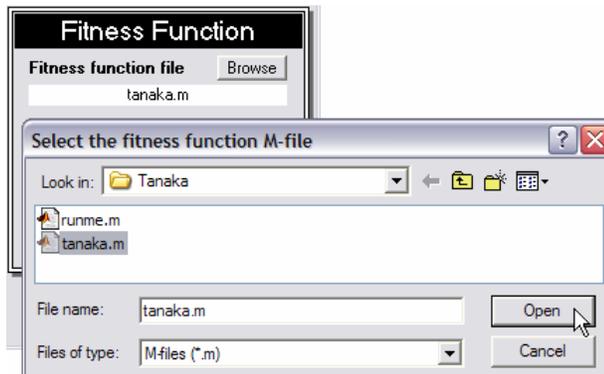
The final population after 200 generation is plotted on the feasible objective space with the non-dominated solutions in black circles in Figure 7.6. Comparison of this figure with Figure 7.4 demonstrates the performance of GOSET with respect to multi-objective optimization problems.

b. GUI approach

As in the previous example, the beginning of GUI approach starts with choosing the fitness function.

Fitness function selection

In the GOSET GUI window, go to fitness function browse menu and locate the fitness function 'tanaka.m' and select it.



Parameter input

Gene parameters are needed to be typed as in the following illustrations.

The image shows two side-by-side screenshots of the 'Gene parameters' dialog box. Both dialog boxes have a title bar 'Gene parameters' and a 'Total number of genes' field set to 2. The first dialog box is for 'Parameters of the gene # 1' and contains the following fields: 'Gene description' with text 'x1', 'Minimum gene value' set to 0, 'Maximum gene value' set to 'pi', 'Gene type' set to 'Linear' (with a dropdown arrow), and 'Chromosome ID number' set to 1. The second dialog box is for 'Parameters of the gene # 2' and contains the following fields: 'Gene description' with text 'x2', 'Minimum gene value' set to 0, 'Maximum gene value' set to 'pi', 'Gene type' set to 'Linear' (with a dropdown arrow), and 'Chromosome ID number' set to 1. Both dialog boxes have 'Apply' and 'Cancel' buttons at the bottom.

Fundamental parameters are set as in the following. There are two fitness functions, so the number of objective function is set to 2 and the objective function to optimize is set to 0 for multi-objective optimization.

The image shows a screenshot of the 'Fundamental parameters' dialog box. It has a title bar 'Fundamental parameters' and several input fields: 'Total generation No.' set to 100, 'Init. population size' set to 100, 'Population size' set to 100, 'No. of objective func.' set to 2 (circled in red), and 'Obj. func. to optimize' set to 0 (circled in red). There are 'Apply' and 'Cancel' buttons at the bottom.

For the scaling algorithm, Quadratic scaling is used with the default scaling parameters.

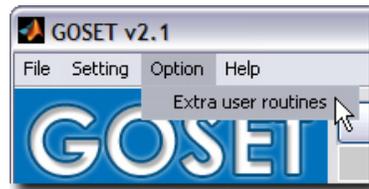
The image shows a screenshot of the 'Scaling' dialog box. It has a title bar 'Scaling' and a 'Scaling algorithm' dropdown menu. The dropdown menu is open, showing the selected option 'Quadratic (mn:kn, av:1, mx:lx)'. There are no other visible fields or buttons in this dialog box.

Plotting parameters are set to display only the Pareto plot as in the following. Axis limits are also given to fix the range of plotting and the maximum number of individuals for plotting is set to 200.

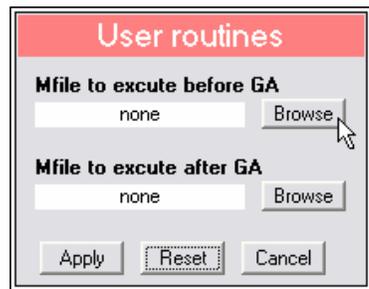
For plotting the Pareto plot, check the output level setting if it has been set to ‘Text and plot.’

User routines

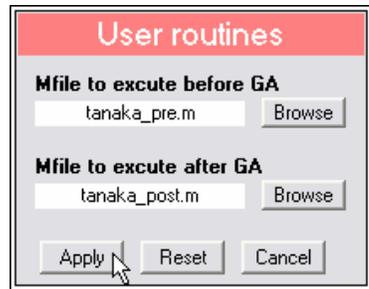
GOSET GUI allows the user to execute user routines before and after the GA optimization process. In the menu bar, select ‘Option’ and then click ‘Extra user routines’.



Then the following user routine menu pops up.



Click 'Browse' button to choose the mfiles executed before and after GA. In this example, 'tanaka_pre.m' and 'tanaka_post.m' are chosen respectively.



'tanaka_pre.m' plots the feasible objective space and the Pareto optimal front of Tanaka problem and 'tanaka_post.m' plots the final population with the non-dominated solutions in black circles.

Starting GOSET

When the GOSET is started, the mfile 'tanaka_pre.m' is first executed to display the Pareto optimal front of Tanaka problem in Figure 7.6. Observe the Pareto plot to see how the solutions are distributed throughout the Pareto front over the generations. At the end of the GOSET run, 'tanaka_post.m' is executed and a figure with final solutions will be shown as in Figure 7.7.

7.3 Power diode curve fitting

Problem description

In this section, GOSET is applied to power diode curve fitting. The diode of interest is a part of Fuji Electric 6MBI 30L-060 which is commonly used for an inverter for motor drivers and AC-DC servo drive amplifiers. The configuration of Fuji 6MBI 30L-060 is shown in Figure 7.7 and its characteristics are listed in Table 7.1

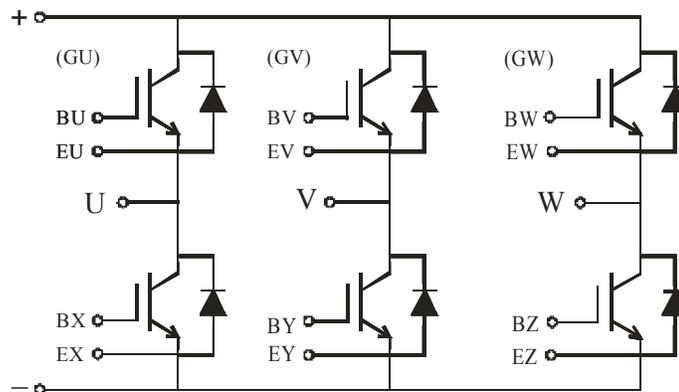


Figure 7.7 Circuit schematic of the IGBT module

Fuji 6MBI 30L-060 Device Characteristics	
Description	Rating
Collector-Emitter Voltage	600V
Gate-Emitter Voltage	±20V
Collector Current – Continuous	30A
Collector Current – 1ms Pulse	60A
Maximum Power Dissipation	120W
Operating Junction Temperature	150°C
Thermal Resistance – IGBT Junction to Case	1.04°C/W (Max)
Thermal Resistance – Diode Junction to Case	2.01°C/W (Max)

Table 7.1 IGBT Module device characteristics

The voltage versus current (V-I) curve of the Power diode is measured using the hardware configuration shown in Figure 7.8

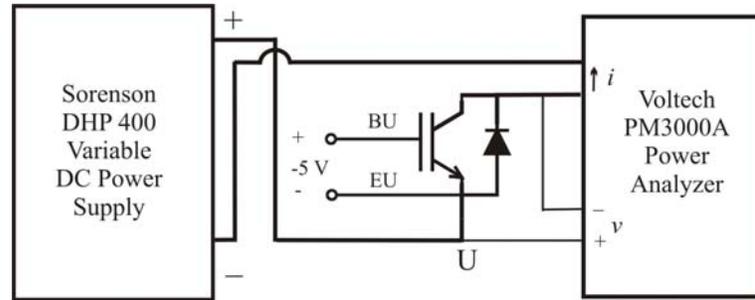


Figure 7.8 Hardware Test Configuration for Diode V-I characteristic

Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage (V)	Current (A)
0.3130	0	1.2178	6.0040	1.5160	18.0660
0.4145	0	1.2548	7.0870	1.5358	19.0300
0.5154	0	1.2844	8.0360	1.5527	19.9480
0.6140	0.0400	1.3122	9.0000	1.5716	21.0100
0.7120	0.1495	1.3412	10.0520	1.5885	22.0200
0.8056	0.3915	1.3654	11.0290	1.6065	23.0800
0.8942	0.8345	1.3888	11.9900	1.6229	24.0400
0.9649	1.4103	1.4134	13.0640	1.6389	25.0000
1.0405	2.3180	1.4345	14.0280	1.6565	26.0500
1.1092	3.4680	1.4570	15.0860	1.6720	27.0000
1.1722	4.8340	1.4768	16.0510	1.6880	27.9700

Table 7.2 Measured voltage and current of the power diode

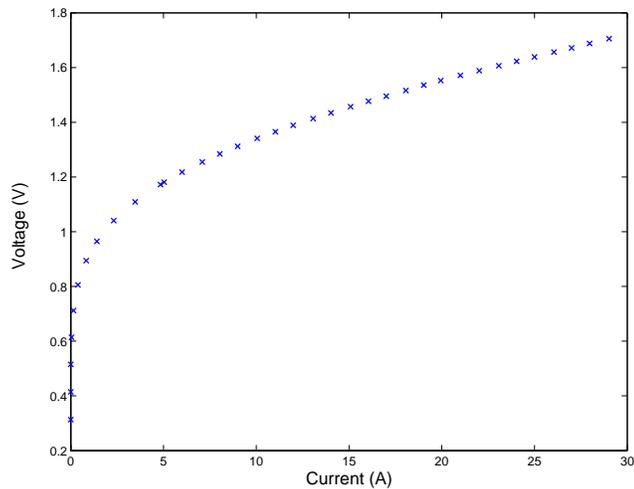


Figure 7.9 Voltage versus current for power diode

The V-I data set measured at 36 points is listed in Table 7.2 and it is depicted in Figure 7.9. Using the measured V-I data set (v_k, i_k) , $k = 1, \dots, n$, a model of the power diode is going to be developed. It is assumed that the voltage is expressed as the function of the current in the following way

$$v = ai + (bi)^c$$

where the parameter a , b , and c are to be identified using GA.

A fitness function candidate is

$$f(a,b,c) = \frac{1}{\sum_{k=1}^n \left| 1 - \frac{ai_k + (bi_k)^c}{v_k} \right| + 10^{-3}}$$

where v_k and i_k are measured voltage and current in k^{th} point. This fitness function is coded to mfile `diode.m` as in the following.

```
% DIODE.M
% IGBT diode V-I curve fitting fitness function

function f = diode(parameters,data)

% assign genes to parameters
a = parameters(1);
b = parameters(2);
c = parameters(3);

v = a*data.i + (b*data.i).^c;
error = abs(1-v./data.v);
f = 1.0/(1.0e-3 + mean(error));
```

a. Command line approach

In the first step, the voltage and current measurement data is defined and saved for later use.

```
data.v = [.313,.4145,.5154,.614,.712,.8056,.8942,.9649,1.0405,1.1092,1.1722, ...
1.1811,1.2178,1.2548,1.2844,1.3122,1.3412,1.3654,1.3888,1.4134,1.4345, ...
1.4570,1.4768,1.4955,1.5160,1.5358,1.5527,1.5716,1.5885,1.6065,1.6229,1.6389, ...
1.6565,1.6720,1.6880,1.7054];

data.i=[0,0,0,.040,.1495,.3915,.8345,1.4103,2.318,3.468,4.834,5.032,6.004,7.087, ...
8.036,9,10.052,11.029,11.990,13.064,14.028,15.086,16.051,17.007,18.066,19.030, ...
19.948,21.01,22.02,23.08,24.04,25,26.05,27,27.97,29.02];

save 'data.mat' data
```

To save some chores, you can load the stored 'data.mat' from the directory '.../GOSET/goset 1.05 examples/power diode curve fit/'.

```
load data
```

The default values are used for GAP except for the mating crossover algorithm and the total generation number for evolution.

```
GAP = gapdefault;           % load the default values for GAP
GAP.mc_alg = 2;            % Scalar simple blend crossover
GAP.fp_ngen = 200;        % Total number of generation to evolve
```

The range, type and chromosome ID vectors are defined as

```
GAP.gd_min = [ 1e-6  1e-6  1e-6  ];
GAP.gd_max = [ 1e+3  1e+3  1e+3  ];
GAP.gd_type = [ 3    3    3    ];
GAP.gd_cid = [ 1    1    1    ];
```

The range of each gene is from 10^{-5} to 10^3 and the logarithmic gene type is used. As the necessary parameters are all defined, execute the GOSET.

```
[P,GAS]= gaoptimize(@diode,GAP,[],[],[],[]);
```

Execute the script 'runme.m' to start GOSET. After 200 generations, the best individual (GAS.bestgenes(:,200)) has the following parameter values.

```
a = 0.0091
b = 0.5066
c = 0.1363
```

These parameters yield the best fitting V-I curve expressed as

$$v = (0.0091)i + (0.5066i)^{0.1363}.$$

The plots of measured data and the estimated curve are shown in Figure 7.10. The estimated curve fits very closely to the measured data.

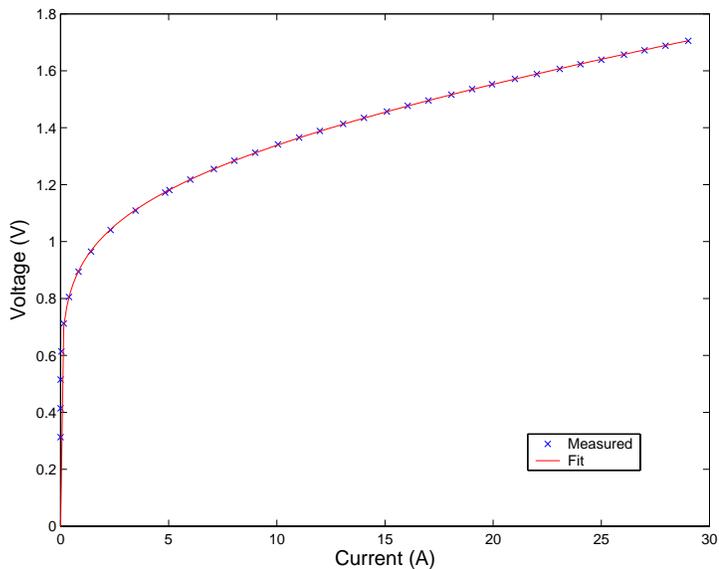
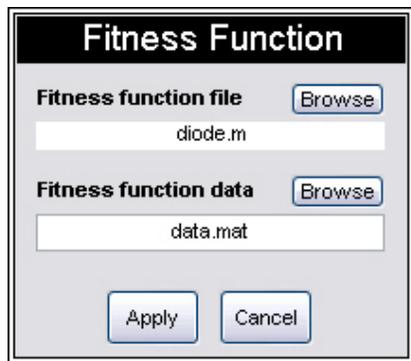


Figure 7.10 Plot of measured data and the estimated curve using GOSET

B. GUI approach

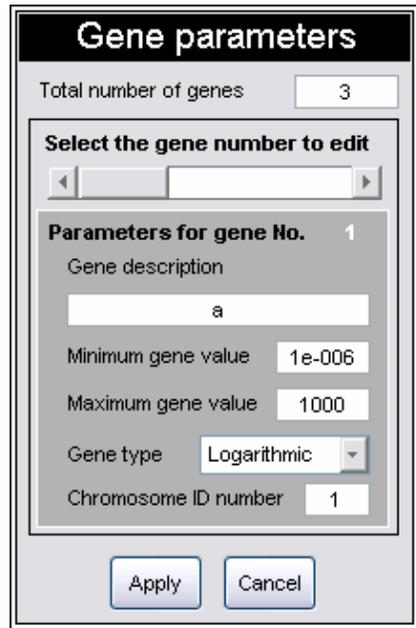
With an assumption that the previous two examples gave enough chance to learn how to start GOSET GUI, how to enter parameter values, etc., only the parts where changes need to be made will be described.

In the fitness function window, browse and select the fitness function 'diode.m.' The optional data for fitness function is set to 'data.mat' which is located in the same folder as 'diode.m'.



The gene parameters are defined next. As there are three parameters to be identified, the total number of gene is set to 3. For each gene, the minimum gene value is set to 1e-5, the

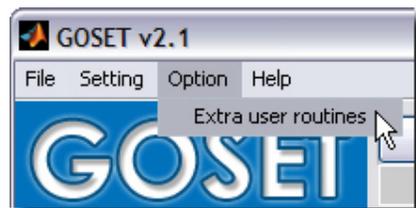
maximum gene value to 1000, gene type to logarithmic and the chromosome ID to 1. Gene description can be specified, if desired. The first gene is names as 'a' in the following figure.



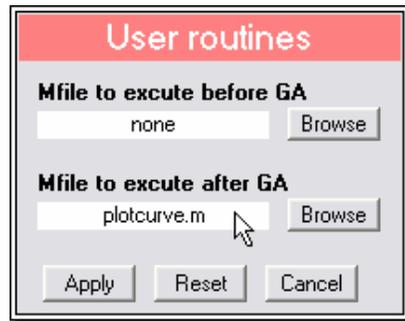
In the fundamental parameter input window, the total generation number for evolution is set to 200.



For the comparison between the measured data and the estimated curve, an m-file named 'plotcurve.m' is provided in the 'power diode curve fitting' folder. To execute this m-file, go to the extra user routine menu



and set 'Mfile to execute after GA' to 'plotcurve.m'



Now the GOSET can be started. When the evolution process is over, 'plotcurve.m' is executed and a comparison plot similar to the Figure 7.10 will be shown.

7.4 Transfer function fitting

Problem description

In this section, GOSET is employed to estimate the transfer function given the transfer function values. The transfer function values are admittances looking into the d-axis of brushless DC motor.

The admittances measured at 60 different frequencies are listed in Table 7.3 and plotted in Figure 7.11.

Freq.(Hz) f_k	Admittance Y_k	Freq.(Hz) f_k	Admittance Y_k	Freq.(Hz) f_k	Admittance Y_k
20	0.2754 + 0.2059i	224	0.0126 + 0.0533i	2516	0.0013 + 0.0062i
23	0.2470 + 0.2106i	253	0.0108 + 0.0478i	2839	0.0012 + 0.0056i
25	0.2299 + 0.2116i	286	0.0094 + 0.0428i	3203	0.0011 + 0.0050i
29	0.1992 + 0.2100i	322	0.0082 + 0.0385i	3615	0.0010 + 0.0045i
32	0.1794 + 0.2066i	364	0.0072 + 0.0345i	4079	0.0009 + 0.0040i
37	0.1517 + 0.1987i	410	0.0063 + 0.0310i	4603	0.0008 + 0.0036i
41	0.1336 + 0.1914i	463	0.0056 + 0.0278i	5195	0.0008 + 0.0033i
47	0.1117 + 0.1798i	523	0.0049 + 0.0249i	5862	0.0007 + 0.0029i
53	0.0948 + 0.1685i	590	0.0044 + 0.0223i	6615	0.0006 + 0.0027i
59	0.0815 + 0.1579i	666	0.0040 + 0.0201i	7465	0.0006 + 0.0024i
67	0.0679 + 0.1452i	751	0.0035 + 0.0180i	8424	0.0005 + 0.0021i
76	0.0565 + 0.1326i	848	0.0032 + 0.0162i	9506	0.0005 + 0.0019i
85	0.0480 + 0.1219i	957	0.0029 + 0.0145i	10728	0.0004 + 0.0017i

96	0.0401 + 0.1108i	1079	0.0026 + 0.0130i	12106	0.0004 + 0.0016i
109	0.0333 + 0.0999i	1218	0.0023 + 0.0117i	13661	0.0004 + 0.0014i
123	0.0280 + 0.0903i	1375	0.0021 + 0.0105i	15416	0.0003 + 0.0012i
138	0.0238 + 0.0818i	1551	0.0019 + 0.0095i	17397	0.0003 + 0.0011i
156	0.0201 + 0.0735i	1750	0.0017 + 0.0085i	19632	0.0003 + 0.0010i
176	0.0171 + 0.0661i	1975	0.0016 + 0.0076i	22154	0.0003 + 0.0009i
199	0.0146 + 0.0593i	2229	0.0014 + 0.0069i	25000	0.0002 + 0.0008i

Table 7.3 Admittances of the brushless DC motor in the d-axis

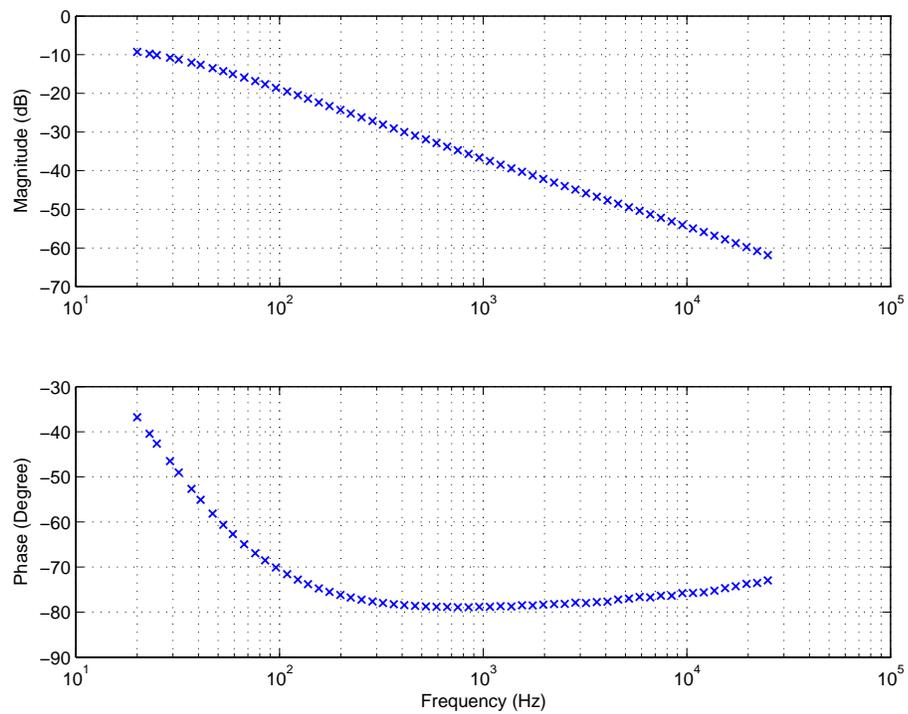


Figure 7.11 Magnitude and phase plot of admittance data

It is assumed that the transfer function of the admittance has the form

$$Y(s) = \frac{a_1}{\tau_1 s + 1} + \frac{a_2}{\tau_2 s + 1} + \dots + \frac{a_n}{\tau_n s + 1},$$

where n is the order of the transfer function, a -s and τ -s are the parameters to be identified.

The fitness function F is defined as

$$F(a_1, \dots, a_n, \tau_1, \dots, \tau_n) = \frac{1}{\frac{1}{m} \sqrt{\sum_{k=1}^m \frac{|Y_k - Y(s_k)|}{|Y_k|}} + 10^{-12}},$$

where m is the number of admittance data set and $s_k = j2\pi f_k$.

In the example, the order of the transfer function to be estimated is assumed to be $n = 6$. The following is the fitness function m-file.

```
% TFFIT.M
% Transfer function fitting fitness function
function f=tffit(parameters,data)

a = parameters(1:6);
tau = parameters(7:12);

tpred = zeros(size(data.s));
for i = 1:6,
    tpred = tpred+a(i)./(tau(i)*data.s+1);
end

terror = data.t-tpred;
error = norm(terror./abs(data.t))/length(tpred);
f = 1.0/(1.0e-12+error);
```

a. Command line approach

The transfer function values at 60 different frequencies are defined first in the workspace.

```
f = [ 20 23 25 29 32 37 41 47 53 59 67 76 85 96 109 123 138 156 176 199 ...
      224 253 286 322 364 410 463 523 590 666 751 848 957 1079 1218 1375 ...
      1551 1750 1975 2229 2516 2839 3203 3615 4079 4603 5195 5862 6615 ...
      7465 8424 9506 10728 12106 13661 15416 17397 19632 22154 25000];

% frequency vector in s-domain
data.s = 1j*2*pi*f;
data.t = [ 0.2754+0.2059i 0.2470+0.2106i 0.2299 + 0.2116i 0.1992 + 0.2100i ...
          0.1794 + 0.2066i 0.1517 + 0.1987i 0.1336 + 0.1914i 0.1117 + 0.1798i ...
          0.0948 + 0.1685i 0.0815 + 0.1579i 0.0679 + 0.1452i 0.0565 + 0.1326i ...
          0.0480 + 0.1219i 0.0401 + 0.1108i 0.0333 + 0.0999i 0.0280 + 0.0903i ...
          0.0238 + 0.0818i 0.0201 + 0.0735i 0.0171 + 0.0661i 0.0146 + 0.0593i ...
          0.0126 + 0.0533i 0.0108 + 0.0478i 0.0094 + 0.0428i 0.0082 + 0.0385i ...
          0.0072 + 0.0345i 0.0063 + 0.0310i 0.0056 + 0.0278i 0.0049 + 0.0249i ...
          0.0044 + 0.0223i 0.0040 + 0.0201i 0.0035 + 0.0180i 0.0032 + 0.0162i ...
          0.0029 + 0.0145i 0.0026 + 0.0130i 0.0023 + 0.0117i 0.0021 + 0.0105i ...
```

```

0.0019 + 0.0095i 0.0017 + 0.0085i 0.0016 + 0.0076i 0.0014 + 0.0069i ...
0.0013 + 0.0062i 0.0012 + 0.0056i 0.0011 + 0.0050i 0.0010 + 0.0045i ...
0.0009 + 0.0040i 0.0008 + 0.0036i 0.0008 + 0.0033i 0.0007 + 0.0029i ...
0.0006 + 0.0027i 0.0006 + 0.0024i 0.0005 + 0.0021i 0.0005 + 0.0019i ...
0.0004 + 0.0017i 0.0004 + 0.0016i 0.0004 + 0.0014i 0.0003 + 0.0012i ...
0.0003 + 0.0011i 0.0003 + 0.0010i 0.0003 + 0.0009i 0.0002 + 0.0008i ]

```

Then `data.s` and `data.t` are saved in `'data.mat'` for later use.

```
save 'data.mat' data
```

The `'data.mat'` also can be directly loaded from `'.../GOSET/goset 1.05 examples/Transfer function fit/'`.

```
load data
```

The default values are used for GAP and the total generation number for evolution is set to 1000.

```
GAP = gapdefault;           % load the default values for GAP
GAP.fp_ngen = 1000;        % Total number of generation to evolve
```

The parameter range, type and chromosome ID vectors are defined as

```
GAP.gd_min = [ 1.0e-8 1.0e-8 1.0e-8 1.0e-8 1.0e-8 1.0e-8...
               1.0e-8 1.0e-8 1.0e-8 1.0e-8 1.0e-8 1.0e-8 ];
GAP.gd_max = [ 1.0e+1 1.0e+1 1.0e+1 1.0e+1 1.0e+1 1.0e+1 ...
               1.0e+0 1.0e+0 1.0e+0 1.0e+0 1.0e+0 1.0e+0 ];
GAP.gd_type = [ 3 3 3 3 3 3 3 3 3 3 3 3 ];
GAP.gd_cid = [ 1 1 1 1 1 1 1 1 1 1 1 1 ];
```

The first six elements correspond to the parameter a , and the rest are for τ . GOSET is ready to go.

```
[P,GAS]= gaoptimize(@tffit,GAP,[],[],[],[]);
```

To start GOSET, execute the script `'runme.m'` with all the commands described above.

After 1000 generations, the best individual (`GAS.bestgenes(:,1000)`) has the following parameter values.

```
a = [ 0.00074282873079 0.00020824030313 0.00000009385065 ...
       0.00079650808510 0.42038798793770 0.00597311661588 ]
```

```
tau = [ 0.00002657084427  0.00000001815644  0.00000011416888 ...
        0.00008665847926  0.00586600530356  0.00038902284811 ]
```

These parameters yield the transfer function

$$Y(s) = \frac{0.0007428}{0.00002657s+1} + \frac{0.0002082}{0.00000001815s+1} + \frac{0.00000009385}{0.0000001141s+1} \\ + \frac{0.0007965}{0.00008666s+1} + \frac{0.4204}{0.005866s+1} + \frac{0.005973}{0.0003890s+1}$$

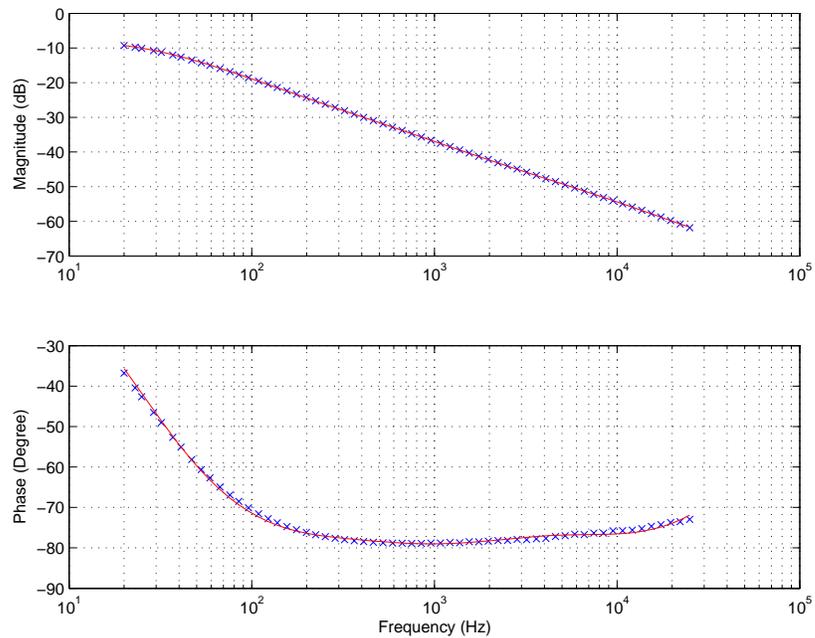
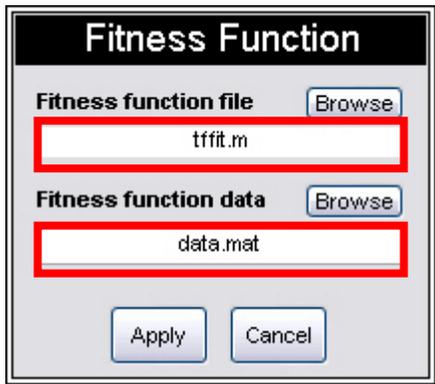


Figure 7.12 Plot of the magnitude and phase of the measured transfer function data and the transfer function obtained using GOSET

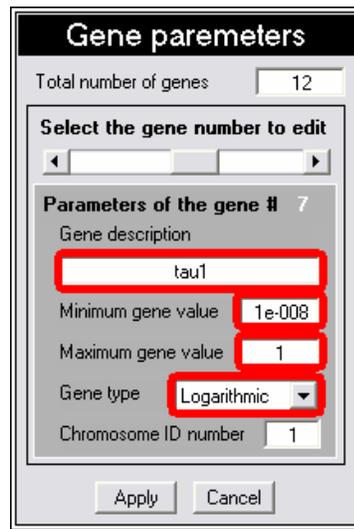
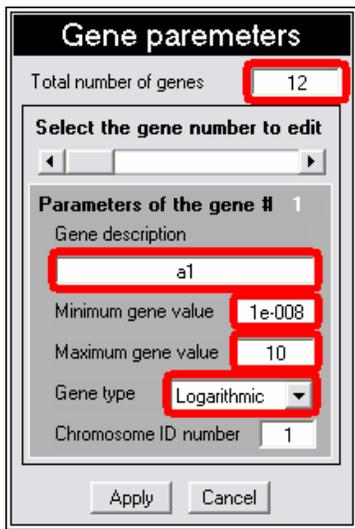
The magnitude and phase plot of the data set and the estimated transfer function are shown in Figure 7.12. The solid red line is for the transfer function estimated using GOSET and the blue x's are the measured transfer function values. The estimated transfer function fits the measured data very closely.

B. GUI approach

In the first step, select the fitness function file and the optional data file.



Then, the gene parameters are defined as in the following figures. Total number of gene is 12. First six genes correspond to the parameters a_1, \dots, a_6 and their maximum and minimum values are set to 10 and 10^{-8} , respectively. Rest of the genes are for parameter τ_1, \dots, τ_6 and the maximum and minimum values are set to 1 and 10^{-8} . The gene type is logarithmic for all genes.



The fundamental parameters are set as in the following

Fundamental parameters	
Total generation No.	100
Init. population size	100
Population size	100
No. of objective func.	1
Obj. func. to optimize	1

Apply Cancel

Setting the plot scale to 0 makes the fitness function axis logarithmic.

Objective plot	
Objectives for plot	[1]
Plot scale	[0]
Sign of fitness	[1]

For the comparison plot after the evolution, 'plotcurve.m' is selected in the 'Mfile to execute after GA'.

User routines	
Mfile to excute before GA	
none	Browse
Mfile to excute after GA	
plotcurve.m	Browse

Apply Reset Cancel

The gene distribution at 1000 generation and the fitness values throughout the evolution are shown in Figure 7.13

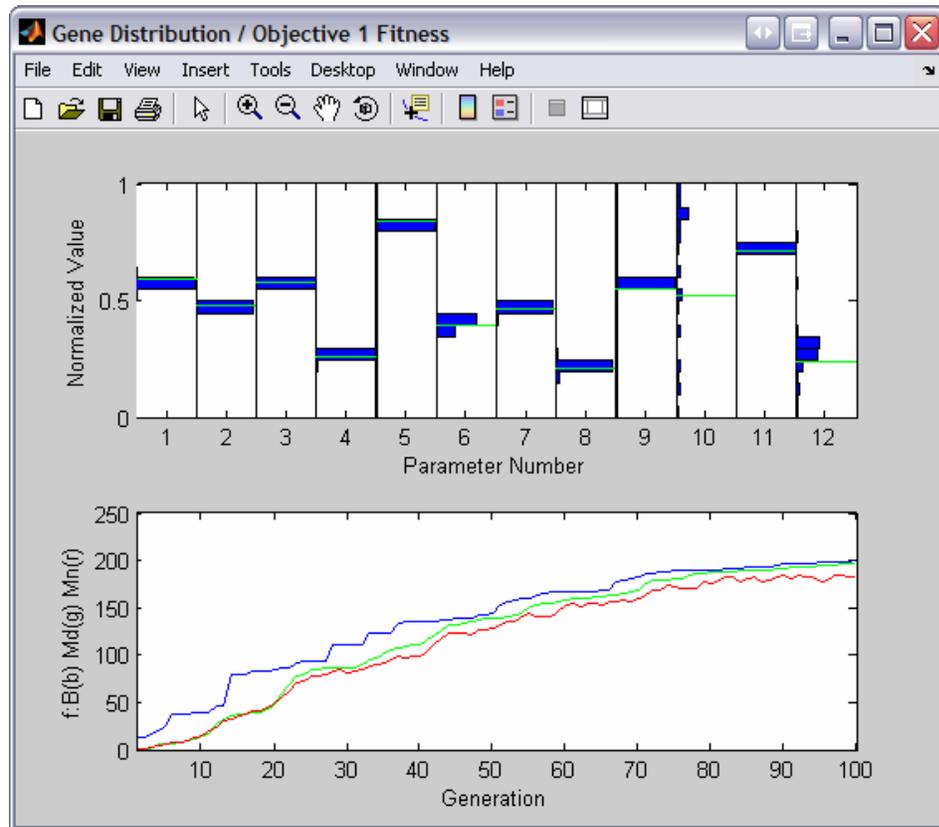


Figure 7.13 Gene distribution and the fitness history

At the end of the evolution, a comparison plot similar to Figure 7.12 will appear.

References

- [CHO96] E. K. P. Chong and S. H. Żak, *An Introduction to optimization*, Wiley-Interscience, 1996
- [TAN95] M. Tanaka, *GA-based decision support system for multi-criteria optimization*, Proceedings of the International Conference on Systems, Man and Cybernetics, Vol. 2, pp. 1556-1561.

Appendix

- A. GOSET function list
- B. GOSET function reference
- C. GOSET parameter list

Appendix A. GOSET function list

Initialization	gapdefault downsize gainit unrndinit gasetup	contains default parameter values for GAP reduce the population size to a desired number initialize the genetic algorithm initialize a population randomly sets up a population of chromosomes
Genetic operators	gaoptimize objwght divcon scale select death matingcrossover mutate migrate updateage evaluate elitism randsearch updatestat normgene rawgene nondom	GOSET main routine generate weight vector for multi-objective functions prevent crowding of the chromosomes determine the scaled fitness select chromosomes for reproduction determine parents to be replaced by children exchanges genes between chromosomes randomly change some gene values move chromosomes from one region to another update the age of all individuals evaluate the fitness values of chromosomes preserve best chromosomes search the vicinity of the best chromosomes update the statistic information of GAS structure updates the normalized genes based on raw genes updates the raw genes based on normalized genes find the non-dominated solutions
Plotting	reportplot distplot paretplot	plots current population plots the distribution of the genes plots the population in the objective space
GUI related	goset	GOSET GUI
Misc.	contents gasyschck	contains general information of GOSET license checking

Appendix B. GOSET function reference

contents

Purpose	Contain general information regarding GOSET
Syntax	<code>contents</code>
Arguments	None
Value	None
Description	<code>contents.m</code> has descriptions on data structures P, GAS and functions of GOSET and upgrade information
See Also	<code>gapdefault</code>

death

Purpose determine parents that are replaced by the children

Syntax `Dlist = select(Pin, Plist, GAP)`

Arguments `Pin` structure of current population
`Plist` parent list generated from select algorithm
`GAP` structure of genetic algorithm parameters

Value `Dlist` death list

Description Death operator determines which individual is to die and replaced by the children. The followings are possible options for the death operators.

Replacing parents (`GAP.dt_alg = 1`)

Parents are replaced by their own children.

Random selection (`GAP.dt_alg = 2`)

The parents to be replaced are randomly chosen.

Tournament on fitness (`GAP.dt_alg = 3`)

The parent to be replaces is determined via the tournament based on the aggregate fitness value. `GAP.dt_nts` number of parents are randomly chosen for a tournament and the one with worst aggregate fitness value is marked for death.

Tournament on age (`GAP.dt_alg = 4`)

The parent to be replaces is determined via the tournament based on the age. Among the randomly chosen `GAP.dt_nts` number of parents, the oldest one is selected and marked for death.

Custom algorithm (`GAP.dt_alg = 5`)

User defined custom death algorithm is used. The handle of the custom function is assigned to `GAP.dt_cah`. The custom function must have the following format

```
D_list = f(region, size, age, mfit, fit)
```

```
D_list indices of the individuals to be replaced by children  
region the region number  
size number of individuals for the death list
```

age vector describing ages of the individuals in population
mfit array with raw fitness values of the individuals in the region
fit vector with aggregate fitness values of individuals in the region

As an example of a custom algorithm, the random death algorithm is written as an mfile called 'customdeath.m' which is shown below.

```
% Custom death algorithm example - random death algorithm
function dlist = customdeath(region,size,region_age,region_mfit,region_fit)

% Randomly select death list
regionsize=length(region_age);
randomlist = randperm(regionsize);

dlist = randomlist(1:size);
```

This mfile must exist in the same folder as the fitness function file or in the GOSET folder. Then the custom file handle `GAP.dt_cah` is set to `@customdeath`.

Random algorithm (`GAP.dt_alg = 6`)

If this option is selected, the death algorithm is randomly chosen among the first four death algorithms at each generation.

distplot

Purpose Plot the distribution of the genes in the individuals

Syntax `distplot (fignum, P, objective, GAP, [region])`

Arguments

<code>fignum</code>	figure number
<code>P</code>	structure of current population
<code>objective</code>	objective function number to show in the plot
<code>GAP</code>	structure of genetic algorithm parameters
<code>region</code>	plot only the individuals in this specified region (optional)

Value None

Description `distplot` shows the distribution of the genes of the individuals. It is called within the `reportplot` and plotted together with the fitness history.

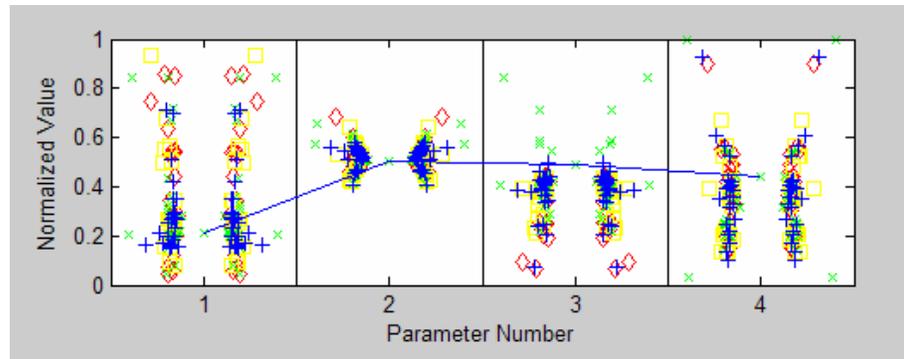


Figure B.1

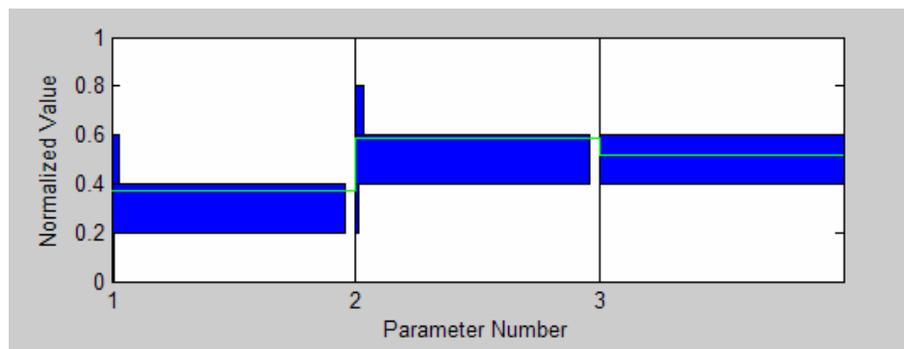


Figure B.2

There are two types of distribution plot. Setting `GAP.dp_type` to 1 will show the first type of distribution plot which displays the normalized gene values as in Figure B.1. In this case, there are four genes in each individual. The top 25 percent of the individuals are marked by blue cross (+), the next 25

percentiles are plotted as green X (x), then the next 25 percentiles are in yellow square (□), and the last 25 percentiles are drawn as the red diamonds(◇). The gene values of the best individual of each region are connected by the blue solid line. For multi-region scheme, there are multiple blue solid lines which represent the best individuals in multiple regions.

The second type (`GAP.dp_type = 2`) of distribution plot shows the histogram of the normalized gene values as in Figure B.2. The number of bars for the histogram can be set using `GAP.dp_res`. In Figure B.2, the number of bars is set to 5 (`GAP.dp_res = 5`). The gene values of the best individual of each region are indicated by green horizontal lines. For each gene values, there are as many green lines as the number of regions.

For both of the distribution plot, only a part of the population can be displayed by setting the parameter `GAP.dp_np` that determines the maximum number of individuals to plot. Only `GAP.dp_np` individuals are randomly chosen from the population and displayed. The positions of green lines represent the normalized gene values of the best individual.

See also `reportplot`, `paretoplot`

divcon

Purpose Compute penalty function values for maintaining diversities of the population

Syntax `Ppen = divcon(Pin,GAP)`

Arguments `Pin` structure of current population
`GAP` structure of genetic algorithm parameters

Value `Ppen` penalty function vector

Description Maintaining genetic diversity in the population is important especially in the multi-objective optimization problem. Diversity control algorithms are employed so that the under represented individuals are emphasized and similar individuals are penalized by degrading their fitness values.

Diversity control can be applied to either the parameter (solution) space or the fitness function space. Setting `GAP.dc_spc = 1` causes the diversity control in the parameter space and setting `GAP.dc_spc = 2` causes the diversity control in the fitness function space.

Presently, four different diversity control algorithms are used in GOSET.

Diversity control algorithm 1

This algorithm is chosen by setting `GAP.dc_alg = 1`. For each individual, the distances with all other individuals are evaluated. Then the number of individuals, whose distance from the individual of interest is smaller than the threshold distance, is counted. The threshold distance is randomly determined as a value between the minimum threshold (`GAP.dc_mnt`) and the maximum threshold (`GAP.dc_mxt`). That is,

$$\text{Threshold distance} = \text{average distance among the individual} + \alpha$$

where $\alpha = (\text{GAP.dc_mnt} + \text{randH}(\text{GAP.dc_mxt} - \text{GAP.dc_mnt}))$. Then the penalty function value of an individual is defined as the reciprocal of the counted number of individuals.

Diversity control algorithm 2

This algorithm is chosen by setting `GAP.dc_alg = 2`. To overcome the problem of the computational load in the first method, this algorithm uses a weighted sum of gene values for diversity control. For an arbitrary weight

vector whose element number is same as gene number in an individual, the weighted sum of each individual is evaluated. Then the modulus after dividing the weighted sum by 1 is taken. If the gene values of individuals are very similar, then the modulus of the weighted sum must be also similar. Then the individuals are grouped according to the modulus values and put into a corresponding bin. The number of bins, that is the number of groups, is randomly determined as the following

$$\text{No. of bins} = \text{round}(\alpha \cdot \text{Number of individual}),$$

where $\alpha = \text{GAP.dc_mnb} + \text{rand}(\text{GAP.dc_mxb} - \text{GAP.dc_mnb})$. Then the interval [0,1] is divided into (No. of bins) equally distanced subintervals. The penalty value of an individual is the reciprocal of the total number of individuals in the same bin.

However, even with different gene values, individuals may have similar modulus for some weight vectors. In such cases, the penalty value does not reflect the actual proximity of gene values. Hence, the procedure is repeated GAP.dc_ntr times and the largest penalty function value is chosen as the final penalty function value for each individual.

Diversity control algorithm 3

This algorithm is chosen by setting $\text{GAP.dc_alg} = 3$. The idea of this diversity control algorithm is similar to the diversity algorithm 1. The sum of infinity norm between the solutions is used to determine the penalty value as shown in the following formula

$$P_{pen}^k = \frac{1}{\sum_{i=1} \exp\left(-\frac{d_{i,k}}{d_c}\right)},$$

where $d_{i,k}$ is the infinity norm between k 'th and i 'th individual and d_c is the distance constant (GAP.dc_dc) which controls the size of the neighborhood. As the distance constant d_c increases, the effective size of the neighborhood increases and the penalty level also increases.

Diversity control algorithm 4

This algorithm is chosen by setting $\text{GAP.dc_alg} = 4$. It is identical to the diversity control algorithm 3 except the fact that only a part of the population, that is, for each individual, GAP.dc_nt individuals are randomly chosen and

used in the distance evaluation. The following formula is used to calculate the fitness penalty weight for k 'th individual.

$$P_{pen}^k = \frac{1}{1 + \frac{\text{Number of population in the region}}{\text{GAP} \cdot \text{dc_nt}} \sum_{i=1}^{\text{GAP} \cdot \text{dc_nt}} \exp\left(-\frac{d_{i,k}}{d_c}\right)}$$

where $d_{i,k}$ is the infinity norm between k 'th and i 'th individual, d_c is the distance constant (GAP . dc_dc)

downsize

Purpose Reduce the population to a desired size

Syntax `Pout = downsize(Pin, Newsize)`

Arguments `Pin` structure of current population
`Newsize` the size of the new population

Value `Pout` structure of downsized population

Description This function reduces the size of the population to a desired number based on the (cumulative) rank of the individual.

In the multiple region (multi-population) case, the number of individuals in a region is determined such that the ratio of individuals among regions is maintained. For example, suppose a population with 100 individuals that are distributed in 3 different regions as in the following table. If we want the new population to have only 50 individuals, then the number of individuals in the new populations becomes the half of the number of individuals in the original population as shown in Table B.1.

Region	1	2	3	total
No. of individuals in P _{in}	30	50	20	100
No. of individuals in P _{out}	15	25	10	50

Table B.1

The selection of the individuals is based on the rank in single objective case. In the multi-objective case, cumulative rank is used to pick the individuals for the new population. Consider a 3-objective optimization problem in Table B.2. If we have four individuals and need to reduce the size to two, then individual **A** and **D** are selected according to the cumulative rank.

Individual	Rank in each objective			Cumulative Rank
	I	II	III	
A	3	1	1	5
B	4	4	2	10
C	2	3	4	9
D	1	2	3	6

Table B.2

elitism

Purpose Preserve the best individuals

Syntax `Pout = elitism(Pin, Porg, GAP, GAS)`

Arguments `Pin` structure of current manipulated population
`Porg` structure of original population
`GAP` structure of genetic algorithm parameters
`GAS` structure of genetic algorithm statistics

Value `Pout` structure of output population

Description Elitism is activated by setting `GAP.el_act = 1`. The starting point of elitism can be using the parameter `GAP.el_fgs` that specifies the fraction of the population. For example, if `GAP.el_fgs = 0.25` with the total generation number of 100, then the elitism is effective starting from 25th generation.

In single objective optimization problems, the best individual in each region of the processed population and the best one in the original population are compared. If the best individual of the processed population is worse than that of the original population, then the best one in the processed population is replaced by the best one in the old population. In multi-objective optimization problem, it is guaranteed that a limited number of non-dominated individuals of the population are preserved up to certain number. The maximum number of preserved non-dominated individuals is determined by (population size H `GAP.el_fpe`).

evaluate

Purpose Evaluate the fitness of chromosomes

Syntax `[mfit,es,une] = evaluate(Pin,GAP,cne,D)`

Arguments `Pin` structure of current population
`GAP` structure of genetic algorithm parameters
`cne` current number of evaluations performed
`D` an optional data structure used for fitness evaluation

Value `mfit` multi-objective fitness
`es` evaluation status of each member of population
`une` updated number of evaluations

Description `evaluate` assigns individuals with fitness values obtained from the fitness function defined by `P.fithandle`.

When `GAP.ev_are` is set to 0, this function only updates the individuals whose fitness values have not been evaluated. When `GAP.ev_are = 1`, the fitness value of all the individuals are evaluated.

Also `GAP.ev_bev` determines whether to pass all the individuals to the fitness evaluation function at the same time (when set to 1) or to evaluate one individual at a time (when set to 0). The fitness function must be written to handle the vector evaluation.

Normally, the only gene values are passed to the fitness function. If the supplementary data flag `GAP.ev_ssd = 1`, then the age(`P.age`), previous fitness values(`P.mfit`) and the region(`P.region`) are also sent to the fitness function.

`D` is the optional data structure that is required for evaluating the fitness function and it is passed to the fitness function if it is defined when the `gaoptimize` is called.

The passed data and its order are listed in the following table.

Optional data <code>D</code>	<code>GAP.ev_ssd</code>	Data and its order passed to the fitness function
exists	0	<code>P.gene, D</code>
	1	<code>P.gene, P.age, P.mfit, P.region, D</code>
does not exist	0	<code>P.gene</code>
	1	<code>P.gene, P.age, P.mfit, P.region</code>

gainit

Purpose Initialize the genetic algorithm

Syntax [GAP, GAS, Pout]=gainit (numargin, @fitfun, D, GAP,
GAS, iP, GUIhdl)

Arguments

numargin	number of argument of the GAOPTIMIZE
@fitfun	name of the m-file that evaluates the fitness
D	optional data needed by fitness function
GAP	structure of genetic algorithm parameters
GAS	structure of genetic algorithm statistics
iP	optional initial population
GUIhdl	handle used for GUI (Pass empty matrix ' [] ' when not in use)

Value

GAP	structure of genetic algorithm parameters
GAS	structure of genetic algorithm statistics
Pout	structure of the population

Description gainit initializes the genetic algorithm by setting up the population. If the optional initial population is passed, gainit only evaluates the fitness of the population. Otherwise gasetup is called to generate initial population, and the fitness is evaluated. If the size of the initial population (GAP.fp_ipop) is larger than the steady state population (GAP.fp_ipop), the population size is reduced. In the last step, gainit generates a report on initial evaluation.

See Also gasetup

gaoptimize

Purpose Perform function optimization using GOSET

Syntax `[Pout, GAS]=gaoptimize(@fitfun, GAP, D, GAS, iP, GUIhdl)`

Arguments

<code>@fitfun</code>	name of the m-file that evaluates the fitness
<code>GAP</code>	structure of genetic algorithm parameters
<code>D</code>	optional data required by fitness function
<code>GAS</code>	structure of genetic algorithm statistics
<code>iP</code>	optional variable with initial population
<code>GUIhdl</code>	handle used for GUI (Use empty matrix when not in use)

Value

<code>Pout</code>	structure of final population
<code>GAS</code>	structure of genetic algorithm statistics

Description As the main function of GOSET, it performs the function optimization using GOSET. The structure of `gaoptimize.m` is modularized. Thus users who want to experiment their own operator, can easily modify this function.

gapdefault

Purpose Assigns default values to the genetic algorithm parameters used in GAP

Syntax `GAP = gapdefault(nobj)`

Arguments `nobj` number of objectives

Value `GAP` structure of genetic algorithm parameters

Description This function returns the structure of genetic algorithm parameters `GAP` with their default values. The user can load the `gapdefault` and then redefine only the required fields, instead of defining all the fields.

The following Table B.3 shows the default values defined in `gapdefault`.

Fundamental parameters	
<code>GAP.fp_ngen = 100</code>	<code>GAP.fp_ipop = 100</code>
<code>GAP.fp_npop = 100</code>	<code>GAP.fp_nobj = 1</code>
<code>GAP.fp_obj = 1</code>	
Diversity control parameters	
<code>GAP.dc_act = 1</code>	<code>GAP.dc_alg = 4</code>
<code>GAP.dc_spc = 1</code>	<code>GAP.dc_mnt = 0.02</code>
<code>GAP.dc_mxt = 0.1</code>	<code>GAP.ntr = 3</code>
<code>GAP.dc_mnb = 0.5</code>	<code>GAP.dc_mxb = 2.0</code>
<code>GAP.dc_dc = 0.001</code>	<code>GAP.dc_nt = 50</code>
Selection algorithm parameters	
<code>GAP.sl_alg = 2</code>	<code>GAP.sl_nts = 4</code>
<code>GAP.sl_cah = []</code>	
Death algorithm parameters	
<code>GAP.dt_alg = 2</code>	<code>GAP.dt_nts = 4</code>
<code>GAP.dt_cah = []</code>	
Mating and crossover parameters	
<code>GAP.mc_pp = 0.6</code>	<code>GAP.mc_fc = 1.0</code>
<code>GAP.mc_alg = 4</code>	<code>GAP.mc_gac = 3</code>
<code>GAP.mc_ec = 2</code>	
Mutation parameters	
<code>GAP.mt_ptgm = 0.001</code>	<code>GAP.mt_prgm = 0.002</code>
<code>GAP.mt_srgm = 0.3</code>	<code>GAP.mt_pagm = 0.002</code>
<code>GAP.mt_sagm = 0.1</code>	<code>GAP.mt_prvm = 0.002</code>
<code>GAP.mt_srvm = 0.3</code>	<code>GAP.mt_pavm = 0.002</code>
<code>GAP.mt_savm = 0.1</code>	<code>GAP.mt_pigm = 0.008</code>
Migration parameters	
<code>GAP.mg_nreg = 1</code>	<code>GAP.mg_tmig = 0</code>

GAP.mg_pmig = 0	
Evaluation Parameters	
GAP.ev_bev = 0	GAP.ev_are = 0
GAP.ev_ssd = 0	
Scaling parameters	
GAP.sc_alg = 1	GAP.sc_klin = 10
GAP.sc_cst = 2	GAP.sc_kmxq = 10
GAP.sc_kmnq = 0.01	
Elitism parameters	
GAP.el_act = 1	GAP.el_fgs = 0.0
GAP.el_fpe = 0.5	
Random search parameters	
GAP.rs_fgs = 0.25	GAP.rs_fps = 0.1
GAP.rs_srp = 0.3	GAP.rs_sap = 0.1
GAP.rs_frp = 0.7	GAP.rs_fea = 0.2
Reporting parameters	
GAP.rp_lvl = 1	GAP.rp_gbr = 5
GAP.rp_crh = []	
Objective plot parameters	
GAP.op_list = [1]	GAP.op_style = 1
GAP.op_sign = 1	
Pareto plot parameters	
GAP.pp_list = []	GAP.pp_xl = 'Objective 1'
GAP.pp_style = 1	GAP.pp_yl = 'Objective 2'
GAP.pp_sign = 1	GAP.pp_axis = []
GAP.pp_title = 'Solution space'	
Distribution plot parameters	
GAP.dp_type = 2	GAP.dp_np = 100
GAP.dp_res = 20	
Gene description parameters	
GAP.gd_min : user defined	GAP.gd_max : user defined
GAP.gd_type : user defined	GAP.gd_cid : user defined

Table B.3 Default values of GAP defined in gapdefault.m

For the full description regarding these parameters, refer to first section of GOSET data structures and algorithm execution or gapdefault.m. The m-file gapdefault.m also has default values of the GAP listed in Table B.3.

gasetup

Purpose Set up a population of chromosomes

Syntax `[P,GAS] = gasetup(popsize,GAP,@fitfun,[D])`

Arguments

<code>popsize</code>	number of individuals in the population
<code>GAP</code>	structure of genetic algorithm parameters
<code>@fitfun</code>	name of the m-file that evaluates the fitness
<code>D</code>	optional data needed by fitness function

Value

<code>P</code>	structure of the population
<code>GAS</code>	structure of genetic algorithm statistics

Description `gasetup` is called within `gainit` when the initial population does not exist. It sets up the population data structure `P` based on the assigned maximum value, minimum value, type, and the chromosome ID of each gene and by defining initial values using `unrndinit`.

The initial evaluation of the fitness function is also included and the statistic structure `GAS` is returned together with the population data structure `P`.

See Also `gainit`, `unrndinit`

gasyschck

Purpose Check the license information

Description Each version of GOSET is subject to the license control. The license of GOSET expires after certain period of time from the date of release. This is to prevent the unlawful distribution of GOSET and also to mandate the users to update their GOSET to the latest version.

gasyschck checks the license information and if the license is expired, GOSET is terminated.

When there is less than a week left in the GOSET license, you will get the following message:

```
There are only n days left in GOSET 2.X License.
```

goset

Purpose Start GOSET GUI (Graphic User Interface)

Syntax goset

Arguments none

Value none

Description goset initiates the GOSET GUI window as in the Figure B.3.



Figure B.3 GOSET GUI main window

For the detailed description of GOSET GUI, refer to Chapter 6.

matingcrossover

Purpose Perform mating and genetic crossover on a population

Syntax `Pout = matingcrossover(Pin, Plist, PLsize, Dlist, GAP, GAS)`

Arguments

<code>Pin</code>	structure of current population
<code>Plist</code>	parent list from selection operator
<code>PLsize</code>	size of the parent list
<code>Dlist</code>	death list from death operator
<code>GAP</code>	structure of genetic algorithm parameters
<code>GAS</code>	structure of genetic algorithm statistics

Value `Pout` structure of the population after crossover

Description Perform crossover operations on a population. Three different types of crossover methods are used in GOSET; single point crossover, simple blend crossover, and simulated binary crossover.

The parameter `GAP.mc_pp` specifies the mating crossover probability, that is, the fraction of the population replaced by children. The fraction of the chromosome undergoes crossover is determined by `GAP.mc_fc`.

All crossover operation is region specific and parents that are selected from one region reproduce children into the same region. Also all the crossover operations are chromosome-ID specific. Hence genes of different chromosome ID are treated separately and the crossover operators are applied independently.

The mating crossover methods are determined by `GAP.mc_alg` as in the following table.

<code>GAP.mc_alg</code>	Mating Crossover method
1	Single point crossover
2	Scalar simple blend crossover
3	Vector simple blend crossover
4	Scalar simulated binary crossover
5	Vector simulated binary crossover
6	Random algorithm

Let's discuss the mating crossover methods one by one.

Single point crossover

This crossover operator is similar to the crossover operator in binary-coded GAs. A crossover point is randomly selected and the gene values after that point are swapped between two parent chromosomes.

If P_1 and P_2 are the parent chromosomes with n genes and c is the crossover point, then the children chromosomes are

$$C_1 = [P_{1:(1:c-1)} \ P_{2:(c:n)}] \text{ and } C_2 = [P_{2:(1:c-1)} \ P_{1:(c:n)}]$$

where $P_{1:(a:b)}$ is a vector whose elements are gene values from a 'th to b 'th positions of P_1 .

Scalar simple blend crossover

Scalar simple blend crossover generates the children from the weighted sum of their parents by the following steps;

STEP 1 : For i 'th gene, choose a random number $u_i \in [-1, 1]$

STEP 2 : Calculate the average of the parents

$$m_i = \frac{P_{1,i} + P_{2,i}}{2}$$

STEP 3 : Calculate the amount of change

$$\delta_i = u_i \cdot |P_{1,i} - P_{2,i}|$$

STEP 4 : Compute the offspring

$$C_{1,i} = m_i + \delta_i \text{ and } C_{2,i} = m_i - \delta_i$$

Note that each gene in the same chromosome is crossed over with the different amount of change.

Vector simple blend crossover

Vector simple blend crossover is similar to the scalar simple blend crossover. The only difference is that all genes in the same chromosome are crossed over with the same amount of change as in the following steps

STEP 1 : Choose a random number $u \in [-1, 1]$

STEP 2 : Calculate the average of the parents

$$m_i = \frac{P_{1,i} + P_{2,i}}{2}$$

STEP 3 : Calculate the amount of change

$$\delta_i = u \cdot |P_{1,i} - P_{2,i}|$$

STEP 4 : Compute the offspring

$$C_{1,i} = m_i + \delta_i \text{ and } C_{2,i} = m_i - \delta_i$$

Note that all genes in the same chromosome are crossovered with the same amount of change.

Scalar simulated binary crossover

Scalar simulated binary crossover generates the children by the following steps;

STEP 1 : For i 'th gene, choose a random number $u_i \in [0, 1]$

STEP 2 : Calculate the spread factor

$$\beta_i = \begin{cases} (2u_i)^{\frac{1}{\eta_c}}, & \text{if } u_i \leq 0.5; \\ \left(\frac{1}{2(1-u_i)}\right)^{\frac{1}{\eta_c}}, & \text{otherwise.} \end{cases}$$

where η_c is the distribution tightness parameter `GAP.mc_ec`.

STEP 3 : Compute the offspring

$$\begin{aligned} C_{1,i} &= 0.5[(1 + \beta_i)C_{1,i} + (1 - \beta_i)C_{2,i}], \\ C_{2,i} &= 0.5[(1 - \beta_i)C_{1,i} + (1 + \beta_i)C_{2,i}]. \end{aligned}$$

Note that each gene in the same chromosome can be recombined with different spread factor.

Vector simulated binary crossover

Vector simulated binary crossover is identical as scalar simulated binary crossover except that the spread factor is same for all the genes in the same chromosome.

The following describes the vector simulated crossover;

STEP 1 : Choose a random number $u \in [0, 1]$

STEP 2 : Calculate the spread factor beta

$$\beta = \begin{cases} (2u)^{\frac{1}{\eta_c+1}}, & \text{if } u \leq 0.5; \\ \left(\frac{1}{2(1-u)}\right)^{\frac{1}{\eta_c+1}}, & \text{otherwise.} \end{cases}$$

STEP 3 : Compute the offspring

$$C_1 = 0.5[(1 + \beta)C_1 + (1 - \beta)C_2],$$
$$C_2 = 0.5[(1 - \beta)C_1 + (1 + \beta)C_2].$$

Random crossover

For every `GAP.mc_gac` generation, a mating crossover methods are randomly selected from the five mating crossover methods described above.

Reference K. Deb. *Multi-Objective Optimization using Evolutionary Algorithms*. John Wiley & Sons, Chichester, UK, 2001

migrate

Purpose Change the region of individuals

Syntax `Pout = migrate(Pin, GAP, cg)`

Arguments `Pin` structure of population before migration
`GAP` structure of genetic algorithm parameters
`cg` current generation number

Value `Pout` structure of population after migration

Description This function works only when there are multiple regions. If the migration occurs, some individuals are selected and moved to other regions. The migration interval is randomly chosen from the integer values between $0.5 \times \text{GAP.tmig}$ and $1.5 \times \text{GAP.tmig}$. For example, if $\text{GAP.tmig} = 6$ then, the migration interval can be any integer from 3 to 9. Each individual is selected and migrated with the probability of GAP.pmig . The target region is chosen randomly among GAP.nreg number of regions.

mutate

Purpose Perform mutation on a population of chromosomes

Syntax `Pout = mutate(Pin, GAP)`

Arguments `Pin` structure of population before mutation
`GAP` structure of genetic algorithm parameters

Value `Pout` structure of the population after mutation

Description This function applies genetic mutation on the population. Four different mutation algorithms are applied sequentially in the order of total mutation, partial mutation, vector mutation, and integer mutation.

These mutation operations are performed on the normalized gene values. When a gene value lies outside of the allowed range after mutation, then its value is corrected using the ring-mapping, that is, its modulus after division by 1 is used instead.

Total mutation

Each gene can be mutated to any value within the predetermined range with the probability of `GAP.mt_ptgm`. Thus, the mutated genes have no relationship to their previous value.

Partial mutation

Each gene can be perturbed with respect to its current value by using a random value generated using a Gaussian random variable. The mutated gene value is related to the original gene value.

Relative gene mutation

In the relative gene perturbation, with the probability of `GAP.mt_prgm`, each gene value is perturbed by certain fraction of the current gene value. The amount of perturbation is determined using a Gaussian random variable with standard deviation of `GAP.mt_srgm`.

The relative gene mutation on j 'th gene in k 'th individual can be expressed as

$$P_{ng;j,k} = P_{ng;j,k} \cdot (1 + N(0, \sigma_{rm}))$$

where $N(0, \sigma_{rvm})$ is a Gaussian random variable with mean 0 and standard deviation $\sigma_{rvm}(\text{GAP.mt_srgm})$.

Absolute gene mutation

In the absolute gene perturbation, each gene value is added with a Gaussian random variable with standard deviation of GAP.mt_sagm . The probability of absolute gene perturbation is defined in GAP.mt_pagm .

The absolute gene mutation on j 'th gene in k 'th individual can be expressed as

$$P_{ng:j,k} = P_{ng:j,k} \cdot (1 + N(0, \sigma_{rvm}))$$

where $N(0, \sigma_{rvm})$ is a Gaussian random variable with mean 0 and standard deviation $\sigma_{rvm}(\text{GAP.mt_srgm})$.

Vector mutation

This function is similar to partial mutation except the fact that all the genes of an individual are involved.

Relative vector mutation

Each individual undergoes the relative vector mutation with the probability of GAP.mt_prvm . Every gene value of the individual is perturbed by certain fraction of the current gene value. The relative vector mutation on the k 'th individual can be expressed as

$$P_{ng:k} = P_{ng:k} \cdot (1 + v_{dir} \cdot N(0, \sigma_{rvm}))$$

where v_{dir} is a normalized random vector ($P_{ngenes} \times 1$) specifying the direction of perturbation and $N(0, \sigma_{rvm})$ is a Gaussian random variable with mean 0 and standard deviation $\sigma_{rvm}(\text{GAP.mt_srvvm})$.

Absolute vector mutation

Each individual undergoes absolute vector mutation with the probability of GAP.mt_pavm . The absolute vector mutation on the k 'th individual can be expressed as

$$P_{ng;k} = P_{ng;k} + v_{dir} \cdot N(0, \sigma_{avm})$$

where v_{dir} is a normalized random vector ($P_{ngenes} \times 1$) specifying the direction of perturbation and $N(0, \sigma_{avm})$ is a Gaussian random variable with mean 0 and standard deviation σ_{avm} (GAP.mt_savm).

Integer mutation

Each integer gene can be mutated to any integer value within the predetermined range with the probability of GAP.mt_pigm.

nondom

Purpose	Find the set of non-dominated solutions for multi-objective optimization
Syntax	$Nd = \text{nondom}(O, \text{flag})$
Arguments	O a matrix of objective function values whose dimension is (Number of objective functions) by (Number of solutions) flag 1 indicates that the larger objective value is better 0 indicates that the smaller objective value is better
Value	Nd a row vector with dimension equal to the number of solutions whose elements are 1 if the solutions are non-dominated and 0 if they are dominated
Description	<code>nondom</code> is used to identify the non-dominated solutions among the solutions using the objective function value matrix. The method proposed by Kung et al. is employed.

Kung et al.'s method of identifying the non-dominated solution set

Step 1 Sort the population according to the descending order of importance in the first objective function and name the population as P

Step 2 Front(P)

```
IF |P| = 1,  
    Return P as the output of Front(P)  
ELSE  
    T = Front ( P(1: [ |P|/2 ] ) )  
    B = Front ( P( [ |P|/2 - 1 ] : |P| ) )  
  
    IF the i-th non-dominated solution of B is not dominated by  
        any non-nominated solution of T,  
        M = T ∪ {i}  
        Return M as the output of Front(P)  
END
```

Note

1. $|\bullet|$ is the number of the elements
2. $P(a : b)$ means all the elements of P from index a to b,
3. $[\bullet]$ is an operator gives the nearest smaller integer value.

It is a recursive algorithm, and it may not be easy to visualize. However, it is the most computationally efficient method known at the time this manual is written.

Examples Suppose we have the following objective function value matrix with two objectives and five solutions ,

$$O = \begin{bmatrix} 4 & 6 & 9 & 8 & 2 \\ 5 & 1 & 6 & 7 & 4 \end{bmatrix}.$$

Then $Nd = \text{nondom}(O, 1)$ returns

$$Nd = [0 \ 0 \ 1 \ 1 \ 0].$$

Reference K. Deb. *Multi-Objective Optimization using Evolutionary Algorithms*. John Wiley & Sons, Chichester, UK, 2001, pp. 38-39

normgene

- Purpose** Update the normalized gene values based on the raw gene values
- Syntax** `Pout = normgene(Pin)`
- Arguments** `Pin` structure of population before updating the normalized gene values
- Value** `Pout` structure of population after updating the normalized gene values

Description `normgene` updates the normalized gene values (`P.normgene`) based on the actual gene values (`P.gene`). The raw gene value is mapped to a value between 0 and 1 according to the type of the gene (`P.type`). Note that only the population members who have not been evaluated are updated.

The following table shows how `normgene` maps the raw gene value to the normalized gene values on j 'th gene of the m 'th chromosome for different types of gene.

Gene type	P_{type}	Operation
Integer & linear	1, 2	$P_{ng;j,k} = (P_{g;j,k} - P_{min;j}) / (P_{max;j} - P_{min;j})$
Logarithmic	3	$P_{ng;j,k} = \frac{\ln(P_{g;j,k}) - \ln(P_{min;j})}{\ln(P_{max;j}) - \ln(P_{min;j})}$

Table B.4

Examples With the following parameters

$$P_{min} = [0 \ 1 \ 10], \quad P_{max} = [10 \ 2 \ 1000], \quad \text{and } P_{type} = [1 \ 2 \ 3],$$

if a chromosome with normalized gene values is

$$P_{g;k} = [5 \ 1.5 \ 500],$$

then the corresponding chromosome with actual gene values is

$$P_{ng;k} = [0.5 \ 0.5 \ 0.8495].$$

See Also `rawgene`

objwght

Purpose Create an objective weight vector for use in multi-objective optimization

Syntax `owv = objwght (GAP)`

Arguments `GAP` structure of genetic algorithm parameters

Value `owv` normalized weight vector for scalarization of the multi-objective function values

Description `objwght` generates a normalized weight vector to be used for scalarization of the fitness function values in the multi-objective optimization problem.

In the single-objective optimization problem where `GAP.fp_nobj = 1`, there is only one objective function. Thus `objwght` returns `owv = 1`

Even in the multi-objective optimization problem (`GAP.fp_nobj > 1`), it is possible to use one objective function value for fitness evaluation. The objective function number to be used is specified in `GAP.fp_obj`. Then the output weight vector `owv` has all zero values except for the element corresponding to the objective function specified by `GAP.fp_obj`.

Example Consider a multi-objective optimization with three objectives f_1 , f_2 and f_3 . A possible weight vector is

$$\text{owv} = [0.2 \quad 0.7 \quad 0.1] .$$

Then the fitness value is calculated as

$$\text{Fitness} = 0.2 f_1 + 0.7 f_2 + 0.1 f_3 .$$

If `GAP.fp_obj = 2`, then `objwght` generates

$$\text{owv} = [0 \quad 1 \quad 0] .$$

Hence the fitness value is calculated as

$$\text{Fitness} = f_2 .$$

paretoplot

Purpose Plot two objective functions in 2D objective space

Syntax `paretoplot (fignum, P, GAP, [region])`

Arguments

<code>fignum</code>	figure number
<code>P</code>	structure of current population
<code>GAP</code>	structure of genetic algorithm parameters
<code>region</code>	an optional integer argument specifies the region of which the chromosomes are plotted

Description `paretoplot` generates 2D plot of 2 objective functions as in Figure B.4. It is called within `reportplot`.

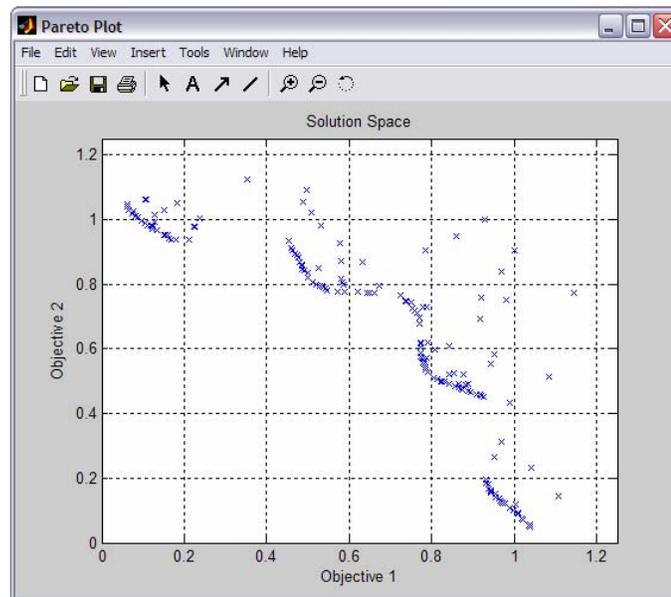


Figure B.4 Pareto plot for Tanaka problem

See also `reportplot`, `distplot`

randsearch

Purpose Perform a random search in the vicinity of the best individual in each region for better individual

Syntax `Pout = randsearch(Pin, GAP, GAS, D)`

Arguments

- `Pin` structure of current population
- `GAP` structure of genetic algorithm parameters
- `GAS` structure of genetic algorithm statistics
- `D` an optional data structure if needed for fitness evaluation

Value `Pout` structure of the population after the random search

Description `randsearch` explores the neighborhood of the best individual for better solution by random mutation of the best individual. By extensively exploring the vicinity of the best individual, it helps the GA to converge to the optimal solution faster.

There are two different random search operations. They are the relative random search that uses the relative vector mutation and the absolute random search that employs the absolute vector mutation. At each generation, only one of the two random search operations is active.

Random search starts at $(GAP.rs_fgs \times GAP.fp_ngen)$ 'th generation and $(GAP.rs_fps \times GAP.fp_npop)$ individuals are randomly generated using relative vector mutation with the standard deviation of `GAP.rs_srp` or absolute vector mutation with the standard deviation of `GAP.rs_sap`. The choice between the two random mutations is dependant on the value `GAP.rs_frp`. `GAP.rs_frp` is the probability that the absolute mutation is used and thus the probability that the relative mutation is utilized is $(1 - GAP.rs_frp)$.

After generating the mutants, the fitness values of the mutants are evaluated. If there exists an individual whose fitness is better than that of the current best individual, then the current best is replaced by the new individual.

rawgene

Purpose Update the raw gene values based on the normalized gene values

Syntax `Pout = rawgene(Pin)`

Arguments `Pin` structure of population before updating raw gene values

Value `Pout` structure of population after updating raw gene values

Description `rawgene` updates the actual gene values (`P.gene`) based on the normalized gene values (`P.normgene`). The normalized gene value is mapped to a value in the predefined range according to the type of the gene (`P.type`). Note that only the population members who have not been evaluated are updated.

The following table shows how `rawgene` maps the normalized gene value to the actual gene values on j 'th gene of the k 'th chromosome for different types of gene.

Gene type	P_{type}	Operation
Integer	1	$P_{g;j,k} = [(P_{max;j} - P_{min;j}) \cdot P_{ng;j,k} + P_{min;j}]$ where $[]$ is the round -up operator
Real	2	$P_{g;j,k} = (P_{max;j} - P_{min;j}) \cdot P_{ng;j,k} + P_{min;j}$
Logarithmic	3	$P_{g;j,k} = \exp((\ln(P_{max;j}) - \ln(P_{min;j})) \cdot P_{ng;j,k} + \ln(P_{min;j}))$

Table B.5

Examples With the following parameters

$$P_{min} = [0 \ 1 \ 10], \ P_{max} = [10 \ 2 \ 1000], \ \text{and } P_{type} = [1 \ 2 \ 3],$$

if a chromosome with normalized gene values is

$$P_{ng;k} = [0.5 \ 0.5 \ 0.5],$$

then the corresponding chromosome with actual gene values is

$$P_{g;k} = [5 \ 1.5 \ 100].$$

See Also `normgene`

reportplot

Purpose Plot the distribution of the genes of the chromosomes, the fitness history and Pareto plot

Syntax `reportplot (GAP , GAS , Pk , GUIhdl)`

Arguments

- GAP structure of genetic algorithm parameters
- GAS structure of genetic algorithm statistics
- P structure of the current population
- GUIhdl handle for GOSET GUI

Value None

Description Plots the distribution of the genes of the chromosomes with the fitness history as in Figure B.5 or the Pareto plot as in Figure B.6

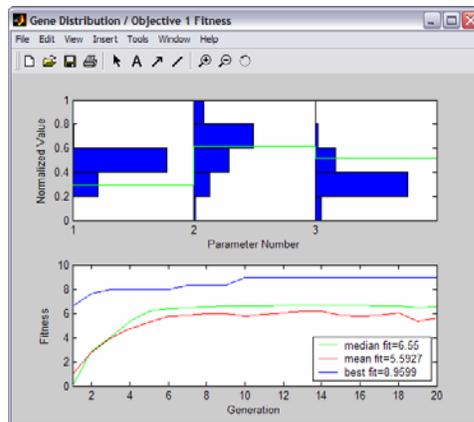


Figure B.5 Gene distribution plot

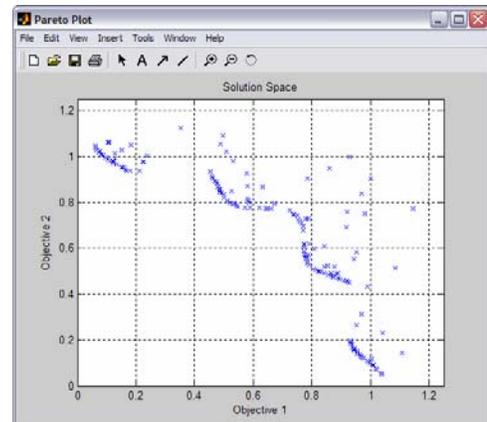


Figure B.6 2D Pareto plot

It is also possible to use a custom plotting routine on top of the distribution/fitness history plot and the Pareto plot by defining custom report plot handle `GAP.rp_crh`. The custom report plotting routine must have the following format without output return value.

`f (P , GAP)`

P structure of current population
GAP structure of genetic algorithm parameters

See also `distplot`, `paretoplot`

scale

Purpose Update scaling parameters and computes the scaled and aggregated fitness

Syntax $F = \text{scale}(Pin, GAP)$

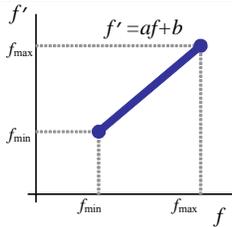
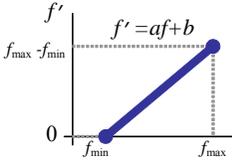
Arguments Pin structure of the input population
 GAP structure of genetic algorithm parameters

Value F scaled and aggregated fitness

Description `scale` generate the scaled and aggregated fitness value ($P.fit$) based on the current GAP and the current population. Scaling operator is applied independently to each region in the multiple region case.

Given the current fitness values, each fitness values ($P.fit$) is penalized by multiplying the penalty function value ($P.pen$) generated from the diversity control routine. Then the maximum (f_{max}), minimum (f_{min}), average (f_{avg}), media (f_{med}) and standard deviation (f_{std}) of the penalized fitness value of the population in each region are found.

Depending on the value of scaling algorithm parameter $GAP.sc_alg$, different scaling method is used as in Table B.6.

Scaling algorithm number ($GAP.sc_alg$)	Scaling method	Operation $f = \text{original fitness}$ $f' = \text{scaled fitness}$
0	None	 $a = 1$ $b = 0$
1	Offset scaling	 $a = 1$ $b = -f_{min}$

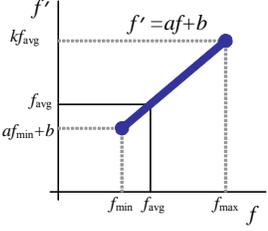
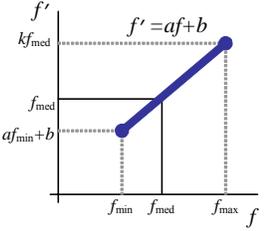
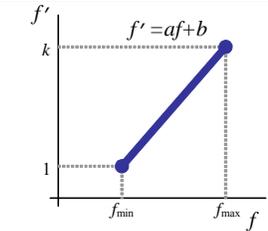
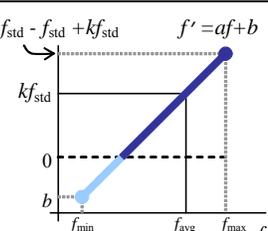
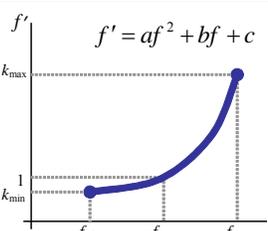
2	Standard linear scaling		$a = \frac{(k-1)f_{avg}}{f_{max} - f_{avg}}$ $b = f_{avg}(1-a)$ $k = \text{GAP.sc_kln}$
3	Modified linear scaling		$a = \frac{(k-1)f_{med}}{f_{max} - f_{med}}$ $b = f_{med}(1-a)$ $k = \text{GAP.sc_kln}$
4	Mapped linear scaling		$a = \frac{k-1}{f_{max} - f_{min}}$ $b = -f_{min} \cdot a + 1$ $k = \text{GAP.sc_kln}$
5	Sigma truncation		$a = 1$ $b = -(f_{avg} - k \cdot f_{std})$ $k = \text{GAP.sc_cst}$
6	Quadratic scaling		$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} f_{max}^2 & f_{max} & 1 \\ f_{avg}^2 & f_{avg} & 1 \\ f_{min}^2 & f_{min} & 1 \end{bmatrix}^{-1} \begin{bmatrix} k_{max} \\ 1 \\ k_{min} \end{bmatrix}$ $k_{max} = \text{GAP.sc_kmaxs}$ $k_{min} = \text{GAP.sc_kmns}$

Table B.6 Scaling algorithms

If $\text{GAP.sc_alg} = 0$, scaling is not used.

If $\text{GAP.sc_alg} = 1$, offset scaling is used and f_{min} is mapped to 0 and f_{max} is mapped to $|f_{max} - f_{min}|$.

When $GAP.sc_alg = 2$, the fitness values are mapped so that the scaled fitness values also have same average fitness value as the original fitness value and the maximum fitness value is $GAP.sc_kln$ times larger than f_{avg} .

The case of $GAP.sc_alg = 3$ is similar to the case of $GAP.sc_alg = 2$, except that median fitness value is used instead of average fitness value.

With $GAP.sc_alg = 4$, fitness values are linearly scaled such that f_{min} is mapped to 1 and f_{max} is mapped to $GAP.sc_kln$.

Sigma truncation is applied when $GAP.sc_alg = 5$. All the fitness values smaller than $(f_{avg} - GAP.sc_cst \cdot H \cdot f_{std})$, where f_{avg} is the average fitness value and the f_{std} is the standard deviation of the fitness values, are mapped to negative values and therefore disregarded later by clipping to zeros. It is useful when there are few individuals with very small fitness value and most individuals have large fitness value.

If $GAP.sc_alg = 6$, quadratic scaling is used. This algorithm emphasizes the large fitness value and deemphasizes the small fitness value. The parameters of a quadratic function is found such that f_{max} is mapped to $GAP.sc_kmaxs$, f_{avg} to 1 and f_{min} to $GAP.sc_kmns$. Then other fitness function values are mapped according to this quadratic function. $GAP.sc_kmns$ is set to less than 1.

After applying the above scaling, all the negative fitness values are set to zeros, the fitness values are divided by the sum of all the fitness values. These final fitness values become the scaled fitness values that represent selection probabilities.

As the last step, the aggregate fitness values $P.fit$ for chromosomes are obtained by summing all the objective functions using the objective function weight vector $GAP.ovv$.

Examples Given the fitness function vector $P.mfit$ with three objective functions and five chromosomes as the following,

$$P.mfit = \begin{bmatrix} 4 & 5 & 10 & 10 & 11.1111 \\ 14 & -7.5 & 20 & 6.25 & 3.3333 \end{bmatrix}$$

If the penalty vector is

$$P.pen = [0.5 \quad 0.8 \quad 0.6 \quad 0.8 \quad 0.9],$$

then the penalized fitness becomes

$$\begin{bmatrix} 2 & 4 & 6 & 8 & 10 \\ 7 & -6 & 12 & 5 & 3 \end{bmatrix}$$

If we apply standard linear scaling with the scaling factor ($GAP.sc_klin$) of 2, we have $a = 1.5$, $b = -3$ for the first objective and $a = 0.5385$, $b = 1.9385$ for the second objective to yield

$$\begin{bmatrix} 0 & 3 & 6 & 9 & 12 \\ 5.7077 & -1.2923 & 8.4000 & 4.6308 & 3.5538 \end{bmatrix}.$$

To make the fitness values non-negative, any negative fitness values are set to zero, that is,

$$\begin{bmatrix} 0 & 3 & 6 & 9 & 12 \\ 5.7077 & 0 & 8.4000 & 4.6308 & 3.5538 \end{bmatrix}.$$

Then the fitness values are normalized by dividing the fitness value by the sum of the fitness value of the corresponding objective.

$$\begin{bmatrix} 0 & 0.1 & 0.2 & 0.3 & 0.4 \\ 0.2560 & 0 & 0.3768 & 0.2077 & 0.1594 \end{bmatrix}$$

With the objective function weight $[0.4 \ 0.6]$, the aggregate fitness values are found to be

$$P.fit = [0.1536 \ 0.0400 \ 0.3061 \ 0.2446 \ 0.2557]$$

Reference D. E. Goldberg, *Genetic Algorithm in Search, Optimization, and Machine Learning*, Addison Wesley Publishing Company, January 1989

select

Purpose Select chromosomes from the population and form a mating pool

Syntax `Pout = select(Pin, GAP)`

Arguments `Pin` structure of current population
`GAP` structure of genetic algorithm parameters

Value `Pout` structure of the population

Description Selection operator picks chromosomes from the current population to construct a mating pool for reproduction. When multiple regions are used, selection is applied within each region. That is, if there are m chromosomes in a region, the selection operator picks the chromosome only from that region until m spaces of the mating pool are filled. There are two different selection methods in GOSET that one can choose from. They are roulette wheel selection and tournament selection.

In the selection operation, the aggregate fitness values (`P.fit`) are divided by the sum of the aggregate fitness value to yield the normalized aggregate fitness values.

Roulette wheel selection

Setting `GAP.sl_alg = 1` will activate roulette wheel selection. In the roulette wheel selection, the probability of an individual to be selected to the mating pool is proportional to the aggregate fitness (`P.fit`).

Tournament selection

Tournament selection is used if `GAP.sl_alg` is set to 2. In the tournament selection, `GAP.sl_nts` individuals are randomly chosen, and their aggregate fitness values (`P.fit`) are compared and the individual with best fitness value is selected to the mating pool. This procedure is repeated until the mating pool is occupied.

Illustrations of these selection operators are in Chapter 2.

Custom selection

Custom selection routine can be used instead of the two existing selection algorithms. This is specified by setting `GAP.sl_alg` to 3 and setting

GAP.dt_cah with the handle of the custom function. The custom function must have the following format

```
P_list = f(region,size,age,mfit,fit)
```

P_list indices of the individuals to become parents
region the region number
size number of individuals for the death list
age vector describing ages of the individuals in population
mfit array with raw fitness values of the individuals in the region
fit vector of aggregate fitness values of individuals in the region

As an example of a custom algorithm, the Roulette wheel selection algorithm is written as an mfile called 'customselect.m' which is shown below.

```
% Custom select algorithm example - Roulette wheel selection algorithm
function plist = customselect(region,size,region_age,region_mfit,region_fit)

% determine the mating probability
Matprob = region_fit/sum(region_fit);

% create a mapping function for selection
map=cumsum(matprob);
% now do the selection
for i=1:size,
    choice=rand;
    j=1;
    while (choice > map(j))
        j=j+1;
    end
    plist(i)=j;
end
```

This mfile must be in the same folder as the fitness function file or in the GOSET folder. Then the custom file handle GAP.sl_cah is set to @customselect.

unrndinit

Purpose Randomly initialize the gene values and the regions of the individuals

Syntax `Pout = unrndinit (Pin, GAP)`

Arguments `Pin` structure of current population
`GAP` structure of genetic algorithm parameters

Value `Pout` structure of the population

Description `unrndinit` randomly generates chromosomes of the initial population.

First, the normalized gene values are randomly assigned as in the following,

$$P_{ng;j,k} = \text{rand}$$

where $P_{ng;j,k}$ represents the normalized gene value of j 'th gene in the k 'th individual and `rand` is MATLAB function that generates a random number between 0 and 1.

For the integer type gene, the normalized gene values are assigned with a discretized value between 0 and 1 such that they can represent correct integer values when mapped to actual gene values, that is,

$$P_{ng;j,k} = \frac{\text{fix}(\text{rand} \times \text{levels})}{\text{levels} - 1}$$

where $\text{levels} = P_{\max;j} - P_{\min;j} + 1$, and `fix` is a MATLAB function that rounds a number towards zero.

After this step, the actual gene values are determined according to their types by using `rawgene`.

If multi-regions are used, the chromosomes are distributed into regions by

$$P_{reg} = \text{ceil}(\text{rand} \times \text{GAP.nreg})$$

where `ceil` is a MATLAB function that rounds a number towards positive direction.

updateage

Purpose Update the age of the each individual in the population

Syntax `Newage = updateage (P)`

Arguments P structure of current population

Value Newage vector of new ages

Description The age of each individual in the population is updated. The age of the individual survived from the previous generation increase by one, and the age of the new individual is set to one.

updatestat

Purpose Update the statistic information of GAS

Syntax `GAS = updatestat (GAS, Pin)`

Arguments `Pin` structure of current population
`GAS` structure of genetic algorithm statistics

Value `GAS` structure of genetic algorithm statistics

Description The current average fitness value, the median fitness value, the best fitness value, and the gene values of the best individual are added to `GAS.meanfit`, `GAS.medianfit`, `GAS.bestfit`, and `GAS.bestgenes` respectively. The number of total evaluation is updated to `GAS.ne`.

Appendix C. GOSET parameter list

P.[*]	Description
P.fithandle	Handle to the fitness function
P.size	The number of individuals in the population
P.mfit	Unconditioned fitness function values
P.fit	Fitness function values
P.eval	Fitness evaluation flag 0: fitness is not evaluated 1: fitness is evaluated
P.age	Ages of the individuals in generation number
P.ngenes	Number of genes in all chromosomes of an individual
P.min	Minimum value of gene
P.max	Maximum value of gene
P.type	Types of genes 1: integer 2: linear 3: logarithmic
P.chrom_id	Chromosome ID of gene (used for multiple chromosome case)
P.normgene	Normalized gene values
P.gene	Gene values
P.region	Geographic region of an individual
P.pen	Penalty function which is used for diversity control

GAP.[*]	Description	Default
Fundamental parameters		
GAP.fp_ngen	No. of generations to evolve	100
GAP.fp_ipop	No. of chromosomes in initial population	100
GAP.fp_npop	No. of chromosome in the population	100
GAP.fp_nobj	No. of objective functions	1
GAP.fp_obj	Objective to optimize (0 for Multi-objective optimization)	1
Diversity control parameters		
GAP.dc_act	Diversity control usage flag 0: non-active 1: active	1
GAP.dc_alg	Diversity control algorithm	4
GAP.dc_spc	Diversity control space 1: Parameter space 2: Fitness function space	1
GAP.dc_mnt	Minimum threshold for algorithm 1	0.02
GAP.dc_mxt	Maximum threshold for algorithm 1	0.1
GAP.dc_ntr	No. of trials for algorithm 2	3
GAP.dc_mnb	Min no. of bins relative to pop. size for algorithm 2	0.5
GAP.dc_mxb	Max no. of bins relative to pop. size for algorithm 2	2
GAP.dc_dc	Diversity control distance const (Algorithm 3 & 4)	0.001
GAP.dc_nt	Diversity control test pop. size (Algorithm 4)	50
Selection algorithm parameters		
GAP.sl_alg	Selection algorithm 1: Roulette wheel 2: Tournament	1
GAP.sl_nts	No. of individuals used in a tournament	4
GAP.sl_cah	Function handle for the custom selection algorithm	[]
Death algorithm parameters		
GAP.dt_alg	Death algorithm 1: replace parents 2: random replacement 3: tournament on fitness 4: tournament on age 5: custom algorithm 6: random among 1 - 4	2
GAP.dt_nts	No. of individuals used in a tournament	4
GAP.dt_cah	Function handle for the custom death algorithm	[]
Mating and crossover parameters		
GAP.mc_pp	Percentage of pop. replaced by children	0.6
GAP.mc_fc	Fraction of chromosomes involved in crossover	1
GAP.mc_alg	Crossover algorithm 1: Single point crossover 2: Scalar simple blend crossover 3: Vector simple blend crossover 4: Scalar simulated binary crossover 5: Vector simulated binary crossover 6: Random algorithms	4
GAP.mc_gac	No. of gen. btw changing Algs for random crossover Alg	3
GAP.mc_ec	Tightness of distribution (η_c) for crossover algorithms 4 and 5	2
Mutation parameters		
GAP.mt_ptgm	Probability of a total gene mutation	0.001
GAP.mt_prgm	Probability of a relative partial gene mutation	0.002
GAP.mt_srgm	Standard deviation of relative partial gene perturbation	0.3
GAP.mt_pagm	Probability of a absolute partial gene mutation	0.002
GAP.mt_sagm	Standard deviation of absolute partial gene mutation	0.1
GAP.mt_prvm	Probability of relative vector mutation	0.002
GAP.mt_srvm	Standard deviation of relative vector mutation	0.3
GAP.mt_pavm	Probability of absolute vector mutation	0.002

GAP.mt_savm	Standard deviation of absolute vector mutation	0.1
GAP.mt_pigm	Probability of integer gene mutation	0.008
Migration parameters		
GAP.mg_nreg	No. of geographic regions the population is distributed	1
GAP.mg_tmig	Time between migrations in generations	0
GAP.mg_pmig	Probability of an individual to migrate	0
Evaluation parameters		
GAP.ev_bev	Block evaluation 0: evaluate an individual 1: evaluate all the individual	0
GAP.ev_are	Fitness reevaluation option 0: evaluate only the unevaluated 1: evaluate all	0
GAP.ev_ssd	Supplementary data 0: Pass P.gene 1: Pass P.age, P.mfit, P.region	0
Scaling parameters		
GAP.sc_alg	Scaling algorithm 0: none 1: offset so minimum fitness is zero 2: lin. scaling ($f_{avg} \rightarrow f_{avg}, f_{max} \rightarrow GAP.sc_klin \times f_{avg}$) 3: lin. scaling ($f_{avg} \rightarrow f_{avg}, f_{max} \rightarrow GAP.sc_klin \times f_{avg}$) 4: lin. scaling ($f_{min} \rightarrow 1, f_{max} \rightarrow GAP.sc_klin$) 5: sigma truncation 6: quadratic scaling	6
GAP.sc_kln	Scaling factor for linear scaling algorithms	10
GAP.sc_cst	Scaling constant for sigma truncation	2
GAP.sc_kmq	Max scaling factor for quadratic scaling ($f_{max} \rightarrow GAP.sc_kmq$)	10
GAP.sc_kmq	Min scaling factor for quadratic scaling ($f_{min} \rightarrow GAP.sc_kmq$)	0.01
Elitism Parameters		
GAP.el_act	Elitism activation flag	1
GAP.el_fgs	Fraction of generation to pass before starting random search	0
GAP.el_fpe	Fraction of pop. protected as elite for multi-objective optimization	0.5
Random search parameters		
GAP.rs_fgs	Fraction of generation to pass before starting random search	0.5
GAP.rs_fps	Fraction of total population size used in random search	0.1
GAP.rs_srp	Standard deviation used in relative perturbation	0.3
GAP.rs_sap	Standard deviation used in absolute perturbation	0.1
GAP.rs_frp	Fraction of time that relative random perturbations are used. Absolute random perturbation is used for the rest of the time.	0.7
GAP.rs_fea	Fraction of generations on which to execute the algorithm	0.2
Reporting parameters		
GAP.rp_lvl	Reporting level -1: no report 0: text only 1: plot & text	1
GAP.rp_gbr	Generation between reports	5
GAP.rp_crh	Function handle for custom reporting algorithm	[]
Objective plot parameters		
GAP.op_list	List of objectives to make objective plots for	[1]
GAP.op_style	Style for each objective 0: logarithmic 1: linear	[1 ... 1]
GAP.op_sgn	Sign of fitness for each objective -1: neg 1: pos/mixed	[1 ... 1]
GAP.dp_type	Distribution plot type 1: plot individuals 2: plot histograms	2
GAP.dp_np	Maximum number of individuals to plot	100
GAP.dp_res	Number of bins in distribution plot for type 2	20
Pareto plot parameters		
GAP.pp_list	List of 2 or 3 objectives to be used in Pareto plot	[]
GAP.pp_xl	x-axis label	'Objective 1'
GAP.pp_yl	y-axis label	'Objective 2'
GAP.pp_title	Pareto plot title	'Solution space'
GAP.pp_style	Style for each objective 0: logarithmic 1: linear	[1 ... 1]
GAP.pp_sgn	Sign of fitness for each objective -1: neg 1: pos/mixed	[1 ... 1]
GAP.pp_axis	Axis limits for Pareto Plot	[]
Gene definition parameters		
GAP.gd_min	Row vector of minimum gene values	Defined by the user
GAP.gd_max	Row vector of maximum gene values	
GAP.gd_type	Row vector of gene types 1: integer 2: linear 3: logarithmic	
GAP.gd_cid	Row vector of chromosome ID number	

GAS.[*]	Description
GAS.cg	Current generation number
GAS.medianfit	The median fitness values of each objective
GAS.meanfit	The average fitness values of each objective
GAS.bestfit	The best fitness values of each objective
GAS.bestgenes	The best gene values for each objective over the generations
GAS.ne	The number of the total objective function evaluations

Abbreviation list No.: Number Min: Minimum Max: Maximum Pop.: population Gen.: Generation Alg: Algorithm Neg: Negative Pos: Positive