

# WWW-NIMBUS for Interactive Multiobjective Optimization

by

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## **Introduction**

Software for solving multiobjective optimization problems is not easy to find. The task gets even more difficult if the problem involves nonlinear functions. WWW-NIMBUS [8], an interactive software system operating on the Internet, has been developed to answer this need. It can be used for solving nonlinear and even nondifferentiable and nonconvex multiobjective optimization problems. Because the Internet is easily accessible, the system is automatically available to large numbers of people. In 1995, the first version of WWW-NIMBUS was the first interactive multiobjective optimization software operating on the Internet. Even now, when version 3.3 of WWW-NIMBUS is available at <http://nimbus.mit.jyu.fi/> it continues to be a unique software system. WWW-NIMBUS has changed quite a lot during the years but it can still be used free of charge for teaching and academic research proposes.

WWW-NIMBUS is based on the principles of centralized computing and distributed interface. This means that all the calculations take place in a server computer at the University of Jyväskylä and the user interface is the browser of each individual user. In this way, the system sets no requirements on the user's computer and the operating system used and/or compilers available play no role. There is nothing to be installed and the latest version of the system is always available. Furthermore, the World-Wide Web (WWW) provides a convenient and graphical user interface with visualization possibilities.

The NIMBUS method is the core of WWW-NIMBUS. NIMBUS (Nondifferentiable Interactive Multiobjective BUNDLE-based optimization System) is an interactive method where preference information is acquired from the decision maker in the form of a classification of the objective functions. The method has been applied, for example, in structural design problems [11], in the optimal control problems of the continuous casting of steel [12] and in the optimal shape design of paper machine headboxes [3]. Results with both small-scale and large-scale problems give evidence of the reliability and efficiency of the method. Different versions of NIMBUS are described in [5,6, 7]. Here we concentrate on the latest, so-called synchronous, version [10].

In NIMBUS, the decision maker can iteratively learn about the problem and can conveniently direct the solution process. NIMBUS has been designed to be easy to use and, unlike many interactive methods, it does not require consistent information from the decision maker. Furthermore, the information handled is straightforward. The objective function values have a direct meaning to the decision maker and no artificial concepts are needed.

## **NIMBUS Method**

The multiobjective optimization problems to be considered are of the form

with  $k$  objective functions to be minimized simultaneously. The decision vector belongs to the (nonempty) compact feasible set  $S$ . The images of the feasible decision vectors are called feasible objective vectors.

The idea of the interactive NIMBUS method is to move around the set of Pareto optimal solutions. Thus, we need information about the ranges of the feasible objective vectors in the Pareto optimal set. We refer to the best values of each objective function as their *ideal values*.

In the interactive solution process, the decision maker can at each iteration indicate what kind of a solution would be more satisfactory than the current with the help of a classification. Thus, the user can evaluate the problem to be solved and adapt one's preferences during the solution process in an iterative and flexible way. Let

stand for the Pareto optimal decision vector at the iteration  $h$ . Then the decision maker is asked to classify the objective functions into up to five classes for objective functions whose values should be decreased

, should be decreased till some aspiration level , are satisfactory at the moment , are allowed to increase till some upper bound and are allowed to change freely .

The difference between the first two classes is that the objective functions in the first class are to be minimized as far as possible but the functions in the second class only till the aspiration level specified. The decision maker is asked to specify the aspiration levels and upper bounds, if needed. Since improvement in the Pareto optimal set in any objective function value is possible only by allowing impairment in some other objective function, the classification is feasible only if neither nor is empty.

After the classification, a *subproblem* [8] is formed based on the information specified as

where are the ideal objective values. We set for some small positive scalar .

Otherwise, we set .

As shown in [9], different subproblems may lead to different solutions even though they are based on the same preference information. Usually method developers select one subproblem, which means that they select the solution to be generated. Yet, there is no general way how to identify the best solution without involving the decision maker.

In the synchronous version of NIMBUS [10], there are three subproblems available in addition to (1). This means that if the decision maker wants so, (s)he can see up to four different solutions after one classification. In other words, by classifying the objective functions once, the decision maker can get a better picture of different Pareto optimal solutions satisfying the preference information specified. Besides, the method developers do not have to make the choice related to the subproblem. Based on the experiments and comparison of different subproblems [9], we have selected subproblems extracted from the STOM, GUESS and Wierzbicki's reference

point methods (see, e.g. [7]). They all involve reference point information that can be derived from the classification.

In NIMBUS, the decision maker can also explore a desired number of intermediate solutions between any two solutions. Note that the solutions generated using different subproblems or as intermediate solutions are not all necessarily different [9]. In this case, we only show the different ones.

The algorithm is terminated if the decision maker does not want to decrease any objective value or is not willing to let any objective value increase. Otherwise, the search continues iteratively by moving around the Pareto optimal set.

**WWW-NIMBUS System available at <http://nimbus.mit.jyu.fi>**

The WWW-NIMBUS system is capable of solving nonlinear problems involving even nondifferentiable and nonconvex functions where the variables can be continuous or integer-valued. The constraints may be linear, nonlinear or bounds for variables.

Personal usernames and passwords enable saving and handling private problems so that the user can return to them later. One can also visit WWW-NIMBUS as a guest but then it is not possible to save any problems to the system. Each page of WWW-NIMBUS has an individual help page. The system has also a tutorial.

The problem to be solved can be specified either by filling a web form or by preparing a Fortran subroutine. The possibility of specifying the problem as a subroutine enables the solution of large-scale problems and/or problems that do not have explicit formulas of functions. (However, this possibility is available for local users only.)

After the optimization problem has been specified, the starting point, either given by the decision maker or generated automatically by the system, is projected onto the Pareto optimal set. This point is the basis of the first classification. The classification of the objective functions can be carried out either symbolically or graphically by indicating desirable values in a bar chart with a mouse. The bars include information about the current objective values as well as the estimated ranges of each objective function in the Pareto optimal set.

After the classification, the user selects the maximum number (between one and four) of different new solutions to be generated. The system produces them by solving different subproblems using some of the underlying optimizers. The user can select the optimizer for each iteration individually. If the user wishes to use a computationally efficient local solver, it is possible to use the proximal bundle method [4]. This method can solve even nondifferentiable problems but it assumes the objective and the constraint functions to be locally Lipschitz continuous and it needs (sub)gradient information. If the problem has been specified using the web form, the user does not have to derive (sub)gradients because the software contains a symbolic (sub)differentiator.

If the user prefers global optimization, (s)he can select between two variants of genetic algorithm. In this case, the problem to be solved may contain also integer-valued variables. The two variants use different constraint-handling techniques. One of them is based on adaptive penalties [2] and the other is a method of parameter free penalties [1]. All the optimizers contain technical parameters and the user can change the default values, if necessary.

Whenever the user attains an interesting solution (s)he can save it in a solution database. This means that the user can comfortably return to previous solutions if they turn out to be interesting, after all. The comparison task between any set of solutions is facilitated by using visualizations of the alternatives. The user can select between bar charts, value paths and petal diagrams in both absolute and relative scales. The user can also drop some of the alternatives from further consideration.

In the implementation of WWW-NIMBUS, the goal has been to keep the system as general as possible. This means that special features available only in certain browsers have been avoided. The size of the problems that can be solved has not been limited in the implementation.

WWW-NIMBUS opens up a worldwide possibility for any Internet user to utilize the achievements of the Optimization Group (<http://www.mit.jyu.fi/optgroup/>) working at the University of Jyväskylä.

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