

TECHNISCHE UNIVERSITÄT DORTMUND

REIHE COMPUTATIONAL INTELLIGENCE

COLLABORATIVE RESEARCH CENTER 531

Design and Management of Complex Technical Processes
and Systems by means of Computational Intelligence Methods

SPOT
Sequential Parameter Optimization Toolbox

Thomas Bartz-Beielstein, Christian Lasarczyk
and Mike Preuß

No. CI-256/08

Technical Report ISSN 1433-3325 November 2008

Secretary of the SFB 531 · Technische Universität Dortmund · Dept. of Computer
Science/LS 2 · 44221 Dortmund · Germany

This work is a product of the Collaborative Research Center 531, "Computational
Intelligence," at the Technische Universität Dortmund and was printed with financial
support of the Deutsche Forschungsgemeinschaft.

SPOT

Sequential Parameter Optimization

Toolbox

Thomas Bartz-Beielstein

Faculty of Computer Science and Engineering Science
Cologne University of Applied Sciences
D-51643 Gummersbach
Germany

Christian Lasarczyk, Mike Preuß

Algorithm Engineering
Dept. of Computer Science
Dortmund University
D-44221 Dortmund
Germany
Version 0.5

November 13, 2008

Contents

1	Introduction	2
2	Requirements	3
3	Installation and Demonstration	4
3.1	Installation - Make Your System Ready	4
3.2	Demonstration - A first Example (CMA-ES algorithm)	5
3.2.1	Running the demo	5
3.2.2	Understanding the results	5
3.2.3	SPO Plots	5
4	How SPO works	8
5	Configuration - Adapting SPOT Settings to your needs	8
5.1	Modifying the 'Region Of Interest'	10
5.2	Modifying the SPO configuration	11
5.2.1	Changing the predictor	11

5.3	Modifying the CMAES configuration	11
5.3.1	Modifying the Problem Dimension	11
5.3.2	Modifying Factors that Remain Constant (Algorithm Design)	14
5.3.3	The file getuseroptions.m	14
5.4	Adding Factors to the Algorithm Design	14
5.4.1	Overview	14
5.4.2	The new Factor: CS (TCCS)	14
5.4.3	The new Factor DAMPS	16
5.5	Summary	17
6	Implementing Interfaces for the CMA-ES	17
6.1	Overview	17
6.2	The SPOT interface to the CMAES program	17
6.2.1	cmaesspot.m	17
6.2.2	getuseroptions.m	18
6.2.3	cmaesdemo1000.m	20
6.2.4	cmaesgenerateresfile	21
6.2.5	The Objective Function	21
6.2.6	The Design File	21
6.2.7	Testing the Interface	22
6.3	Parameter Tuning With SPO	22
6.3.1	Specifying the Region of Interest File	22
6.3.2	Specifying the SPO configuration file	22
6.3.3	Starting SPOT	23
7	Documentation of SPOT Interfaces	23
7.1	Design Files	24
7.2	Result Files	24
8	Common Errors	24
9	FAQ	26

1 Introduction

This article describes the SPO toolbox. SPO is an acronym for *sequential parameter optimization* (Bartz-Beielstein, 2006). The SPO *toolbox* described in this article is referred to as SPOT. It was developed over the last years by Thomas Bartz-Beielstein, Christian Lasarczyk, and Mike Preuß. The main purpose of SPO is to determine improved parameter settings for optimization algorithms to analyze and understand their performance. SPO was successfully applied to numerous optimization algorithms, especially in the field of evolutionary computation, i.e., evolution strategies, particle swarm optimization, algorithmic chemistries etc. in the following domains:

- machine engineering: design of mold temperature control (Mehnen et al., 2005; Weinert et al., 2004; Mehnen et al., 2004)
- aerospace industry: airfoil design optimization (Bartz-Beielstein and Naujoks, 2004)
- simulation and optimization: elevator group control (Bartz-Beielstein et al., 2005c; Markon et al., 2006)
- technical thermodynamics: non sharp separation (Bartz-Beielstein et al., 2005b)
- economy: agri-environmental policy-switchings (de Vegt, 2005)

Other fields of application are in fundamental research:

- algorithm engineering: graph drawing (Tosic, 2006)
- statistics: selection under uncertainty (optimal computational budget allocation) for PSO (Bartz-Beielstein et al., 2005a)
- evolution strategies: threshold selection and step-size adaptation (Bartz-Beielstein, 2005)
- other evolutionary algorithms: genetic chromodynamics (Stoean et al., 2005)
- computational intelligence: algorithmic chemistry (Bartz-Beielstein et al., 2005b)
- particle swarm optimization: analysis and application (Bartz-Beielstein et al., 2004a)
- numerics: comparison and analysis of classical and modern optimization algorithms (Bartz-Beielstein et al., 2004b)

Further projects, e.g., vehicle routing and door-assignment problems and the application of methods from computational intelligence to problems from bioinformatics are subject of current research.

2 Requirements

The SPO Toolbox relies on functions provided by the MATLAB Kriging toolbox DACE developed by Lophaven et al. (2002). MATLAB itself and the MATLAB statistics toolbox (which is already included in MATLAB) are also required. SPOT is able to run under different operating systems. Experiments described in Bartz-Beielstein (2006) were performed on various Linux Systems (Debian, Suse).

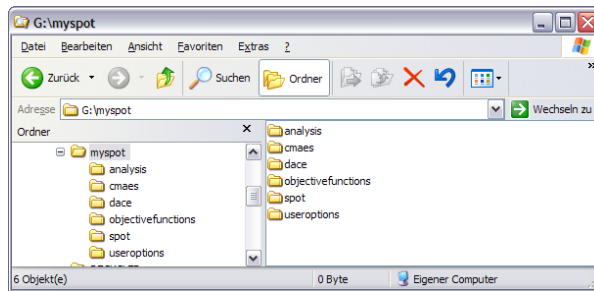


Figure 1: resulting directory structure

3 Installation and Demonstration

3.1 Installation - Make Your System Ready

1. Download the spot.zip file, which includes SPOT from <http://www.gm.fh-koeln.de/~bartz/experimentalresearch/spot.zip>
2. Download the MATLAB DACE toolbox, which is freely available from <http://www2.imm.dtu.dk/~hbn/dace/>
3. After the two files have been downloaded, create a new directory of your choice where you want SPOT to be executed from and unzip both toolboxes into this directory (in this example we want `g:\myspot` to be this directory).

4. SPOT can be used to tune every algorithm that allows (or requires) the specification of exogenous parameters. Since there are several algorithms available, we use an *Evolution Strategy with Covariance Matrix Adaptation* (CMA-ES) algorithm to exemplify the procedure.

The CMA-ES sourcecode (`cmaes.m`) is already included in the spot.zip. For more information and other versions of the CMA-ES package please visit the official website http://www.bionik.tu-berlin.de/user/niko/cmaes_inmatlab.html.

Please note, that the CMA-ES package and SPOT can be used independently.

5. The resulting directory structure should look like in Fig. 1.
6. Now start MATLAB and add the directory with all subfolders to the PATH library of MATLAB. This can be done by selecting **File** $\Rightarrow$ **Set Path** to use the SetPath dialog box or using the functions `addpath` and `genpath` in combination, e.g. `addpath(genpath('g:\myspot'))`. Next you should change your current working directory to `g:\myspot`.

Adding the directory to the PATH library and changing current directory can also be automated. The file `startup.m` will be executed automatically on MATLAB startup if it exist in the MATLAB startup folder (`startup`

folder may be s.th. like this on windows systems: '%HOMEPATH%\My Documents\MATLAB'). Content of the startup.m file could look like this:

```
PATH_STR='G:\myspot';  
addpath(genpath([PATH_STR]));  
eval(['cd ' PATH_STR]);  
clear PATH_STR;
```

3.2 Demonstration - A first Example (CMA-ES algorithm)

3.2.1 Running the demo

Now, after you followed all steps above, you are able to run a demonstration by simply calling `spotdriver('demo1000')` from the MATLAB command console. This will start the SPO for two parameters of the CMA-ES algorithm. The two parameters to be optimized in this example are named 'NPARENTS' and 'NU'. They are used to assign the 'number of parents' and the 'population size' for the used Evolution Strategy algorithm. The number of parents and the population size are two of the main preferred parameters to play with on Evolution Strategy algorithms. At the beginning `spotdriver` generates the initial design and starts the sequential parameter optimization after that. The performance of the CMA-ES algorithm will be improved sequentially while the SPO algorithm is running. This demo takes a few seconds or minutes (which is mainly depending on your System components). While the SPO is running, a plot window will pop up, which visualizes the improvement of the optimization process until then. This window is updated after each SPO-loop walk through. After the SPO has finished its work, several statistical plots are generated automatically to show the progress of the optimization process. In the following we will go discuss some of these plots.

3.2.2 Understanding the results

The initial console output from the SPOT run (see Fig. 2) can be explained as follows. First, all files from previous runs are deleted to ensure a clean start (line 2-8). After that, the user defined region of interest for the (two) factors to be optimized are displayed (line 9,10). The initial design consists of 16 points within the specified regions. The design points are displayed in line 11-26.

The last lines from the console output read as shown in Fig. 3. Line 4 shows the factor settings from the best configuration and the corresponding function values.

3.2.3 SPO Plots

Figure 4 shows results from the run `demo1000`.

```

1: >> spotdriver('demo1000')
2: Clean up finished.
3: spot/demo1000.des deleted.
4: spot/demo1000.bst deleted.
5: spot/demo1000.res deleted.
6: spot/demo1000.dac deleted.
7: spot/demo1000.bcl deleted.
8: spot/demo1000.fbs deleted.
9:      1      50
10:     2      10
11:      25.347      5.2225
12:      44.583      2.9659
13:      15.108      3.233
14:      26.988      4.2093
15:      34.355      2.4231
16:      43.146      6.2626
17:      29.96      8.1013
18:      37.807      4.8361
19:      18.828      7.9191
20:      8.4869      9.5098
21:      36.572      3.8406
22:      49.363      5.6897
23:      22.198      9.4159
24:      12.448      7.2514
25:      4.6023      6.8547
26:      2.2425      8.7144
27: Initial designs written: Initialization done.....

```

Figure 2: SPOT generated output.

```

1: --- SP0 step 7 of Inf. ---Algorithm runs: 63 of 50 ---
2:      'NPARENTS'      'NU'
3:          2      8.7144
4: Min: 9.60936e-07, MinMerged: 4.81543e-05
5: Theta values:      0.5946      2.181

```

Figure 3: SPOT generated output. Final values.

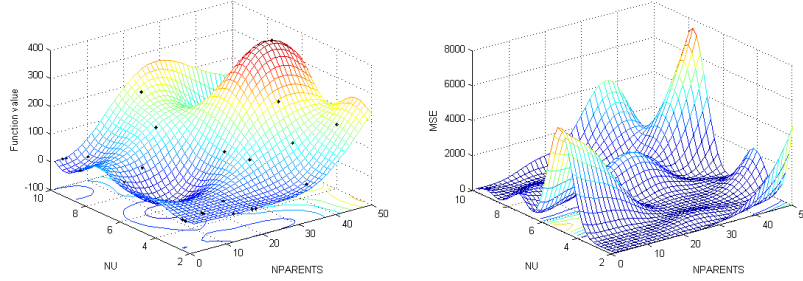


Figure 4: *left*: predicted function values; *right*: mean squared error

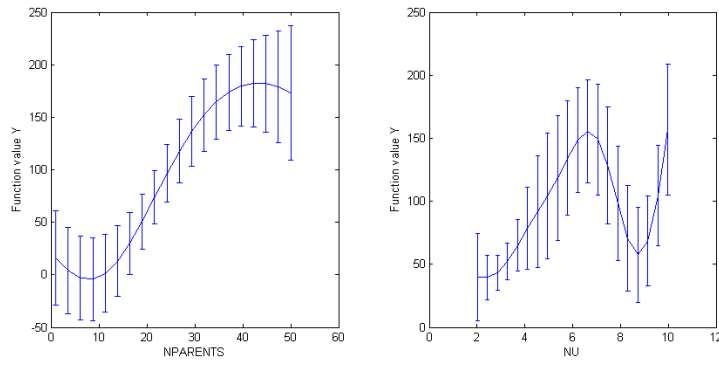


Figure 5: Effect plots

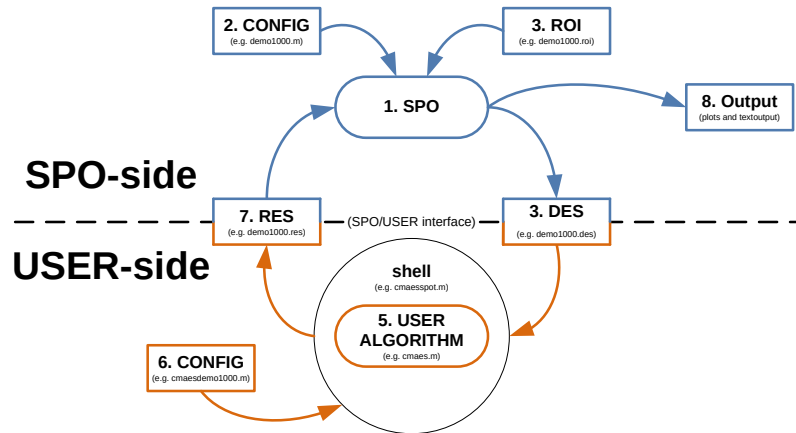


Figure 6: Functional principle of the SPO Toolbox

4 How SPO works

The SPO can determinate and improve parameter settings for any extern algorithm, which could be written in any programming language. The communication between SPO and the extern algorithm is transacted via simple structured text files. To make your algorithm able to interact with SPO it is necessary to build up a shell around your algorithm, so you don't need to modify your algorithm at all. The shell must be able to read parameter settings from a file, start the algorithm with these parameter settings and finally write the algorithm result to another file after it has finished.

The following files have to be set up by the user to configure the SPOT and the algorithm:

CONFIG file for SPO: This file contains important SPO setup parameters. For detailed parameter information see Table 1

ROI file - Region of Interests for the SPO: This file specifies the value range of the algorithm parameters which should be optimized.

CONFIG file for external algorithm: This file contains setup parameters for the external algorithm

Figure 6 clarifies how SPO mainly works and how it interacts with a user defined algorithm. At startup SPO and the algorithms shell read initial information from this specified configuration files (2, 3 and 6 in Fig. 6) to initialize SPO and the algorithm. After that step was done, the optimization sequence begins: SPO writes a design file (4 in Fig. 6). Afterward the shell runs the algorithm with the parameter settings read out from the design file and writes the results to a result file (7 in Fig. 6) after the algorithm has finished. Now the SPO reads the result file and start the first optimization loop to fit the stochastic process model and adapt the design file for better results next time. This whole optimization sequence is running again and again until the enumeration of loops to walk through is reached.

5 Configuration - Adapting SPOT Settings to your needs

Based on the example from Sect. 3.2, we demonstrate several features of the SPOT. Remember, there are three different configuration files related to SPOT and CMA-ES (as described in Sect. 4):

SPOT - CONFIG files: e.g., `demo1000.m`, see Fig. 7

SPOT - ROI files: e.g., `demo1000.roi`, see Fig. 8

CMAES - CONFIG files: e.g., `cmaesdemo1000.m`, see Fig. 10.

```

algorithmname= 'cmaesspot';
budget=50;
dacemodelname='';
defaulttheta=1;
designtype = 'lhd';
doecenterpoints = 4;
isotropic=0;
lhdintervals=0;
lhdsamples= 16;
loval=1E-3;
maxsteps=Inf;
maxrepeats=50;
mergetype=2;
meta = 0;
na=40;
new=1;
newdesignsize=2;
npoints=10;
ntestpointspersdim=10000;
repeats=1;
seed=0;
spotdirname='spot/';
spotcmodel='corrgauss';
%spotpredictor='tree';
spotpredictor='dace';
spotrmodel='regpoly0';
tol=1.e-2;
upval=100;
verbosity=2;
yname='Y';

```

Figure 7: demo1000.m. Table 1 explains these variables.

```

name low high isint pretty
NPARENTS 1 50 TRUE 'NPARENTS'
NU 2 10 FALSE 'NU'

```

Figure 8: demo1000.roi specifies the region of interest for two factors.

Changing the parameter settings in these files will take effect on the whole optimization process. But first a few words about these configuration files needed to be set up by the user for each experimental run. The prefix filename of all SPO related configuration files have to be the same for each experimental run. In Section 3.2 'demo1000' was used for this filename prefix. The name of the configuration file related to the user algorithm have to be handled by the user within the programmed shell, which is responsible for file interaction with the user algorithm. In section 3.2 the CMAES shell uses 'cmaesdemo1000' for filename prefix. The interface files `demo1000.des` and `demo1000.res` are generated automatically by SPO.

5.1 Modifying the 'Region Of Interest'

The ROI (*region of interest*) file contains the interesting value ranges of the algorithm parameters that should be optimized. These ranges are specified by two design points each (high and low limit value). The content of the ROI file used in the example from section 3.2 is shown in figure 8. The file structure is comparable with an array which elements are separated by blanks. First line acts as a headline for the specified regions of interest which are listed below. Each remaining line contains ROI information for one parameter to be optimized. The values, that have to be set up for each parameter are explained below:

1. name - factor name to be tuned
2. low - specifies the lower limit value for this factor
3. high - specifies the upper limit value for this factor
4. isint - exclusive use of integer for values of this factor? (could be TRUE or FALSE)
5. pretty - pretty print variant of the factor name, e.g., for axes labeling

The regions of interest can be modified to have a look on the performance with other parameter value ranges. To adjust the regions of interest, the ROI file can be modified using a simple text editor, or Matlab's editor. This change is related to the SPO (and not to the user's algorithm), therefore changes are performed in the file `demo1000.m`. Our general philosophy is to generate reproducible results. This can be achieved by assigning each experimental setup one unique experiment number. In our first example, we started with `demo1000`. Thus, the next experiment will be `demo1001`. This experiment requires the following files:

demo1001.m: SPOT related setup

demo1001.roi: Names and regions of interest of the factors to be tuned

cmaesdemo1001.m: Setup of the user defined optimization algorithm. We use `cmaes.m` and add the prefix `cmaes` to the names of the configuration files.

```

name low high isint pretty
NPARENTS 1 10 TRUE 'NPARENTS'
NU 2 20 FALSE 'NU'

```

Figure 9: Region of interest file `demo1001.roi`

Change the ROI file content like shown in figure 9 and run SPOT by calling

```
>> spotdriver('demo1001')
```

to see how it affects the SPO result.

5.2 Modifying the SPO configuration

5.2.1 Changing the predictor

The predictions used in the `demo1000` setup are based on the DACE model. Other models, e.g., classical regression or tree based models can be used, too. Next, we discuss how to use a tree-based regression model. Again, this change is related to the SPO (and not to the user's algorithm), therefore changes are performed in the file `demo1001.m`. Our general philosophy is to generate reproducible results. This can be achieved by assigning each experimental setup one unique experiment number. In our previous example, we used `demo1001`. Thus, the next experiment will be `demo1002`. This experiment requires the following files:

demo1002.m: SPOT related setup

demo1002.roi: Names and regions of interest of the factors to be tuned

cmaesdemo1002.m: Setup of the user defined optimization algorithm. We use `cmaes.m` and add the prefix `cmaes` to the names of the configuration files.

5.3 Modifying the CMAES configuration

5.3.1 Modifying the Problem Dimension

The experimenter might be interested in the question if similar algorithm designs are beneficial for different problem dimensions. Therefore, he has to modify the problem design. The problem design subsumes information about the objective function, e.g., the problem dimension, and specifies the available budget, e.g., time, number of function evaluations etc. To modify the problem dimension, the file `cmaesdemo1000.m` (Fig. 10) has to be edited. For example, using a text editor, you can change `dim = 10` to `dim =100` to analyze a 100 dimensional problem.

Table 1: detailed information about parameters in SPOT Configuration files (e.g. demo1000.m)

algorithmname	Call to the algorithm to be tuned. A script or batch file that calls the optimization algorithm has to be specified here.
budget	Maximum number of runs of the heuristic. Can be set to "Inf" if other termination criteria should be used.
defaulttheta	Only for spotpredictor = 'dace': Default theta values in the DACE model
designtype	Set this to "lhd" in order to use space filling (Latin hypercube designs) or to "doe" to use classical desing of experiments.
doecenterpoints	Only for spotpredictor = 'doe': Number of center points for the DOE
isotropic	Define number of theta values, default is # of factors, which defines anisotropic models. Set nTheta to 1 to use isotropic models.
lhdivtervals	Lower and upper bound for the LHS. Used for the ROI.
lhdsamples	Number of initial configurations (initial sample size) of the heuristic to be performed.
loval	Only for spotpredictor = 'dace': lower bound for theta values in the DACE model
maxrepeats	Maximum number of repeats for one algorithm parameter setting. "Inf" if other termination criteria should be used. See also: budget , maxsteps .
maxsteps	Maximum number of runs of the SPO. Can be set to "Inf" if other termination criteria should be used. See also: budget , maxrepeats .
mergetype	Determines how results from one run configuration should be aggregated. Can be one of the following: "1": mean, "2": median
meta	Set this value to "1" if meta runs should be performed, see Sect. ?? . Otherwise choose "0" (default).
na	Only for spotpredictor = 'dace' or if a dace model is plotted: Grid size for the dace model plot. Default "40".
new	To start a new run, especially with filenames that have been used for other runs and these files should be overwritten, set this value to "1". To continue an existing experiment, choose "0".
newdesignsize	Number of algorithm configurations to be evaluated by the algorithm (should be small). Default "2".
npoints	number of points for effect plots
nsteps	Number of sequential optimization steps to be performed.
ntestpointsperdim	Number of testpoints (huge!) generated by the predictor.
repeats	Number of repeats in the initial design. Default "1".
seed	Initial seed for the SPOT functions. Default "0".
spotcmodel	Only for spotpredictor = 'dace': correlation model in the DACE model
spotdirname	Directory where the optimization algorithm reads configuration and writes results files (use a closing \ or /). Default: Directory where the spot files reside.
spotpredictor	Specify the SPOT predictor: "dace" uses Kriging (slow, but exact), "tree" uses regression trees (fast, can handle categorical factors as well)
spotrmodel	Only for spotpredictor = 'dace': regression model in the DACE model
tol	tolerance for effect plots
upval	Only for spotpredictor = 'dace': upper bound for theta values in the DACE model
yname	name of the value to be optimized (minimization). Default "Y". Will be written in the res and desfiles.

```

%Algorithm design:
nparents = 1;
nu = 1;
%Problem design:
fname = 'fsphere';
tmax = 1000;
startpoint = 10;
lb = 10;
ub = 100;
stepinit = 'detmod';
delta = 0;
dim = 10;
% Technical stuff
userdirname=pwd;
%
%The following parameters might be useful for future releases:
%
init = 'nunirnd';
termcriteria = 'iterations';
noisetype = 'noNoise';
noisedistribution = 'noNoise';
noiselevel = 0;
testset = 'gert';
gm = 0;
xopt = 0;
successlimit = 0.01;
showrun = 0;
showpoints = 0;
showendpoints = 0;
showsuccessfullstartpoints = 0;
showunsuccessfullstartpoints = 0;
interval = 0;
intervalsize = 100;

```

Figure 10: cmaesdemo1000.m

Table 2: detailed information about parameters in CMAES Configuration file (e.g. cmaesdemo1000.m)

userdirname	Path to the *des and *res-files
-------------	---------------------------------

5.3.2 Modifying Factors that Remain Constant (Algorithm Design)

Factors that are varied during the sequential parameter optimization are specified in the ROI file. Many algorithms have factors that remain constant during the sequential parameter optimization. They are specified in the `cmaesdemo1000.m` file. By default, every factor of the optimization algorithm is specified in the `cmaesdemo1000.m` file and SPO overwrites these values with values generated in the ROI file.

5.3.3 The file `getuseroptions.m`

The file `getuseroptions.m` can be found in the subdirectory `useroptions`. Users can specify default factor settings and some rather technical information such as directory names. It has to be modified if new factors are added to the algorithm design as explained in Sect. 5.4

5.4 Adding Factors to the Algorithm Design

5.4.1 Overview

In this section we consider how new factors can be added to the algorithm design. The example presented in section 5 uses two factors: `NPARENTS` and `NU`. The related experiment will be referred to as `demo1002`. The following files have to be modified to include a new factor:

`cmaes.m`: Since CMA-ES does not provide an interface for factors, we have to change the source code of `cmaes.m`. This is against our philosophy, because we usually do not change the source code. Future releases of the CMA-ES might provide an interface.

`cmaesspot.m`: Here we add the additional factor which is passed to `cmaes.m`.

`getuseroptions.m`: This function has to be modified, because it assigns a default value to the new factor.

`cmaesgenerateresfile.m`: This function writes results from the CMA-ES runs. Here we have to add the new factor, too.

`demo1002.roi`: Here we specify the additional region of interest for the new factor.

`demo1002.m`: Here we specify the settings (number of algorithm runs, predictor, etc.) of the SPO.

5.4.2 The new Factor: CS (TCCS)

We consider the time constant for cumulation for step-size control (`tccs` $\in [0, 1]$). Since `cs` is already used by MATLAB, we changed the variable name from `cs` to `tccs` in the `cmaes.m` file (Hansen and Ostermeier, 2001). Unfortunately,

CMA-ES does not provide an interface for this factor. Therefore, we added the following lines to the `cmaes.m` source code:

```
defopts.tccs = '0.5 % time constant for cumulation for step-size control';
...
%qqq hacking of a different parameter setting, e.g. for ccov or damps,
% can be done here.
% ccov = 0.0*ccov; disp(['CAVE: ccov=' num2str(ccov)]);
%TBB (Feb, 12th 2008):
tccs = opts.tccs;
```

Now we can use the `opts` structure to handle the `tccs` parameter. Modifications of the `cmaes.m` file are documented in the source code.

The next file we have to consider is `cmaesspot.m`. Here we add the lines

```
tccs = spotgetdesignvalues(a, b, 'TCCS');
...
if ismember('TCCS', b)
    useroptions.ad.tccs = tccs(i);
    opts.tccs = tccs(i);
end;
```

Since `cmaesspot.m` calls `getuseroptions.m`, we have to modify this function, too. We have to add one line to the algorithm design:

```
'ad', struct(... % algorithm design from Table 6.3 in [Bart06a, p.97]
'designfactorname1', '', ... %factors to be tuned
'nparents', nparents, ... % population size [cmaes]
'tccs', tccs, ... % time constant for cumulation for step-size control
'designfactornamen', ''), ... %n-th factor to be tuned
...
```

The new factor can be read by the CMA-ES, but it not written to the result-file. Therefore we modify the function `cmaesgenerateresfile.m` as follows:

```
function cmaesgenerateresfile(options)
a = exist(options.file.resfilename,'file');
if (a == 0)
    fid = fopen(options.file.resfilename,'w');
    fprintf(fid,'%s %s %s %s %s %s %s %s %s %s %s %s %s',...
        'Y','SUCC','NPARENTS','NU','TCCS','FNAME','ITER',...
        'DIM',...
        'CONFIG','SEED');
    fclose(fid);
end
fid = fopen(options.file.resfilename,'a');
fprintf(fid,'\n%g %d %d %g %g %s %d %d %d %d',...
    options.obj.y,...
    options.obj.succ, ...
    options.ad.nparents,...
    options.ad.nu,...
    options.ad.tccs,...
    options.pd.fname, ...
    options.pd.tmax,...
    options.pd.dim,...
    options.vars.configurationnumber,...
    options.obj.thisseed);
fclose(fid);
```

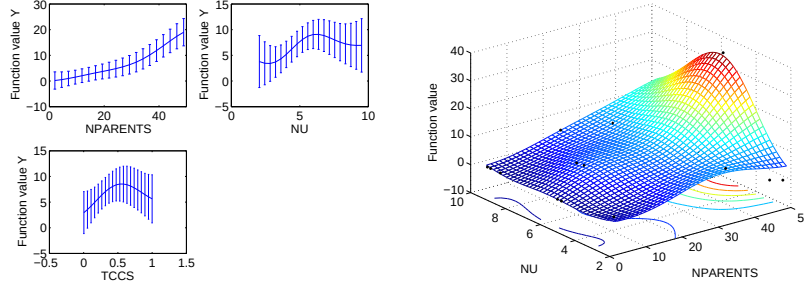


Figure 11: Results from the SPOT run with TCCS included.

```
name low high isint pretty
NPARENTS 1 50 TRUE 'NPARENTS'
NU 2 10 FALSE 'NU'
TCCS 0 1 FALSE 'TCCS'
DAMPS 0.25 0.99 FALSE 'DAMPS'
```

Figure 12: ROI file for 4 factors of the CMA-ES.

And, we have to set up the region of interest in the `demo1002.roi` file for this factor:

```
name low high isint pretty
NPARENTS 1 50 TRUE 'NPARENTS'
NU 2 10 FALSE 'NU'
TCCS 0 1 FALSE 'TCCS'
```

Finally, we have to specify the file for the SPO `demo1002.m` (here we simply copy the file `demo1000.m`, and add the following line to the file `demo1000.m` which will be save as `tt demo1002.m`):

```
%CMAES:
%Algorithm design:
nparents = 1;
nu = 1;
tccs = 0.5;
```

Now we are ready to perform the experiments:

```
spotdriver('demo1002.m')
```

The plots from these run are shown in Fig. 11.

5.4.3 The new Factor DAMPS

A fourth factor of the CMA-ES, called **damps**, can be tuned in the current SPOT version. The corresponding ROI file is shown in Fig. 12. Modifications presented in this documentation are already implemented in the SPOT version. So, if you want to try out the tuning process for 4 factors of the CMA-ES, you can use the setting from experiment `demo1003`, i.e., simply enter

```
>> spotdriver('demo1003')
```

in the command window.

5.5 Summary

SPO requires the specification of the following parameters:

1. Algorithm parameters to be tuned and varied. They are specified in the ROI file, e.g., `demo1000.roi`.
2. SPOT specific parameters, e.g., (`demo1000.m`)

In addition, the algorithm which should be tuned requires the specification of the following parameters:

1. Algorithm parameters that remain constant
2. Problem specific parameters

In our example (`cmaesdemo1000.m`) was used to specify these parameters.

6 Implementing Interfaces for the CMA-ES

6.1 Overview

In the following section, details of the SPOT implementation will be explained. We present examples, how SPOT can be adapted to your needs. This section will present some guidelines so that SPOT can be used for new algorithms.

6.2 The SPOT interface to the CMAES program

`cmaes.m` should be able to read SPO design files and write SPO resfiles. Therefore we write a MATLAB function called `cmaesspot.m`.

6.2.1 `cmaesspot.m`

```
function cmaesspot(filename)
clear useroptions;
useroptions = getuseroptions(filename);
opts.MaxFunEvals=useroptions.pd.tmax;
clear A;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% 2. Load design file data
[a,b] = autotextread(useroptions.file.desfilename);
CONFIG = (eval(strcat('a.','CONFIG')));
REPEATS = (eval(strcat('a.','REPEATS')));
SEED = (eval(strcat('a.','SEED')));
nofexp = length(CONFIG); %number of experiments

% Assign vectors of algorithm design values:
```

```

nparents = spotgetdesignvalues(a, b, 'NPARENTS');
nu = spotgetdesignvalues(a, b, 'NU');
%
for i=1:nofexp
    useroptions.vars.numberofruns = REPEATS(i);
    for j=1:REPEATS(i) %each experimental setting is repeated REPEAT(i) times
        useroptions.vars.repeatcounter = j;
        %opts=cmaes;
        opts.StopFitness=1e-10;
        % Overwrite default values with algorithm design values.
        if ismember('NPARENTS', b)
            useroptions.ad.nparents = round(nparents(i));
            opts.ParentNumber = useroptions.ad.nparents;
        end;
        if ismember('NU', b)
            useroptions.ad.nu = nu(i);
            opts.PopSize = round(nparents(i)*nu(i));
        end;

        % Run specific settings:
        useroptions.vars.configurationnumber = CONFIG(i);

        % SEED
        useroptions.obj.thisseed = SEED(i)+j;
        % the following is performed in cmaes.m:
        %rand('state',useroptions.obj.thisseed);
        %randn('state',useroptions.obj.thisseed);
        opts.Seed = useroptions.obj.thisseed;

        % Start one CMAES run:
        opts.Display = 'off'; opts.Plotting = 'off';
        opts.VerboseModulo = 0;

        %objectivefunctionhandle = str2func();
        [XMIN, FMIN, COUNTVAL, STOPFLAG, OUT, BESTEVER]=cmaes(useroptions.pd.fname,5*ones(10,1), 1.5, opts);
        useroptions.obj.y = FMIN;
        fprintf(' ');
        cmaesgenerateresfile(useroptions);
        % End of one CMA-ES run
    end
end
end

```

We recommend the adaption of the function `getuseroptions.m`, which specifies a generic options structure.

6.2.2 getuseroptions.m

The function `getuseroptions` calls the function `cmaesdemo1000.m` which specifies the default settings for the algorithm and problem design. Based on these values, `getuseroptions` generates the structure `useroptions`, which is used during the optimization runs.

```

function useroptions = getuseroptions(filename)
userprefix = 'cmaes';
userfhandle = str2func(strcat(userprefix,filename)); % add es specific prefix for the configuration file
userfhandle();

```

```

useroptions = struct(...)
...
... % ALGORITHM DESIGN
'ad', struct(... % algorithm design from Table 6.3 in [Bart06a, p.97]
'designfactorname1', '', ... %factors to be tuned
'nparents', nparents, ... % population size [cmaes]
'designfactornamen', ''), ... %n-th factor to be tuned
...
... % PROBLEM DESIGN
'pd', struct(...)
'fname', fname, ... % objective function
'startpoint', startpoint, ... % starting point (see also dim)
'lb', lb, ... %Lower bounds of Initialization
'ub', ub, ... %Upper bounds of Initialization
'stepinit', stepinit, ... % initialization of the step sizes
'delta', delta, ...% (machine precision) determine border for success
'dim', dim, ... % problem dimension
'init', init, ... %initialization method
'tmax', tmax, ... % maximum number of iterations
'termcriteria', termcriteria, ... % 'iterations', 'xDistance', 'yDistance'
'noisetype', noisetype, ... %noise type to use. Either noNoise, additive or proportional
'noisedistribution', noisedistribution, ... %noise Distribution to use. Either noNoise, normalDistributed or
'noiselevel', noiselevel), ... %noise level of the distribution function
...
... % OPERATING SYSTEM
'system', struct(...)
'unix', isunix), ... %are we running Windows ("0") or Unix ("1")
...
... % file AND I/O
'file', struct(...)
'dirname', userdirname, ...
'filename', filename), ...
...
... % TECHNICAL OBJECTIVE FUNCTION OPTIONS
'obj', struct(...)
'testset', testset, ...%set of test functions
'moren', 2, ...%variable n for the More test set
'morem', 2, ...%variable m for the More test set
'moreopt', 1, ...%variable option for the More test set
'fhandle', @Sphere, ... %function handle (use makeHandle.m to change handle
'gm', gm, ... %Value of Global Minima (Required if Error goal is a termination criteria).
'xopt', xopt, ...% x value of Global Minima, default value: repmat(Dim,xOpt)
'successlimit', successlimit, ...% function values smaller than SuccessLimit are treated as successful
'yreal', Inf, ... % best objective function value (YREAL) without noise
'y', Inf, ... % best objective function values (Y) with noise
'yalltime', Inf, ... % all time best function value (noisy)
'succ', 0, ... % run terminated successfully (SUCC)
'ybestlist', [], ... %list of best function value from every generation (for one run only)
'thisseed', 0), ... % seed used for this run
...
... % DISPLAY OPTIONS
'disp', struct( ...
'showrun', showrun, ... % Display best function value when the run is finished
'showlogrun', showlogrun, ... % Display best function value when the run is finished
'showcities', showcities, ... % Display best function value when the run is finished
'showpoints', showpoints, ... % Display starting and end points

```

```

'showendpoints', showendpoints, ... % Display starting and end points
'showsuccessfullstartpoints', showsuccessfullstartpoints, ... % Display starting and end points
'showUnsuccessfullstartpoints', showunsuccessfullstartpoints, ... % Display starting and end points
'interval', interval, ... %Notify about the progress after these many iterations (Default = 0 = OFF)
'intervalsize', intervalsize, ... % interval length around the best
'figurenumber', 1) ... %figure
);
useroptions.ad.noffspring = round(nu*nparents);%number of offspring individuals

useroptions.file.dirname= strcat(useroptions.file.dirname,'/', 'spot04/');
useroptions.file.desfilename = strcat(useroptions.file.dirname,useroptions.file.filename, '.des');
useroptions.file.bestfilename = strcat(useroptions.file.dirname,useroptions.file.filename, '.bst');
useroptions.file.resfilename = strcat(useroptions.file.dirname,useroptions.file.filename, '.res');
useroptions.file.dacmodelname = strcat(useroptions.file.dirname,useroptions.file.filename, '.dac');
useroptions.file.bestconfiglistname = strcat(useroptions.file.dirname,useroptions.file.filename, '.bcl');
useroptions.file.xbestfilename = strcat(useroptions.file.dirname,useroptions.file.filename, '.xbst');
useroptions.file.finalbestfilename = strcat(useroptions.file.dirname,useroptions.file.filename, '.fbs');

useroptions.obj.ffhandle = spotmakehandle(useroptions.pd.fname);
useroptions.pd.startpoint = useroptions.pd.startpoint * ones(1,useroptions.pd.dim);

```

6.2.3 cmaesdemo1000.m

The file `cmaesdemo1000.m` is a classical configuration file. It defines the settings for the algorithm and problem design. For example, if you want to change the problem dimension, you do not have to change the MATLAB code, but the settings in this configuration file.

```

%CMAES:
%Algorithm design:
nparents = 1;
nu = 1;
%Problem design:
fname = 'fsphere';
tmax = 1000;
startpoint = 10;
lb = 10;
ub = 100;
stepinit = 'detmod';
delta = 0;
dim = 100;
% Technical stuff
userdirname=pwd;
%
%The following parameters might be useful for future releases:
%
init = 'nunirnd';
termcriteria = 'iterations';
noisetype = 'noNoise';
noisedistribution = 'noNoise';
noiselevel = 0;
testset = 'gert';
gm = 0;
xopt = 0;
successlimit = 0.01;
showrun = 0;

```

```

showpoints = 0;
showendpoints = 0;
showsuccessfullstartpoints = 0;
showunsuccessfullstartpoints = 0;
interval = 0;
intervalsize = 100;
%
mutation = 'standard';
cities = 'loadst70';
showlogrun = 0;
showcities = 0;

```

6.2.4 cmaesgenerateresfile

The `cmaesspot.m` function calls the function `cmaesgenerateresfile.m` to write data in the resfile format.

```

function cmaesgenerateresfile(options)
a = exist(options.file.resfilename,'file');
    if (a == 0)
        fid = fopen(options.file.resfilename,'w');
        fprintf(fid,'%s %s %s %s %s %s %s %s %s %s %s %s %s',...
            'Y','SUCC','NPARENTS','NU','FNAME','ITER',...
            'DIM',...
            'CONFIG','SEED');
        fclose(fid);
    end
    fid = fopen(options.file.resfilename,'a');
    fprintf(fid,'\n%g %d %d %g %s %d %d %d %d',...
        options.obj.y,...
        options.obj.succ, ...
        options.ad.nparents,...
        options.ad.nu,...
        options.pd.fname, ...
        options.pd.tmax,...
        options.pd.dim,...
        options.vars.configurationnumber,...
        options.obj.thisseed);
    fclose(fid);

```

6.2.5 The Objective Function

For this demo, we have chosen the following objective function: `fsphere.m` which is located in the directory `objectivefunctions`.

```

function f=fsphere(x)
    f=sum(x.^2, 1);

```

6.2.6 The Design File

Each line in the design file contains one run configuration. Note, each configuration can be repeated several times (with different seeds). Configuration 1 from the file `demo1000.des` is repeated twice, whereas configuration 2 is repeated only once:

```
NPARENTS NU REPEATS CONFIG SEED STEP
2 2 2 1 123 1
7 4 1 2 123 1
```

6.2.7 Testing the Interface

Now we are ready for testing the interface. We can call the `cmaesspot.m` function as follows:

```
cmaesspot('demo1000')
```

6.3 Parameter Tuning With SPO

Until now, we have implemented the interface for the algorithm. The algorithm is able to read manually created design files and write results to result files. Next, we will show how to generate design files automatically and how to use data from the result files to perform statistical analyses.

6.3.1 Specifying the Region of Interest File

We specify the regions of interest for the design. The designs will be written to the design files. As we have chosen NPARENTS and NU, we write the `demo1000.roi` file which is located in the directory `myspot04`:

```
name low high isint pretty
NPARENTS 1 50 TRUE 'NPARENTS'
NU 2 5 FALSE 'NU'
```

6.3.2 Specifying the SPO configuration file

Finally, we have to define the SPO predictor, the number of SPO runs etc., i.e. SPO specific parameters. These are written to the file `demo1000.m` which is also located in the directory `myspot04`:

```
meta = 0;
new=1;
designtype = 'lhd';
spotpredictor='tree';
%spotpredictor='dace';
defaulttheta=1;
loval=1E-3;
upval=100;
spotrmodel='regpoly0';
spotcmodel='corrgauss';
isotropic=0;
repeats=1;
maxrepeats=50;
mergetype=1;
```



```

ntestpointsperdim=10000;
seed=0;
na=40;
newdesignsize=2;
lhdsamples= 16;
doecenterpoints = 4;
lhdintervals=0;
budget=1000;
maxsteps=Inf;
spotdirname='spot04/';
dacemodelname='';
npoints=10;
tol=1.e-2;
algorithmname= 'spotga';
yname='Y';
verbosity=1;

```

6.3.3 Starting SPOT

We are ready for the SPOT process. It can be called via

```
spotdriver('demo1000')
```

Please note, that `myspot04` has to be chosen as the working directory and all subdirectories have to be included in the MATLAB path.

Summarizing, the following files are necessary for the SPOT, where `xxx` denotes the experiment name, e.g. `demo1000`:

xxx.roi: Region of interest.

xxx.m: SPOT configuration file.

cmaesxxx.m: CMA-ES configuration file. Optimization problem configuration.

cmaesspot.m: Interface to the `cmaes.m` algorithm. Read design file.

getuseroptions.m: Read configuration from the `cmaesxxx.m` file and generate the options structure.

cmaesgenerateresfile.m: Generate the result file.

7 Documentation of SPOT Interfaces

The SPOT concept is very simple and can be used for any optimization algorithm that can read and write ASCII files.

SPOT proposes algorithm designs for the algorithm. The algorithm is run with these designs, results from these runs are written to *result files* (res-files).

SPOT reads the res-files and builds a stochastic process model. Based on this model, new algorithm design points are generated and written to the *design file* (des-file). See also Bartz-Beielstein et al. (2005b).

7.1 Design Files

Design files are ASCII files which store information columnwise. They consist of two parts: Header and body. The first line of a design file, the header, describes the variable names. Entries are separated by blanks. Each of the following lines contains information from one algorithm run. A minimum design file has two lines. It might contain the following information:

```
A REPEATS CONFIG SEED
2 3 1 123
```

“A” denotes the name of algorithm parameter to be tuned, e.g., NPARENTS. Each run is repeated three times with different random seeds, the first run uses seed 123. This is configuration 1.

Based on the values from the des-file the optimization algorithm is run. Its results are written to the res-file.

The header has to be the first line while the order of the other lines (rows) is arbitrary. The order of the columns is arbitrary, too. The example from above could be written as:

```
REPEATS CONFIG SEED A
3 1 123 2
```

7.2 Result Files

The structure of result files is the same as for design files: They are des-files with one additional column which contains the result from the optimization runs. A minimum result file contains the following information:

```
Y A REPEATS CONFIG SEED
0.2 2 3 1 123
```

This might be one result from an experiment which is based on the des-file from above. The algorithm run yields an function value of $Y = 0.2$.

Based on the values from the res-file SPOT will fit a stochastic process model to predict promising design points.

8 Common Errors

Table 3 lists errors, possible causes, and solutions.

Table 3: Common errors.

Error message	Possible cause	Solution
Unable to open file. ??? Undefined function or variable 'Y'.	Wrong MATLAB working directory	Change the MATLAB working directory. The MATLAB <code>cd</code> command changes the working directory. Alternatively you can use the Current Directory field in the MATLAB desktop toolbar.
	Batch file/shell script is not executed correctly	Test the script (permissions etc.) in a DOS/UNIX shell separately. If it works fine, you can execute it in the MATLAB command window.
??? Error using ==> dacefit least squares problem is underdetermined	Not enough design points	Increase the number of design points by modifying the value of <code>SpotOptions.Design.LHDSamples</code> . Reduce the model complexity.
??? Error using ==> textread File not found. Error in ==> spotreadroi at 6 [factornames, lb, ub, whole, pp] = textread(spotoptions.File.roifilename,... Error in ==> demoSpotJava at 18 SpotOptions = spotreadroi(SpotOptions);	Wrong spotdirname	Select the correct value for <code>spotdirname</code> in <code>demoSpotJava.m</code> or related files.
??? Error using ==> eval Undefined function or variable 'Y'. Error in ==> demoSpotJava at 64 Y=eval(SpotOptions.Vars.yname)	Wrong dir for external batch file (shell script)	Select the correct setting in external files, e.g., <code>runJava.bat</code>
??? Error using ==> predictor DMODEL has not been found Error in ==> demoSpotMatlab at 147 [yLhd0, dy0, mse0] = predictor(xLhd(i,:), dmodel0);	Result file contains non numerical results (Y values), e.g., Inf	1. Modify algorithm or problem designs to avoid divergent behaviour or 2. Replace "Inf" with large values (not recommended)

9 FAQ

- *Where can I find more information about the DACE toolbox?*
Check: <http://www2.imm.dtu.dk/~hbn/dace/>
- *My optimization algorithm was written in JAVA, C, C++,... Can I use SPOT?*
You can use any language if your algorithm is able to handle des- and res-files.
- *Does SPOT run without MATLAB?*
No.
- *My optimization algorithm is written in MATLAB. Is there a generic method to read des-files?*
Yes. Reading des-files from MATLAB can be done as follows.

1. Specify the algorithm design variables from your algorithm, e.g., mu and nu:

```
factornames = {'MU', 'NU'};
```

2. Read the des-file:

```
tdfread(designfilename, ' ');
```

3. Overwrite default values with values from the des-file:

```
for i=1:length(factornames)
    A(i)=factornames(i);
end
for i=1:length(eval(A{i})) %number of experiments
    for j=1:REPEATS(i) %each experimental setting is
        % repeated REPEAT(i) times.
        % Overwrite default values with algorithm
        % design values.
        if ismember('MU', A)
            mu = MU(i);
        end
        if ismember('NU', A)
            nu = NU(i);
        end
        ...
        RUN YOUR ALGORITHM
        ...
        WRITE RESULT FILE
    end
end
```

- *How can I evaluate an initial design specified in the ROI file without performing any sequential parameter optimization?*
Set the value `maxsteps=0`; in the spot configuration file.
- *I found a bug in the toolbox.*
Please report bugs and suggestions for improvement to `thomas.bartz-beielstein[at]fh-koeln.de`.
- *Is there any support available?*
Currently we cannot provide any support.
- *Is SPOT free?*
Yes. SPOT is published under the GPL.
- *Where can I find more information about experimental research, design of experiments (DOE), and design and analysis of computer experiments (DACE)?*
Bartz-Beielstein (2006) and Santner et al. (2003) are good starting points.
- *How can I quote this article?*
Please mention Bartz-Beielstein et al. (2006) if you have used the SPO toolbox.

References

- Bartz-Beielstein, T. (2005). Evolution strategies and threshold selection. In Blesa Aguilera, M. J., Blum, C., Roli, A., and Sampels, M., editors, *Proceedings Second International Workshop Hybrid Metaheuristics (HM'05)*, volume 3636 of *Lecture Notes in Computer Science*, pages 104–115, Berlin, Heidelberg, New York. Springer.
- Bartz-Beielstein, T. (2006). *Experimental Research in Evolutionary Computation—The New Experimentalism*. Springer, Berlin, Heidelberg, New York.
- Bartz-Beielstein, T., Blum, D., and Branke, J. (2005a). Particle swarm optimization and sequential sampling in noisy environments. In Hartl, R. and Doerner, K., editors, *Proceedings 6th Metaheuristics International Conference (MIC2005)*, pages 89–94, Vienna, Austria.
- Bartz-Beielstein, T., de Vegt, M., Parsopoulos, K. E., and Vrahatis, M. N. (2004a). Designing particle swarm optimization with regression trees. Interner Bericht des Sonderforschungsbereichs 531 Computational Intelligence CI–173/04, Universität Dortmund, Germany.
- Bartz-Beielstein, T., Lasarczyk, C., and Preuß, M. (2005b). Sequential parameter optimization. In McKay, B. et al., editors, *Proceedings 2005 Congress on Evolutionary Computation (CEC'05)*, *Edinburgh, Scotland*, volume 1, pages 773–780, Piscataway NJ. IEEE Press.

- Bartz-Beielstein, T., Lasarczyk, C., and Preuß, M. (2006). Sequential parameter optimization toolbox. Technical Report CI-15x/06, Universität Dortmund, Germany.
- Bartz-Beielstein, T. and Naujoks, B. (2004). Tuning multicriteria evolutionary algorithms for airfoil design optimization. Interner Bericht des Sonderforschungsbereichs 531 Computational Intelligence CI-159/04, Universität Dortmund, Germany.
- Bartz-Beielstein, T., Parsopoulos, K. E., and Vrahatis, M. N. (2004b). Design and analysis of optimization algorithms using computational statistics. *Applied Numerical Analysis & Computational Mathematics (ANACM)*, 1(2):413–433.
- Bartz-Beielstein, T., Preuß, M., and Markon, S. (2005c). Validation and optimization of an elevator simulation model with modern search heuristics. In Ibaraki, T., Nonobe, K., and Yagiura, M., editors, *Metaheuristics: Progress as Real Problem Solvers*, Operations Research/Computer Science Interfaces, pages 109–128. Springer, Berlin, Heidelberg, New York.
- de Vegt, M. (2005). Einfluss verschiedener Parametrisierungen auf die Dynamik des Partikel-Schwarm-Verfahrens: Eine empirische Analyse. Interner Bericht der Systems Analysis Research Group SYS-3/05, Universität Dortmund, Fachbereich Informatik, Germany.
- Hansen, N. and Ostermeier, A. (2001). Completely derandomized self-adaptation in evolution strategies. *Evolutionary Computation*, 9(2):159–195.
- Lophaven, S., Nielsen, H., and Søndergaard, J. (2002). DACE—A Matlab Kriging Toolbox. Technical Report IMM-REP-2002-12, Informatics and Mathematical Modelling, Technical University of Denmark, Copenhagen, Denmark.
- Markon, S., Kita, H., Kise, H., and Bartz-Beielstein, T., editors (2006). *Modern Supervisory and Optimal Control with Applications in the Control of Passenger Traffic Systems in Buildings*. Springer, Berlin, Heidelberg, New York.
- Mehnen, J., Michelitsch, T., Bartz-Beielstein, T., and Henkenjohann, N. (2004). Systematic analyses of multi-objective evolutionary algorithms applied to real-world problems using statistical design of experiments. In Teti, R., editor, *Proceedings Fourth International Seminar Intelligent Computation in Manufacturing Engineering (CIRP ICME'04)*, volume 4, pages 171–178, Naples, Italy.
- Mehnen, J., Michelitsch, T., Bartz-Beielstein, T., and Lasarczyk, C. W. G. (2005). Multiobjective evolutionary design of mold temperature control using DACE for parameter optimization. In Pfützner, H. and Leiss, E., editors, *Proceedings Twelfth International Symposium Interdisciplinary Electromagnetics, Mechanics, and Biomedical Problems (ISEM 2005)*, volume L11-1, pages 464–465, Vienna, Austria. Vienna Magnetics Group Reports.

- Santner, T. J., Williams, B. J., and Notz, W. I. (2003). *The Design and Analysis of Computer Experiments*. Springer, Berlin, Heidelberg, New York.
- Stoean, C., Preuss, M., Gorunescu, R., and Dumitrescu, D. (2005). Elitist Generational Genetic Chromodynamics - a New Radii-Based Evolutionary Algorithm for Multimodal Optimization. In McKay, B. et al., editors, *Proc. 2005 Congress on Evolutionary Computation (CEC'05)*, volume 2, pages 1839 – 1846, Piscataway NJ. IEEE Press.
- Tosic, M. (2006). Evolutionäre Kreuzungsminimierung. Diploma thesis, University of Dortmund, Germany.
- Weinert, K., Mehnen, J., Michelitsch, T., Schmitt, K., and Bartz-Beielstein, T. (2004). A multiobjective approach to optimize temperature control systems of moulding tools. *Production Engineering Research and Development, Annals of the German Academic Society for Production Engineering*, XI(1):77–80.

Index

getuseroptions.m, 12

CONFIG, 23

demonstration, 3

des-file, *see* design file

design file, 22

installation, 2

MATLAB DACE toolbox, 2

region of interest (ROI), 7

REPEATS, 23

res-file, *see* result file

result file, 22, 23

SEED, 23

sequential parameter optimization (SPO),
1

sequential parameter optimization tool-
box (SPOT), 1