



**HAL**  
open science

# BBOB 2010: Comparison Tables of All Algorithms on All Noiseless Functions

Anne Auger, Steffen Finck, Nikolaus Hansen, Raymond Ros

► **To cite this version:**

Anne Auger, Steffen Finck, Nikolaus Hansen, Raymond Ros. BBOB 2010: Comparison Tables of All Algorithms on All Noiseless Functions. [Technical Report] RT-388, INRIA. 2010, pp.152. inria-00516689

**HAL Id: inria-00516689**

**<https://inria.hal.science/inria-00516689>**

Submitted on 10 Sep 2010

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

***BBOB 2010: Comparison Tables of All Algorithms  
on All Noiseless Functions***

Anne Auger — Steffen Finck — Nikolaus Hansen — Raymond Ros

**N° 0388**

July 2010

Domaine 1



*R*apport  
technique



## **BBOB 2010: Comparison Tables of All Algorithms on All Noiseless Functions**

Anne Auger , Steffen Finck , Nikolaus Hansen , Raymond Ros

Domaine : Mathématiques appliquées, calcul et simulation  
Équipe-Projet TAO

Rapport technique n° 0388 — July 2010 — [152](#) pages

**Abstract:** This document presents the results from the BBOB Black-Box Optimization Benchmarking workshop of the GECCO Genetic and Evolutionary Computation Conference 2010 in tables. Each table presents the performance of each algorithm submitted to BBOB 2010 on one function and dimension from the noiseless testbed.

**Key-words:** continuous optimization, benchmarking

Anne Auger, Nikolaus Hansen and Raymond Ros are affiliated to the TAO team-project, INRIA Saclay – Ile-de-France, Université Paris Sud, LRI, F-91405 Orsay Cedex, France.

Steffen Finck is affiliated to the Research Center PPE, University of Applied Science Vorarlberg, Hochschulstrasse 1, 6850 Dornbirn, Austria.

## **BBOB 2010: Tables de comparaison de tous les algorithmes sur toutes les fonctions non-bruitées**

**Résumé :** Ce document présente les résultats sous forme de table du workshop Black-Box Optimization Benchmarking (BBOB) de la conférence Genetic and Evolutionary Computation Conference (GECCO), Portland, Oregon, États-Unis, 2010. Chaque table présente les performances des algorithmes soumis à BBOB 2010 pour un problème de la suite de fonctions tests.

**Mots-clés :** optimisation continue, banc d'essai

This document provides tabular results of the workshop for Black-Box Optimization Benchmarking (BBOB) at GECCO 2010<sup>1</sup>. Many algorithms have been tested on 24 benchmark functions in dimensions between 2 and 40. A description of the used objective functions can be found in [15, 11]. The experimental set-up is described in [14].

The performance measure provided in the following tables is the expected number of objective function evaluations to reach a given target function value (ERT, expected running time), divided by the respective value for the best algorithm. Consequently, the best (smallest) value is 1 and the value 1 appears in each column at least once. If the target was never reached, the median over all trials of the best function value is shown. See [14] for details on how ERT is obtained. Bold entries in the table correspond to values below 3 or the top-three best values.

## List of Tables

|    |                         |    |
|----|-------------------------|----|
| 1  | $f_1$ in dimension 2    | 7  |
| 2  | $f_2$ in dimension 2    | 8  |
| 3  | $f_3$ in dimension 2    | 9  |
| 4  | $f_4$ in dimension 2    | 10 |
| 5  | $f_5$ in dimension 2    | 11 |
| 6  | $f_6$ in dimension 2    | 12 |
| 7  | $f_7$ in dimension 2    | 13 |
| 8  | $f_8$ in dimension 2    | 14 |
| 9  | $f_9$ in dimension 2    | 15 |
| 10 | $f_{10}$ in dimension 2 | 16 |
| 11 | $f_{11}$ in dimension 2 | 17 |
| 12 | $f_{12}$ in dimension 2 | 18 |
| 13 | $f_{13}$ in dimension 2 | 19 |
| 14 | $f_{14}$ in dimension 2 | 20 |
| 15 | $f_{15}$ in dimension 2 | 21 |
| 16 | $f_{16}$ in dimension 2 | 22 |
| 17 | $f_{17}$ in dimension 2 | 23 |
| 18 | $f_{18}$ in dimension 2 | 24 |
| 19 | $f_{19}$ in dimension 2 | 25 |
| 20 | $f_{20}$ in dimension 2 | 26 |
| 21 | $f_{21}$ in dimension 2 | 27 |
| 22 | $f_{22}$ in dimension 2 | 28 |
| 23 | $f_{23}$ in dimension 2 | 29 |
| 24 | $f_{24}$ in dimension 2 | 30 |
| 25 | $f_1$ in dimension 3    | 31 |
| 26 | $f_2$ in dimension 3    | 32 |
| 27 | $f_3$ in dimension 3    | 33 |
| 28 | $f_4$ in dimension 3    | 34 |
| 29 | $f_5$ in dimension 3    | 35 |
| 30 | $f_6$ in dimension 3    | 36 |
| 31 | $f_7$ in dimension 3    | 37 |

---

<sup>1</sup>see <http://coco.gforge.inria.fr/doku.php?id=bbob-2010>

|    |                         |    |
|----|-------------------------|----|
| 32 | $f_8$ in dimension 3    | 38 |
| 33 | $f_9$ in dimension 3    | 39 |
| 34 | $f_{10}$ in dimension 3 | 40 |
| 35 | $f_{11}$ in dimension 3 | 41 |
| 36 | $f_{12}$ in dimension 3 | 42 |
| 37 | $f_{13}$ in dimension 3 | 43 |
| 38 | $f_{14}$ in dimension 3 | 44 |
| 39 | $f_{15}$ in dimension 3 | 45 |
| 40 | $f_{16}$ in dimension 3 | 46 |
| 41 | $f_{17}$ in dimension 3 | 47 |
| 42 | $f_{18}$ in dimension 3 | 48 |
| 43 | $f_{19}$ in dimension 3 | 49 |
| 44 | $f_{20}$ in dimension 3 | 50 |
| 45 | $f_{21}$ in dimension 3 | 51 |
| 46 | $f_{22}$ in dimension 3 | 52 |
| 47 | $f_{23}$ in dimension 3 | 53 |
| 48 | $f_{24}$ in dimension 3 | 54 |
| 49 | $f_1$ in dimension 5    | 55 |
| 50 | $f_2$ in dimension 5    | 56 |
| 51 | $f_3$ in dimension 5    | 57 |
| 52 | $f_4$ in dimension 5    | 58 |
| 53 | $f_5$ in dimension 5    | 59 |
| 54 | $f_6$ in dimension 5    | 60 |
| 55 | $f_7$ in dimension 5    | 61 |
| 56 | $f_8$ in dimension 5    | 62 |
| 57 | $f_9$ in dimension 5    | 63 |
| 58 | $f_{10}$ in dimension 5 | 64 |
| 59 | $f_{11}$ in dimension 5 | 65 |
| 60 | $f_{12}$ in dimension 5 | 66 |
| 61 | $f_{13}$ in dimension 5 | 67 |
| 62 | $f_{14}$ in dimension 5 | 68 |
| 63 | $f_{15}$ in dimension 5 | 69 |
| 64 | $f_{16}$ in dimension 5 | 70 |
| 65 | $f_{17}$ in dimension 5 | 71 |
| 66 | $f_{18}$ in dimension 5 | 72 |
| 67 | $f_{19}$ in dimension 5 | 73 |
| 68 | $f_{20}$ in dimension 5 | 74 |
| 69 | $f_{21}$ in dimension 5 | 75 |
| 70 | $f_{22}$ in dimension 5 | 76 |
| 71 | $f_{23}$ in dimension 5 | 77 |
| 72 | $f_{24}$ in dimension 5 | 78 |
| 73 | $f_1$ in dimension 10   | 79 |
| 74 | $f_2$ in dimension 10   | 80 |
| 75 | $f_3$ in dimension 10   | 81 |
| 76 | $f_4$ in dimension 10   | 82 |
| 77 | $f_5$ in dimension 10   | 83 |
| 78 | $f_6$ in dimension 10   | 84 |
| 79 | $f_7$ in dimension 10   | 85 |
| 80 | $f_8$ in dimension 10   | 86 |
| 81 | $f_9$ in dimension 10   | 87 |

|     |                                    |     |
|-----|------------------------------------|-----|
| 82  | $f_{10}$ in dimension 10 . . . . . | 88  |
| 83  | $f_{11}$ in dimension 10 . . . . . | 89  |
| 84  | $f_{12}$ in dimension 10 . . . . . | 90  |
| 85  | $f_{13}$ in dimension 10 . . . . . | 91  |
| 86  | $f_{14}$ in dimension 10 . . . . . | 92  |
| 87  | $f_{15}$ in dimension 10 . . . . . | 93  |
| 88  | $f_{16}$ in dimension 10 . . . . . | 94  |
| 89  | $f_{17}$ in dimension 10 . . . . . | 95  |
| 90  | $f_{18}$ in dimension 10 . . . . . | 96  |
| 91  | $f_{19}$ in dimension 10 . . . . . | 97  |
| 92  | $f_{20}$ in dimension 10 . . . . . | 98  |
| 93  | $f_{21}$ in dimension 10 . . . . . | 99  |
| 94  | $f_{22}$ in dimension 10 . . . . . | 100 |
| 95  | $f_{23}$ in dimension 10 . . . . . | 101 |
| 96  | $f_{24}$ in dimension 10 . . . . . | 102 |
| 97  | $f_1$ in dimension 20 . . . . .    | 103 |
| 98  | $f_2$ in dimension 20 . . . . .    | 104 |
| 99  | $f_3$ in dimension 20 . . . . .    | 105 |
| 100 | $f_4$ in dimension 20 . . . . .    | 106 |
| 101 | $f_5$ in dimension 20 . . . . .    | 107 |
| 102 | $f_6$ in dimension 20 . . . . .    | 108 |
| 103 | $f_7$ in dimension 20 . . . . .    | 109 |
| 104 | $f_8$ in dimension 20 . . . . .    | 110 |
| 105 | $f_9$ in dimension 20 . . . . .    | 111 |
| 106 | $f_{10}$ in dimension 20 . . . . . | 112 |
| 107 | $f_{11}$ in dimension 20 . . . . . | 113 |
| 108 | $f_{12}$ in dimension 20 . . . . . | 114 |
| 109 | $f_{13}$ in dimension 20 . . . . . | 115 |
| 110 | $f_{14}$ in dimension 20 . . . . . | 116 |
| 111 | $f_{15}$ in dimension 20 . . . . . | 117 |
| 112 | $f_{16}$ in dimension 20 . . . . . | 118 |
| 113 | $f_{17}$ in dimension 20 . . . . . | 119 |
| 114 | $f_{18}$ in dimension 20 . . . . . | 120 |
| 115 | $f_{19}$ in dimension 20 . . . . . | 121 |
| 116 | $f_{20}$ in dimension 20 . . . . . | 122 |
| 117 | $f_{21}$ in dimension 20 . . . . . | 123 |
| 118 | $f_{22}$ in dimension 20 . . . . . | 124 |
| 119 | $f_{23}$ in dimension 20 . . . . . | 125 |
| 120 | $f_{24}$ in dimension 20 . . . . . | 126 |
| 121 | $f_1$ in dimension 40 . . . . .    | 127 |
| 122 | $f_2$ in dimension 40 . . . . .    | 128 |
| 123 | $f_3$ in dimension 40 . . . . .    | 129 |
| 124 | $f_4$ in dimension 40 . . . . .    | 130 |
| 125 | $f_5$ in dimension 40 . . . . .    | 131 |
| 126 | $f_6$ in dimension 40 . . . . .    | 132 |
| 127 | $f_7$ in dimension 40 . . . . .    | 133 |
| 128 | $f_8$ in dimension 40 . . . . .    | 134 |
| 129 | $f_9$ in dimension 40 . . . . .    | 135 |
| 130 | $f_{10}$ in dimension 40 . . . . . | 136 |
| 131 | $f_{11}$ in dimension 40 . . . . . | 137 |



|     |                                    |     |
|-----|------------------------------------|-----|
| 132 | $f_{12}$ in dimension 40 . . . . . | 138 |
| 133 | $f_{13}$ in dimension 40 . . . . . | 139 |
| 134 | $f_{14}$ in dimension 40 . . . . . | 140 |
| 135 | $f_{15}$ in dimension 40 . . . . . | 141 |
| 136 | $f_{16}$ in dimension 40 . . . . . | 142 |
| 137 | $f_{17}$ in dimension 40 . . . . . | 143 |
| 138 | $f_{18}$ in dimension 40 . . . . . | 144 |
| 139 | $f_{19}$ in dimension 40 . . . . . | 145 |
| 140 | $f_{20}$ in dimension 40 . . . . . | 146 |
| 141 | $f_{21}$ in dimension 40 . . . . . | 147 |
| 142 | $f_{22}$ in dimension 40 . . . . . | 148 |
| 143 | $f_{23}$ in dimension 40 . . . . . | 149 |
| 144 | $f_{24}$ in dimension 40 . . . . . | 150 |

Table 1: Running time excess  $ERT/ERT_{best}^{2009}$  on  $f_1$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>1 Sphere</b>                        |          |            |            |            |            |             |             |             |             |             |                                        |
|----------------------------------------|----------|------------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|----------------------------------------|
| $\Delta ft_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02       | 1e-03       | 1e-04       | 1e-05       | 1e-07       | $\Delta ft_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                           | <b>1</b> | <b>1</b>   | 4.9        | 7.8        | 14         | 19          | 24          | 32          | 38          | 53          | (1,2)-CMA-ES [5, 3]                    |
| (1,2m)-CMA-ES                          | <b>1</b> | <b>1</b>   | <b>2.1</b> | <b>2.3</b> | 8.4        | 15          | 19          | 28          | 34          | 48          | (1,2m)-CMA-ES [5]                      |
| (1,2ms)-CMA-ES                         | <b>1</b> | <b>1</b>   | <b>2.8</b> | <b>2.9</b> | 6.5        | 11          | 17          | 24          | 29          | 39          | (1,2ms)-CMA-ES [5]                     |
| (1,2s)-CMA-ES                          | <b>1</b> | <b>1</b>   | 5.2        | 3.4        | 8.2        | 11          | 20          | 28          | 36          | 49          | (1,2s)-CMA-ES [3]                      |
| (1,4)-CMA-ES                           | <b>1</b> | <b>1</b>   | 3.8        | 3.4        | 6.4        | 9.4         | 14          | 20          | 24          | 32          | (1,4)-CMA-ES [6, 4]                    |
| (1,4m)-CMA-ES                          | <b>1</b> | <b>1</b>   | <b>2.1</b> | <b>2.3</b> | 6.6        | 10          | 16          | 19          | 22          | 30          | (1,4m)-CMA-ES [6]                      |
| (1,4ms)-CMA-ES                         | <b>1</b> | <b>1.1</b> | 3.3        | <b>2.4</b> | <b>4.8</b> | <b>8.5</b>  | <b>11</b>   | <b>14</b>   | <b>17</b>   | <b>24</b>   | (1,4ms)-CMA-ES [1, 6]                  |
| (1,4s)-CMA-ES                          | <b>1</b> | <b>1</b>   | 5.1        | 3.5        | 6.4        | <b>9.0</b>  | 13          | 16          | <b>19</b>   | <b>25</b>   | (1,4s)-CMA-ES [4]                      |
| (1+1)-CMA-ES                           | <b>1</b> | <b>1</b>   | <b>2.9</b> | 3.4        | 7.1        | 11          | 13          | 18          | 20          | 27          | (1+1)-CMA-ES [7]                       |
| (1+2ms)-CMA-ES                         | <b>1</b> | <b>1</b>   | 3.0        | <b>2.4</b> | <b>6.0</b> | 9.3         | <b>13</b>   | <b>16</b>   | 20          | 25          | (1+2ms)-CMA-ES [2]                     |
| Artif Bee Colony                       | <b>1</b> | <b>1</b>   | <b>2.3</b> | 7.4        | 22         | 38          | 60          | 82          | 105         | 151         | Artif Bee Colony [8]                   |
| avg NEWUOA                             | <b>1</b> | <b>1</b>   | <b>1.9</b> | <b>1.1</b> | <b>1.1</b> | <b>0.97</b> | <b>0.97</b> | <b>0.97</b> | <b>0.97</b> | <b>0.97</b> | avg NEWUOA [23]                        |
| CMA-EGS (IPOP,r1)                      | <b>1</b> | 7.7        | 14         | 7.3        | 15         | 22          | 47          | 66          | 94          | 125         | CMA-EGS (IPOP,r1) [12]                 |
| Adap DE (F-AUC)                        | <b>1</b> | <b>1</b>   | 3.6        | 6.1        | 19         | 29          | 39          | 58          | 69          | 101         | Adap DE (F-AUC) [10]                   |
| DE (Uniform)                           | <b>1</b> | <b>1</b>   | <b>2.5</b> | 4.5        | 18         | 31          | 44          | 57          | 71          | 100         | DE (Uniform) [9]                       |
| IPOP-aCMA-ES                           | <b>1</b> | <b>1</b>   | 3.6        | 3.3        | 8.3        | 11          | 17          | 22          | 26          | 36          | IPOP-aCMA-ES [16]                      |
| IPOP-CMA-ES                            | <b>1</b> | <b>1</b>   | 5.1        | 4.5        | 10         | 15          | 19          | 23          | 27          | 36          | IPOP-CMA-ES [22]                       |
| CMA+DE-MOS                             | <b>1</b> | <b>1</b>   | <b>2.3</b> | 3.6        | 22         | 44          | 74          | 92          | 122         | 171         | CMA+DE-MOS [18]                        |
| NBC-CMA                                | <b>1</b> | <b>1</b>   | <b>2.5</b> | 4.1        | 29         | 53          | 69          | 85          | 94          | 116         | NBC-CMA [21]                           |
| POEMS                                  | <b>1</b> | <b>1</b>   | 172        | 84         | 116        | 324         | 694         | 986         | 1394        | 1965        | POEMS [17]                             |
| PM-AdapSS-DE                           | <b>1</b> | <b>1.1</b> | <b>2.3</b> | 3.3        | 16         | 25          | 38          | 55          | 67          | 91          | PM-AdapSS-DE [9, 10]                   |
| pPOEMS                                 | <b>1</b> | <b>1</b>   | 54         | 82         | 153        | 342         | 2401        | 4014        | 6242        | 12106       | pPOEMS [17, 20]                        |
| Basic RCGA                             | <b>1</b> | <b>1</b>   | <b>2.2</b> | 9.2        | 46         | 77          | 188         | 346         | 466         | 734         | Basic RCGA [24]                        |
| SPSA                                   | <b>1</b> | 27         | 42         | 20         | 26         | 28          | 33          | 38          | 46          | 61          | SPSA [13]                              |

Table 2: Running time excess  $ERT/ERT_{best}$  2009 on  $f_2$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>2 Ellipsoid separable</b>          |            |            |            |            |            |           |                  |           |           |           |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|-----------|------------------|-----------|-----------|-----------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02     | 1e-03            | 1e-04     | 1e-05     | 1e-07     | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 10         | 42         | 67         | 80         | 65         | 66        | 66               | 65        | 64        | 67        | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | 15         | 30         | 85         | 99         | 85         | 86        | 86               | 83        | 82        | 85        | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 4.8        | 26         | 55         | 70         | 61         | 62        | 63               | 61        | 61        | 63        | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 4.9        | 46         | 201        | 214        | 168        | 166       | 166              | 160       | 157       | 156       | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>3.0</b> | <b>4.8</b> | 17         | 26         | 24         | 26        | 27               | 26        | 27        | 28        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 4.3        | 6.2        | 23         | 29         | 25         | 25        | 26               | 26        | 26        | 28        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>3.5</b> | 6.0        | 18         | 19         | 18         | 19        | 19               | 19        | 19        | 20        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | 3.6        | 9.3        | 19         | 26         | 22         | 23        | 23               | 23        | 23        | 24        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | 4.2        | 8.1        | <b>11</b>  | 16         | <b>14</b>  | <b>15</b> | <b>15</b>        | <b>15</b> | <b>16</b> | <b>17</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | 3.5        | <b>4.8</b> | <b>5.8</b> | <b>11</b>  | <b>11</b>  | <b>12</b> | <b>12</b>        | <b>13</b> | <b>13</b> | <b>14</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 14         | 20         | 22         | 32         | 38         | 46        | 52               | 56        | 62        | 77        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.2</b> | <b>1.1</b> | <b>1.9</b> | <b>5.6</b> | <b>8.5</b> | <b>10</b> | <b>14</b>        | 17        | 20        | 27        | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 11         | 269        | 1331       | 1953       | 4172       | 4065      | 3995             | 3783      | 3689      | 3624      | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 8.2        | 10         | 14         | 16         | 16         | 19        | 22               | 23        | 26        | 31        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 8.0        | 10         | 12         | 16         | 16         | 19        | 22               | 23        | 27        | 32        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | 4.6        | 5.1        | 14         | 18         | 15         | 16        | 17               | <b>17</b> | <b>18</b> | <b>19</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 4.2        | 7.5        | 16         | 21         | 18         | 19        | 20               | 20        | 21        | 22        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 13         | 20         | 24         | 30         | 34         | 40        | 45               | 54        | 59        | 69        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 15         | 21         | 38         | 102        | 118        | 157       | 203              | 253       | 295       | 305       | NBC-CMA [21]                          |
| POEMS                                 | 179        | 330        | 377        | 408        | 392        | 450       | 546              | 568       | 642       | 807       | POEMS [17]                            |
| PM-AdapSS-DE                          | 7.5        | 11         | 12         | <b>15</b>  | 15         | 19        | 22               | 24        | 25        | 30        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 156        | 708        | 1840       | 2152       | 2416       | 2672      | 3142             | 3515      | 4175      | 5218      | pPOEMS [17, 20]                       |
| Basic RCGA                            | 10         | 18         | 37         | 56         | 64         | 125       | 155              | 266       | 350       | 543       | Basic RCGA [24]                       |
| SPSA                                  | 12         | 149        | 1599       | 8950       | 13921      | 17255     | <i>33e-2/1e5</i> | .         | .         | .         | SPSA [13]                             |

Table 3: Running time excess  $ERT/ERT_{best}$  2009 on  $f_3$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>3 Rastrigin separable</b> |            |            |            |            |                  |            |            |            |            |                                       |
|---------------------------------------|------------------------------|------------|------------|------------|------------|------------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                        | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1.1</b>                   | 3.2        | 14         | 15         | 47         | 47               | 47         | 47         | 47         | 46         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                     | <b>2.1</b> | <b>3.3</b> | 8.4        | 28         | 35               | 43         | 43         | 43         | 42         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1.3</b>                   | 3.0        | <b>3.4</b> | 6.2        | 18         | 25               | 25         | 25         | 25         | 25         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                     | 4.7        | 18         | 15         | 44         | 44               | 43         | 51         | 51         | 50         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1.6</b>                   | <b>2.5</b> | 10         | 8.8        | 14         | 14               | 14         | 14         | 14         | 14         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                     | <b>1.1</b> | 3.5        | 3.8        | 5.4        | 6.1              | 6.1        | 6.1        | 6.2        | 6.2        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1.3</b>                   | <b>2.0</b> | <b>2.1</b> | 3.0        | 8.5        | 11               | 11         | 11         | 11         | 11         | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>2.1</b>                   | 4.5        | 5.3        | 7.1        | 20         | 24               | 24         | 24         | 24         | 24         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                     | <b>1.6</b> | 5.6        | 12         | 26         | 26               | 26         | 26         | 26         | 26         | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                     | <b>1.5</b> | 9.2        | 6.6        | 8.6        | 8.6              | 8.6        | 8.6        | 8.6        | 8.5        | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1.1</b>                   | <b>1.7</b> | 5.6        | <b>1.7</b> | <b>1.6</b> | <b>2.4</b>       | <b>2.9</b> | 3.5        | 4.1        | 5.0        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                     | <b>2.7</b> | 5.1        | <b>1.6</b> | 3.2        | 3.2              | 3.2        | <b>3.2</b> | <b>3.2</b> | <b>3.1</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 5.1                          | 10         | 96         | 273        | 443        | 726              | 1244       | 2884       | 2875       | 2815       | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1.3</b>                   | <b>1.6</b> | 5.3        | <b>2.0</b> | <b>1.6</b> | <b>2.0</b>       | <b>2.4</b> | <b>2.6</b> | <b>2.8</b> | <b>3.1</b> | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1.2</b>                   | <b>1.6</b> | 5.2        | <b>2.0</b> | <b>1.7</b> | <b>2.3</b>       | <b>2.5</b> | <b>2.7</b> | <b>2.9</b> | <b>3.1</b> | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1.1</b>                   | <b>2.5</b> | 4.2        | 3.5        | 7.1        | 7.4              | 7.6        | 7.7        | 7.8        | 8.0        | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1.2</b>                   | 4.2        | 4.2        | 3.3        | 7.7        | 8.0              | 8.7        | 8.9        | 9.0        | 9.1        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1.1</b>                   | <b>2.2</b> | 6.7        | <b>2.4</b> | <b>2.2</b> | <b>2.9</b>       | 3.4        | 3.8        | 4.3        | 5.1        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1.3</b>                   | <b>1.7</b> | 6.3        | 4.9        | 6.5        | 9.4              | 10         | 10         | 10         | 10         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                     | 220        | 42         | 10         | 12         | 18               | 23         | 29         | 32         | 41         | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1.3</b>                   | <b>1.6</b> | 5.0        | <b>1.8</b> | 34         | 34               | 34         | 34         | 34         | 34         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                     | <b>2.1</b> | 45         | 22         | 42         | 103              | 125        | 157        | 201        | 267        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1.1</b>                   | <b>1.6</b> | 5.9        | 18         | 18         | 38               | 67         | 79         | 81         | 83         | Basic RCGA [24]                       |
| SPSA                                  | 22                           | 10266      | 998        | 943        | 1281       | <i>14e-1/1e5</i> | .          | .          | .          | .          | SPSA [13]                             |

Table 4: Running time excess  $ERT/ERT_{best}$  2009 on  $f_4$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 4 Skew Rastrigin-Bueche separ |            |            |            |                  |            |            |                  |            |            |                                       |
|---------------------------------------|-------------------------------|------------|------------|------------|------------------|------------|------------|------------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                         | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03      | 1e-04            | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>                      | 5.0        | 8.4        | 13         | 58               | 73         | 70         | 68               | 67         | 65         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1.1</b>                    | 3.1        | 7.9        | 10         | 26               | 30         | 29         | 28               | 28         | 27         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                      | 3.2        | <b>2.2</b> | 13         | 48               | 46         | 43         | 42               | 42         | 40         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                      | 8.9        | 6.9        | 30         | 72               | 68         | 65         | 63               | 63         | 61         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                      | 3.0        | <b>1.3</b> | 7.9        | 27               | 25         | 24         | 23               | 23         | 22         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                      | <b>2.7</b> | <b>2.0</b> | 8.5        | 24               | 27         | 26         | 25               | 25         | 24         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                      | 5.5        | 6.0        | 5.0        | 14               | 17         | 16         | 16               | 16         | 15         | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                      | 3.3        | 3.4        | 3.9        | 18               | 17         | 16         | 16               | 16         | 15         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                      | <b>2.0</b> | 3.6        | 13         | 48               | 44         | 42         | 41               | 41         | 39         | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                      | <b>1.5</b> | <b>1.7</b> | 4.8        | <b>13</b>        | <b>12</b>  | <b>12</b>  | <b>11</b>        | <b>11</b>  | <b>11</b>  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1.0</b>                    | <b>2.7</b> | 3.7        | <b>1.9</b> | <b>2.6</b>       | <b>3.0</b> | <b>3.4</b> | <b>3.9</b>       | <b>4.6</b> | <b>5.6</b> | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                      | 4.5        | 6.2        | 4.0        | 14               | 13         | 12         | 12               | 12         | 11         | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 11                            | 23         | 19         | 178        | 1790             | 5680       | 5391       | 5242             | 5200       | 4998       | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                      | <b>2.8</b> | 4.0        | <b>2.0</b> | 111              | 103        | 98         | 95               | 95         | 91         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                      | <b>2.5</b> | 4.5        | <b>1.9</b> | 111              | 104        | 142        | 137              | 136        | 131        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                      | 4.1        | 3.1        | 5.7        | 39               | 62         | 80         | 84               | 85         | 85         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1.1</b>                    | 7.5        | 4.7        | 12         | 61               | 97         | 114        | 169              | 171        | 171        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1.1</b>                    | 3.3        | 4.3        | 3.1        | <b>5.2</b>       | <b>5.8</b> | <b>6.1</b> | <b>6.3</b>       | <b>6.8</b> | <b>7.6</b> | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                      | <b>2.7</b> | 6.6        | 5.8        | 14               | 16         | 16         | 20               | 26         | 25         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                      | 302        | 34         | 14         | 29               | 31         | 35         | 37               | 40         | 47         | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                      | 3.8        | 3.7        | 147        | 292              | 271        | 257        | 249              | 248        | 238        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                      | <b>2.6</b> | 34         | 31         | 45               | 103        | 131        | 150              | 180        | 216        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1.1</b>                    | 3.6        | 9.0        | 39         | 222              | 472        | 2793       | <i>36e-3/5e4</i> | .          | .          | Basic RCGA [24]                       |
| SPSA                                  | 25                            | 18094      | 4669       | 3783       | <i>47e-1/1e5</i> | .          | .          | .                | .          | .          | SPSA [13]                             |



Table 6: Running time excess  $ERT/ERT_{best}$  2009 on  $f_6$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 6 Attractive sector |            |            |            |            |            |            |                  |            |            |                                       |
|---------------------------------------|---------------------|------------|------------|------------|------------|------------|------------|------------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03               | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 3.4                 | <b>2.4</b> | 4.4        | 4.7        | 3.9        | 5.1        | 6.5        | 6.6              | 6.8        | 6.5        | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>2.7</b>          | <b>2.5</b> | <b>2.4</b> | 4.6        | 5.9        | 5.8        | 6.0        | 7.4              | 6.9        | 6.4        | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 3.0                 | 4.2        | 3.2        | 4.5        | 3.8        | 4.3        | 5.6        | 5.6              | 5.2        | 5.3        | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 3.4                 | <b>2.8</b> | 4.1        | 7.4        | 16         | 14         | 14         | 13               | 12         | 11         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 3.3                 | <b>2.8</b> | <b>1.6</b> | <b>2.8</b> | <b>2.6</b> | <b>2.9</b> | 3.1        | 3.1              | 3.1        | 3.2        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 3.5                 | <b>2.3</b> | <b>1.4</b> | <b>2.2</b> | <b>2.7</b> | <b>3.0</b> | 3.0        | 3.0              | <b>3.0</b> | 3.0        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1.8</b>          | <b>1.5</b> | <b>1.7</b> | <b>2.7</b> | <b>2.5</b> | <b>2.4</b> | <b>2.5</b> | <b>2.4</b>       | <b>2.4</b> | <b>2.3</b> | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | 6.1                 | 4.4        | <b>2.0</b> | <b>2.6</b> | <b>2.7</b> | <b>2.6</b> | <b>2.7</b> | <b>2.8</b>       | <b>2.7</b> | <b>2.6</b> | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | 3.9                 | <b>2.7</b> | <b>2.1</b> | <b>2.5</b> | <b>2.2</b> | <b>2.3</b> | <b>2.2</b> | <b>2.2</b>       | <b>2.1</b> | <b>2.1</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>2.1</b>          | <b>1.6</b> | <b>1.1</b> | <b>1.9</b> | <b>1.8</b> | <b>2.0</b> | <b>1.9</b> | <b>2.0</b>       | <b>2.0</b> | <b>2.0</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 5.4                 | 3.9        | <b>2.8</b> | 9.5        | 20         | 51         | 149        | 571              | 874        | 1167       | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.4</b>          | <b>2.1</b> | 3.1        | 4.7        | 3.9        | 4.4        | 4.4        | 4.5              | 4.7        | 4.6        | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 13                  | 132        | 72         | 909        | 1848       | 1428       | 1564       | 1318             | 1120       | 1129       | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>2.8</b>          | <b>1.9</b> | <b>2.9</b> | 5.9        | 6.3        | 7.3        | 7.8        | 8.5              | 8.6        | 8.9        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>2.8</b>          | <b>3.0</b> | <b>2.9</b> | 7.8        | 7.8        | 8.5        | 9.1        | 9.2              | 9.4        | 10         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | 4.2                 | <b>3.0</b> | <b>2.1</b> | 3.2        | 3.2        | 3.5        | 4.0        | 4.0              | 4.0        | 3.8        | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 4.6                 | 3.5        | <b>2.3</b> | 5.0        | 4.2        | 4.7        | 4.5        | 4.6              | 4.4        | 4.5        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 3.2                 | <b>2.3</b> | <b>2.4</b> | 12         | 13         | 16         | 16         | 18               | 17         | 18         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 3.1                 | <b>2.6</b> | <b>3.0</b> | 8.4        | 33         | 28         | 24         | 22               | 20         | 17         | NBC-CMA [21]                          |
| POEMS                                 | 204                 | 157        | 61         | 92         | 99         | 112        | 121        | 138              | 136        | 147        | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>2.9</b>          | <b>2.3</b> | <b>1.9</b> | 4.0        | 6.1        | 8.2        | 8.8        | 9.0              | 8.8        | 8.9        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 68                  | 62         | 54         | 116        | 362        | 602        | 806        | 846              | 915        | 976        | pPOEMS [17, 20]                       |
| Basic RCGA                            | 4.3                 | 16         | 6.0        | 121        | 375        | 596        | 1340       | 1819             | 3139       | 5724       | Basic RCGA [24]                       |
| SPSA                                  | 75                  | 4649       | 10152      | 8487       | 7901       | 8286       | 19888      | <i>27e-2/1e5</i> | .          | .          | SPSA [13]                             |

Table 7: Running time excess  $ERT/ERT_{best}$  2009 on  $f_7$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>7 Step-ellipsoid</b>               |            |            |            |            |                  |             |             |             |             |             |                                       |
|---------------------------------------|------------|------------|------------|------------|------------------|-------------|-------------|-------------|-------------|-------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02       | 1e-03       | 1e-04       | 1e-05       | 1e-07       | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1.5</b> | 3.5        | 6.2        | 6.5        | 24               | 13          | 37          | 37          | 37          | 259         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1.9</b> | <b>2.0</b> | 5.5        | 9.2        | 10               | 17          | 23          | 23          | 23          | 54          | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1.5</b> | <b>1.9</b> | 4.3        | 4.5        | 13               | 24          | 32          | 32          | 32          | 69          | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>2.5</b> | 3.5        | 21         | 21         | 15               | 27          | 35          | 35          | 35          | 89          | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>2.4</b> | <b>2.5</b> | 5.1        | 3.6        | 4.1              | <b>2.8</b>  | <b>3.0</b>  | <b>3.0</b>  | <b>3.0</b>  | 4.3         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1.1</b> | <b>1.8</b> | 4.9        | 5.7        | 4.8              | 4.9         | 5.3         | 5.3         | 5.3         | 5.6         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1.3</b> | <b>1.5</b> | 16         | 6.3        | 4.4              | <b>2.3</b>  | <b>2.7</b>  | <b>2.7</b>  | <b>2.7</b>  | 6.4         | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1.7</b> | <b>2.1</b> | <b>3.5</b> | 5.0        | 3.8              | 3.6         | 5.6         | 5.6         | 5.6         | 7.7         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1.1</b> | <b>1.2</b> | <b>3.7</b> | <b>2.7</b> | <b>2.0</b>       | <b>0.72</b> | <b>0.70</b> | <b>0.70</b> | <b>0.70</b> | <b>0.72</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1.3</b> | <b>1.6</b> | 4.7        | 4.3        | <b>2.6</b>       | <b>1.1</b>  | <b>1.0</b>  | <b>1.0</b>  | <b>1.0</b>  | <b>0.99</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1.5</b> | <b>1.8</b> | 6.4        | 4.2        | 9.5              | 17          | 60          | 60          | 60          | 123         | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.7</b> | <b>2.7</b> | 4.0        | 3.7        | 6.8              | 5.0         | 10          | 10          | 10          | 9.0         | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 268        | 296        | 861        | 719        | 589              | 936         | 1093        | 1093        | 1093        | 1610        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1.3</b> | <b>1.7</b> | <b>3.9</b> | <b>2.9</b> | <b>2.3</b>       | <b>1.3</b>  | <b>1.4</b>  | <b>1.4</b>  | <b>1.4</b>  | <b>1.6</b>  | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1.8</b> | <b>2.5</b> | 6.5        | 3.9        | <b>2.8</b>       | <b>1.3</b>  | <b>1.3</b>  | <b>1.3</b>  | <b>1.3</b>  | <b>1.4</b>  | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>2.4</b> | <b>2.7</b> | 6.2        | 3.8        | <b>2.6</b>       | <b>1.0</b>  | <b>1.1</b>  | <b>1.1</b>  | <b>1.1</b>  | <b>1.4</b>  | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1.3</b> | <b>2.9</b> | 7.4        | 4.0        | 3.7              | <b>1.9</b>  | <b>1.7</b>  | <b>1.7</b>  | <b>1.7</b>  | <b>1.9</b>  | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1.4</b> | <b>2.4</b> | 4.3        | 3.9        | 5.2              | 3.0         | 3.4         | 3.4         | 3.4         | 3.5         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1.9</b> | <b>2.1</b> | 4.0        | 3.9        | 4.5              | <b>2.5</b>  | <b>2.7</b>  | <b>2.7</b>  | <b>2.7</b>  | 4.5         | NBC-CMA [21]                          |
| POEMS                                 | 182        | 189        | 166        | 39         | 41               | 19          | 22          | 22          | 22          | 24          | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1.5</b> | <b>2.2</b> | 4.3        | <b>3.2</b> | <b>2.6</b>       | <b>1.4</b>  | <b>1.4</b>  | <b>1.4</b>  | <b>1.4</b>  | <b>1.6</b>  | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1.7</b> | 33         | 109        | 41         | 45               | 69          | 96          | 96          | 96          | 125         | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1.2</b> | <b>1.5</b> | 4.1        | 7.0        | 81               | 127         | 240         | 240         | 240         | 302         | Basic RCGA [24]                       |
| SPSA                                  | 354        | 7871       | 17652      | 39270      | <i>34e-1/1e5</i> | .           | .           | .           | .           | .           | SPSA [13]                             |



Table 8: Running time excess  $ERT/ERT_{best}$  2009 on  $f_8$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>8 Rosenbrock original</b>          |            |            |            |            |            |            |            |                  |            |                  |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 6.5        | 6.0        | 26         | 65         | 36         | 35         | 22         | 22               | 23         | 20               | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | 5.2        | 4.1        | 24         | 47         | 27         | 30         | 18         | 18               | 18         | 16               | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 5.3        | 5.4        | 5.7        | 19         | 15         | 21         | 12         | 12               | 12         | 11               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 6.1        | 4.5        | 53         | 236        | 123        | 117        | 87         | 90               | 96         | 82               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 4.8        | 3.1        | 5.3        | 22         | 14         | 13         | 8.0        | 8.2              | 8.4        | 7.7              | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 3.4        | 3.8        | 5.5        | 8.0        | 6.8        | 7.9        | 5.4        | 5.7              | 6.1        | 5.6              | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | 3.3        | <b>2.7</b> | <b>2.9</b> | 10         | 7.0        | 8.7        | 5.1        | 5.0              | 5.2        | 4.7              | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | 3.1        | <b>2.6</b> | 5.6        | 18         | 11         | 11         | 7.0        | 7.2              | 7.2        | 6.5              | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | 4.1        | 3.1        | 5.2        | 12         | 6.5        | <b>6.8</b> | <b>4.0</b> | <b>4.2</b>       | <b>4.3</b> | <b>4.0</b>       | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>2.5</b> | <b>1.9</b> | <b>3.6</b> | <b>6.6</b> | <b>5.0</b> | <b>5.3</b> | <b>3.2</b> | <b>3.2</b>       | <b>3.4</b> | <b>3.2</b>       | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 3.7        | <b>2.6</b> | 5.7        | 10         | 18         | 188        | 822        | 4247             | 18261      | <i>92e-6/1e5</i> | Artif Bee Colony [8]                  |
| avg NEWUOA                            | 3.9        | <b>2.5</b> | <b>2.6</b> | <b>4.6</b> | <b>2.4</b> | <b>2.4</b> | <b>1.4</b> | <b>1.4</b>       | <b>1.4</b> | <b>1.3</b>       | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 36         | 16         | 20         | 42         | 34         | 43         | 24         | 26               | 26         | 25               | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 4.6        | 3.9        | 7.3        | 11         | <b>6.3</b> | 10         | 6.7        | 7.7              | 8.2        | 8.5              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>2.9</b> | <b>2.9</b> | 6.6        | 10         | 399        | 320        | 173        | 163              | 161        | 136              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | 5.2        | 4.5        | 6.6        | <b>7.9</b> | 7.6        | 8.6        | 5.2        | 5.2              | 5.6        | 5.2              | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 9.2        | 5.2        | 5.5        | 14         | 10         | 11         | 6.3        | 6.4              | 6.7        | 6.1              | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>2.6</b> | <b>2.9</b> | 6.2        | 16         | 15         | 22         | 14         | 15               | 17         | 17               | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>2.9</b> | 3.5        | 6.0        | 10         | 13         | 20         | 13         | 14               | 17         | 17               | NBC-CMA [21]                          |
| POEMS                                 | 238        | 111        | 207        | 379        | 173        | 185        | 119        | 138              | 177        | 193              | POEMS [17]                            |
| PM-AdapSS-DE                          | 3.4        | 3.3        | 6.9        | 8.0        | 7.5        | 8.5        | 6.0        | 6.9              | 7.5        | 7.9              | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 40         | 85         | 111        | 109        | 128        | 486        | 463        | 546              | 796        | 1002             | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>2.6</b> | 3.1        | 10         | 16         | 144        | 478        | 781        | 1572             | 7166       | 12810            | Basic RCGA [24]                       |
| SPSA                                  | 931        | 548        | 3157       | 7112       | 22724      | 61485      | 33559      | <i>85e-2/1e5</i> | .          | .                | SPSA [13]                             |

Table 9: Running time excess  $ERT/ERT_{best}$  2009 on  $f_9$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>9 Rosenbrock rotated</b> |            |           |            |                  |            |            |            |            |            |                                       |
|---------------------------------------|-----------------------------|------------|-----------|------------|------------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                       | 1e+02      | 1e+01     | 1e+00      | 1e-01            | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>2.9</b>                  | 8.1        | 69        | 38         | 55               | 51         | 36         | 33         | 32         | 29         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>2.7</b>                  | 10         | 24        | 19         | 26               | 28         | 21         | 19         | 19         | 18         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 3.2                         | <b>6.1</b> | 22        | 15         | 22               | 22         | 17         | 16         | 16         | 15         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 3.3                         | <b>6.4</b> | 21        | 43         | 108              | 87         | 65         | 60         | 59         | 55         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 6.0                         | 10         | <b>21</b> | 8.0        | 11               | 11         | 8.1        | 7.5        | 7.7        | 7.4        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>2.7</b>                  | 6.9        | 22        | <b>3.2</b> | 11               | 9.5        | 7.5        | 7.1        | 7.1        | 7.2        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>2.9</b>                  | 8.3        | 29        | <b>4.0</b> | <b>6.1</b>       | 6.2        | 4.7        | 4.5        | 4.5        | 4.6        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | 3.5                         | 9.1        | <b>15</b> | 8.3        | 10               | 10         | 8.0        | 7.5        | 7.6        | 7.2        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | 5.3                         | 10         | 21        | 5.5        | 6.4              | <b>5.7</b> | <b>4.2</b> | <b>4.1</b> | <b>4.2</b> | <b>4.1</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | 3.5                         | 6.9        | 26        | 5.0        | <b>5.3</b>       | <b>5.1</b> | <b>3.7</b> | <b>3.6</b> | <b>3.6</b> | <b>3.7</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 3.9                         | 10         | 29        | 6.8        | 14               | 42         | 242        | 1552       | 5121       | 9398       | Artif Bee Colony [8]                  |
| avg NEWUOA                            | 7.7                         | 10         | 22        | <b>4.7</b> | <b>4.0</b>       | <b>3.2</b> | <b>2.3</b> | <b>2.1</b> | <b>2.0</b> | <b>1.9</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 16                          | 39         | 693       | 65         | 58               | 49         | 34         | 31         | 31         | 29         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 5.0                         | 14         | 44        | 7.9        | 489              | 342        | 224        | 200        | 388        | 344        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 3.1                         | 8.9        | 28        | 7.3        | 10               | 12         | 10         | 10         | 10         | 11         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>2.0</b>                  | <b>4.8</b> | 22        | 6.8        | 8.8              | 8.0        | 6.3        | 5.8        | 6.0        | 5.9        | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 3.7                         | 11         | 39        | 10         | 12               | 11         | 7.8        | 7.4        | 7.3        | 7.2        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1.9</b>                  | 11         | <b>20</b> | 6.2        | 8.4              | 11         | 11         | 11         | 13         | 14         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 3.3                         | 7.3        | 32        | 8.1        | 18               | 17         | 13         | 14         | 16         | 17         | NBC-CMA [21]                          |
| POEMS                                 | 337                         | 444        | 558       | 58         | 75               | 104        | 106        | 106        | 127        | 156        | POEMS [17]                            |
| PM-AdapSS-DE                          | 7.1                         | 19         | 33        | 11         | 497              | 716        | 467        | 412        | 390        | 346        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 159                         | 319        | 558       | 51         | 173              | 500        | 609        | 674        | 894        | 1105       | pPOEMS [17, 20]                       |
| Basic RCGA                            | 3.3                         | 10         | 49        | 8.0        | 29               | 206        | 994        | 1278       | 2857       | 15260      | Basic RCGA [24]                       |
| SPSA                                  | 469                         | 1759       | 55199     | 8901       | <i>96e-2/1e5</i> | .          | .          | .          | .          | .          | SPSA [13]                             |

Table 10: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{10}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04      | 1e-05            | 1e-07      |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|------------|------------------|------------|------------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ |            |            |            |            |            |            |                  |            |                  |            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 13         | 56         | 39         | 39         | 36         | 34         | 30               | 28         | 27               | 23         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | 8.9        | 25         | 49         | 36         | 33         | 30         | 27               | 26         | 25               | 22         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 6.4        | 14         | 29         | 23         | 22         | 23         | 21               | 20         | 19               | 17         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 6.7        | 109        | 120        | 115        | 106        | 95         | 92               | 85         | 80               | 68         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 6.4        | 6.0        | 8.9        | 11         | 11         | 11         | 10               | 9.2        | 8.8              | 8.0        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 7.9        | 10         | 12         | 13         | 12         | 11         | 10               | 10         | 9.4              | 8.5        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | 6.1        | <b>5.9</b> | 7.9        | 7.5        | 8.1        | 7.6        | 7.1              | 6.8        | 6.6              | 5.9        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>5.8</b> | 8.7        | 8.8        | 8.3        | 8.7        | 8.4        | 8.4              | 7.9        | 7.5              | 6.7        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | 9.3        | 7.0        | 6.4        | <b>5.5</b> | <b>5.6</b> | <b>5.6</b> | <b>5.2</b>       | <b>5.0</b> | <b>5.0</b>       | <b>4.6</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>5.9</b> | <b>4.6</b> | <b>5.7</b> | 5.6        | <b>5.4</b> | <b>5.0</b> | <b>4.8</b>       | <b>4.6</b> | <b>4.5</b>       | <b>4.2</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 12         | 13         | 20         | 97         | 771        | 6940       | <i>11e-3/1e5</i> | .          | .                | .          | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>2.6</b> | <b>3.6</b> | <b>3.8</b> | <b>4.8</b> | 6.9        | 7.6        | 8.8              | 9.5        | 10               | 11         | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 13         | 62         | 144        | 364        | 642        | 865        | 772              | 697        | 647              | 545        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 12         | 10         | 6.8        | 6.9        | 7.2        | 7.8        | 8.2              | 8.4        | 8.5              | 8.6        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 9.1        | 10         | 7.2        | 7.0        | 7.5        | 8.1        | 8.4              | 8.6        | 9.1              | 9.3        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | 8.8        | 8.8        | <b>5.3</b> | <b>5.4</b> | <b>5.8</b> | <b>6.1</b> | <b>5.9</b>       | <b>5.6</b> | <b>5.4</b>       | <b>5.3</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 9.4        | 9.1        | 10         | 8.7        | 8.4        | 7.8        | 7.5              | 7.1        | 6.9              | 6.4        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 13         | 14         | 13         | 19         | 20         | 20         | 20               | 20         | 20               | 20         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 16         | 24         | 25         | 51         | 64         | 77         | 81               | 90         | 96               | 87         | NBC-CMA [21]                          |
| POEMS                                 | 103        | 87         | 302        | 742        | 1322       | 1758       | 1884             | 2353       | 2694             | 2655       | POEMS [17]                            |
| PM-AdapSS-DE                          | 8.8        | 10         | 7.4        | 6.5        | 7.3        | 7.4        | 7.8              | 8.2        | 8.5              | 8.9        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 90         | 117        | 155        | 463        | 837        | 1017       | 1256             | 1447       | 1579             | 1747       | pPOEMS [17, 20]                       |
| Basic RCGA                            | 25         | 27         | 115        | 1504       | 1874       | 3104       | 6551             | 19727      | <i>17e-3/5e4</i> | .          | Basic RCGA [24]                       |
| SPSA                                  | 29         | 229        | 874        | 1873       | 16681      | 24345      | <i>27e-2/1e5</i> | .          | .                | .          | SPSA [13]                             |

Table 11: Running time excess  $ERT/ERT_{\text{best}}^{2009}$  on  $f_{11}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                                     | <b>11 Discus</b> |            |            |            |            |            |                  |                  |                  |            |                                                     |
|-----------------------------------------------------|------------------|------------|------------|------------|------------|------------|------------------|------------------|------------------|------------|-----------------------------------------------------|
| $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ | 1e+03            | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04            | 1e-05            | 1e-07      | $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ |
| (1,2)-CMA-ES                                        | 5.1              | 22         | 26         | 35         | 35         | 31         | 28               | 26               | 25               | 22         | (1,2)-CMA-ES [5, 3]                                 |
| (1,2m)-CMA-ES                                       | 12               | 44         | 33         | 36         | 34         | 30         | 28               | 26               | 25               | 22         | (1,2m)-CMA-ES [5]                                   |
| (1,2ms)-CMA-ES                                      | 4.6              | 21         | 24         | 26         | 27         | 26         | 25               | 23               | 22               | 19         | (1,2ms)-CMA-ES [5]                                  |
| (1,2s)-CMA-ES                                       | 5.3              | 35         | 53         | 75         | 105        | 87         | 85               | 77               | 72               | 61         | (1,2s)-CMA-ES [3]                                   |
| (1,4)-CMA-ES                                        | 3.9              | 11         | 12         | 12         | 11         | 10         | 10               | 9.1              | 8.8              | 7.9        | (1,4)-CMA-ES [6, 4]                                 |
| (1,4m)-CMA-ES                                       | 4.9              | 6.6        | 12         | 13         | 12         | 11         | 10               | 10               | 9.3              | 8.3        | (1,4m)-CMA-ES [6]                                   |
| (1,4ms)-CMA-ES                                      | <b>3.2</b>       | <b>6.1</b> | 6.9        | 8.5        | 9.2        | 8.4        | 8.0              | 7.4              | 7.1              | 6.4        | (1,4ms)-CMA-ES [1, 6]                               |
| (1,4s)-CMA-ES                                       | 10               | 18         | 11         | 10         | 10         | 8.6        | 8.3              | 7.9              | 7.6              | 6.7        | (1,4s)-CMA-ES [4]                                   |
| (1+1)-CMA-ES                                        | 4.5              | 6.9        | <b>4.2</b> | <b>6.5</b> | <b>6.7</b> | <b>5.8</b> | <b>5.5</b>       | <b>5.3</b>       | <b>5.1</b>       | <b>4.8</b> | (1+1)-CMA-ES [7]                                    |
| (1+2ms)-CMA-ES                                      | <b>3.9</b>       | <b>5.6</b> | <b>3.3</b> | <b>5.5</b> | <b>5.6</b> | <b>5.0</b> | <b>4.9</b>       | <b>4.6</b>       | <b>4.6</b>       | <b>4.2</b> | (1+2ms)-CMA-ES [2]                                  |
| Artif Bee Colony                                    | 7.3              | 13         | 11         | 103        | 813        | 7859       | 40809            | <i>11e-3/1e5</i> | .                | .          | Artif Bee Colony [8]                                |
| avg NEWUOA                                          | <b>1.3</b>       | <b>1.5</b> | <b>1.5</b> | <b>3.3</b> | <b>5.1</b> | <b>5.4</b> | 6.8              | 7.3              | 8.0              | 8.8        | avg NEWUOA [23]                                     |
| CMA-EGS (IPOP,r1)                                   | 8.1              | 128        | 517        | 994        | 1265       | 1264       | 1159             | 1041             | 962              | 812        | CMA-EGS (IPOP,r1) [12]                              |
| Adap DE (F-AUC)                                     | 7.6              | 13         | 6.3        | 7.0        | 8.0        | 7.9        | 8.2              | 8.7              | 8.8              | 9.0        | Adap DE (F-AUC) [10]                                |
| DE (Uniform)                                        | 9.0              | 12         | 6.0        | 6.9        | 7.8        | 8.3        | 8.5              | 8.9              | 9.0              | 9.4        | DE (Uniform) [9]                                    |
| IPOP-aCMA-ES                                        | 4.2              | 6.7        | 5.1        | 6.7        | 6.9        | 6.2        | <b>6.0</b>       | <b>5.9</b>       | <b>5.8</b>       | <b>5.5</b> | IPOP-aCMA-ES [16]                                   |
| IPOP-CMA-ES                                         | 5.1              | 12         | 7.5        | 8.3        | 8.7        | 7.6        | 7.4              | 7.1              | 6.8              | 6.4        | IPOP-CMA-ES [22]                                    |
| CMA+DE-MOS                                          | 11               | 23         | 13         | 19         | 23         | 21         | 21               | 21               | 21               | 20         | CMA+DE-MOS [18]                                     |
| NBC-CMA                                             | 13               | 22         | 24         | 41         | 58         | 66         | 87               | 97               | 101              | 88         | NBC-CMA [21]                                        |
| POEMS                                               | 68               | 69         | 533        | 811        | 1297       | 1891       | 2292             | 2546             | 2824             | 3255       | POEMS [17]                                          |
| PM-AdapSS-DE                                        | 7.9              | 12         | 6.2        | 7.3        | 8.2        | 8.3        | 8.8              | 9.1              | 9.1              | 9.4        | PM-AdapSS-DE [9, 10]                                |
| pPOEMS                                              | 76               | 124        | 113        | 477        | 866        | 1087       | 1260             | 1491             | 1643             | 1787       | pPOEMS [17, 20]                                     |
| Basic RCGA                                          | 10               | 23         | 75         | 958        | 2135       | 6917       | <i>44e-3/5e4</i> | .                | .                | .          | Basic RCGA [24]                                     |
| SPSA                                                | 15               | 483        | 1404       | 4983       | 17942      | 46844      | 42861            | 38450            | <i>50e-2/1e5</i> | .          | SPSA [13]                                           |

Table 12: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{12}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>12 Bent cigar</b>                  |            |            |             |            |            |            |                  |            |            |                  |                                       |
|---------------------------------------|------------|------------|-------------|------------|------------|------------|------------------|------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01       | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04      | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 5.9        | 12         | 12          | 24         | 27         | 31         | 33               | 31         | 35         | 30               | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | 5.4        | 30         | 32          | 28         | 26         | 26         | 24               | 22         | 20         | 21               | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 21         | 38         | 42          | 52         | 43         | 37         | 34               | 29         | 25         | 21               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 5.9        | 37         | 95          | 170        | 142        | 116        | 105              | 88         | 73         | 57               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 9.3        | 12         | 16          | 21         | 18         | 16         | 16               | 14         | 13         | 11               | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 8.6        | 11         | 16          | 21         | 19         | 18         | 17               | 16         | 15         | 13               | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | 4.5        | 8.0        | 16          | 22         | 18         | 16         | 15               | 14         | 12         | 10               | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>2.9</b> | 6.8        | 14          | 20         | 16         | 15         | 14               | 13         | 11         | 10               | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | 4.6        | 7.0        | 8.8         | 10         | 7.7        | <b>7.0</b> | <b>6.7</b>       | <b>6.1</b> | <b>5.6</b> | <b>5.2</b>       | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | 4.6        | <b>3.2</b> | <b>4.2</b>  | <b>7.6</b> | <b>6.9</b> | <b>6.5</b> | <b>6.5</b>       | <b>6.4</b> | <b>5.9</b> | <b>5.6</b>       | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 8.9        | 7.7        | 13          | 175        | 568        | 1467       | 2630             | 3353       | 2793       | 2258             | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.7</b> | <b>1.1</b> | <b>0.96</b> | <b>1.6</b> | <b>1.5</b> | <b>1.5</b> | <b>1.5</b>       | <b>1.5</b> | <b>1.4</b> | <b>1.4</b>       | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 10         | 438        | 1070        | 8143       | 10929      | 8731       | 12445            | 22378      | 18388      | <i>15e-1/1e5</i> | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 11         | 7.9        | 8.1         | 8.2        | <b>7.5</b> | 7.1        | 7.6              | 7.9        | 7.6        | 7.2              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 10         | 7.7        | 8.1         | 320        | 417        | 334        | 302              | 253        | 209        | 165              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>4.4</b> | <b>3.8</b> | <b>5.0</b>  | <b>7.8</b> | 8.3        | 8.2        | 8.5              | 8.1        | 13         | 11               | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 4.6        | 7.0        | 10          | 12         | 9.3        | 9.0        | 8.6              | 7.8        | 7.3        | 6.5              | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 13         | 12         | 16          | 22         | 18         | 18         | 19               | 19         | 18         | 17               | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 14         | 13         | 20          | 66         | 73         | 69         | 76               | 80         | 69         | 57               | NBC-CMA [21]                          |
| POEMS                                 | 91         | 79         | 332         | 726        | 1039       | 1490       | 2235             | 2363       | 2530       | 2595             | POEMS [17]                            |
| PM-AdapSS-DE                          | 9.5        | 9.0        | 8.3         | 8.6        | 197        | 334        | 301              | 405        | 334        | 263              | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 76         | 78         | 282         | 408        | 622        | 667        | 730              | 788        | 801        | 843              | pPOEMS [17, 20]                       |
| Basic RCGA                            | 13         | 23         | 118         | 730        | 852        | 804        | 1022             | 912        | 1577       | 1575             | Basic RCGA [24]                       |
| SPSA                                  | 3230       | 4072       | 15645       | 60799      | 37286      | 29781      | <i>30e+0/1e5</i> | .          | .          | .                | SPSA [13]                             |

Table 13: Running time excess  $ERT/ERT_{\text{best}}^{2009}$  on  $f_{13}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                                     | 13 Sharp ridge |            |            |            |            |            |                  |                  |            |                  |                                                     |
|-----------------------------------------------------|----------------|------------|------------|------------|------------|------------|------------------|------------------|------------|------------------|-----------------------------------------------------|
| $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ | 1e+03          | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04            | 1e-05      | 1e-07            | $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ |
| (1,2)-CMA-ES                                        | <b>2.2</b>     | 3.4        | 17         | 30         | 31         | 29         | 29               | 28               | 28         | 37               | (1,2)-CMA-ES [5, 3]                                 |
| (1,2m)-CMA-ES                                       | <b>1.1</b>     | 3.5        | 13         | 32         | 41         | 39         | 40               | 50               | 67         | 68               | (1,2m)-CMA-ES [5]                                   |
| (1,2ms)-CMA-ES                                      | <b>2.1</b>     | 13         | 11         | 26         | 30         | 31         | 37               | 43               | 51         | 51               | (1,2ms)-CMA-ES [5]                                  |
| (1,2s)-CMA-ES                                       | <b>1.1</b>     | 19         | 69         | 57         | 99         | 97         | 94               | 115              | 102        | 152              | (1,2s)-CMA-ES [3]                                   |
| (1,4)-CMA-ES                                        | <b>1.3</b>     | 3.9        | 7.1        | 10         | 10         | 8.5        | 10               | 10               | 10         | 10               | (1,4)-CMA-ES [6, 4]                                 |
| (1,4m)-CMA-ES                                       | <b>1.7</b>     | 3.5        | 6.3        | 7.7        | 7.7        | 11         | 11               | 11               | 11         | 11               | (1,4m)-CMA-ES [6]                                   |
| (1,4ms)-CMA-ES                                      | <b>1.5</b>     | <b>2.4</b> | <b>2.9</b> | 6.5        | 8.2        | 7.2        | 7.4              | 7.4              | 7.3        | 8.0              | (1,4ms)-CMA-ES [1, 6]                               |
| (1,4s)-CMA-ES                                       | <b>1.3</b>     | 6.3        | 9.2        | 10         | 10         | 10         | 10               | 10               | 10         | 10               | (1,4s)-CMA-ES [4]                                   |
| (1+1)-CMA-ES                                        | <b>1.4</b>     | <b>2.3</b> | <b>4.1</b> | <b>5.6</b> | <b>6.8</b> | <b>6.6</b> | <b>6.1</b>       | <b>6.0</b>       | <b>7.1</b> | <b>8.0</b>       | (1+1)-CMA-ES [7]                                    |
| (1+2ms)-CMA-ES                                      | <b>1.1</b>     | <b>1.8</b> | <b>3.7</b> | <b>5.6</b> | 9.1        | 8.2        | 8.1              | 7.5              | 8.1        | 8.9              | (1+2ms)-CMA-ES [2]                                  |
| Artif Bee Colony                                    | <b>1.4</b>     | 3.6        | 5.6        | 61         | 2262       | 18469      | <i>23e-3/1e5</i> | .                | .          | .                | Artif Bee Colony [8]                                |
| avg NEWUOA                                          | <b>1.8</b>     | 6.7        | 6.7        | 17         | 38         | 54         | 73               | 131              | 140        | 771              | avg NEWUOA [23]                                     |
| CMA-EGS (IPOP,r1)                                   | 17             | 95         | 386        | 2717       | 4951       | 9966       | <i>48e-3/1e5</i> | .                | .          | .                | CMA-EGS (IPOP,r1) [12]                              |
| Adap DE (F-AUC)                                     | <b>1.5</b>     | 4.1        | 4.5        | 6.9        | 8.2        | 8.5        | 9.3              | 9.4              | 9.3        | 9.5              | Adap DE (F-AUC) [10]                                |
| DE (Uniform)                                        | <b>1.5</b>     | <b>2.8</b> | 4.5        | 7.1        | 8.5        | 8.2        | 8.8              | 9.5              | 10         | 10               | DE (Uniform) [9]                                    |
| IPOP-aCMA-ES                                        | <b>1.7</b>     | 4.2        | 4.3        | <b>6.1</b> | <b>6.2</b> | <b>5.9</b> | <b>6.1</b>       | <b>5.9</b>       | <b>5.9</b> | <b>5.8</b>       | IPOP-aCMA-ES [16]                                   |
| IPOP-CMA-ES                                         | <b>1.4</b>     | <b>2.1</b> | 5.0        | 6.3        | <b>6.7</b> | <b>6.3</b> | <b>6.6</b>       | <b>6.9</b>       | <b>6.8</b> | <b>7.1</b>       | IPOP-CMA-ES [22]                                    |
| CMA+DE-MOS                                          | <b>1.3</b>     | <b>2.7</b> | 7.7        | 17         | 19         | 19         | 20               | 20               | 19         | 19               | CMA+DE-MOS [18]                                     |
| NBC-CMA                                             | <b>1.5</b>     | 3.0        | 7.9        | 14         | 17         | 25         | 44               | 52               | 48         | 40               | NBC-CMA [21]                                        |
| POEMS                                               | 125            | 104        | 54         | 103        | 146        | 491        | 1449             | 4402             | 15360      | 69407            | POEMS [17]                                          |
| PM-AdapSS-DE                                        | <b>1.7</b>     | 3.3        | 5.2        | 6.4        | 7.8        | 8.1        | 8.7              | 9.1              | 9.2        | 9.1              | PM-AdapSS-DE [9, 10]                                |
| pPOEMS                                              | <b>1.4</b>     | 51         | 48         | 233        | 856        | 1073       | 1441             | 1587             | 1967       | 2202             | pPOEMS [17, 20]                                     |
| Basic RCGA                                          | <b>1.4</b>     | 3.6        | 85         | 1010       | 2805       | 7126       | 20886            | <i>19e-2/5e4</i> | .          | .                | Basic RCGA [24]                                     |
| SPSA                                                | 23             | 27         | 47         | 332        | 2459       | 15906      | 20509            | 17764            | 31370      | <i>21e-3/1e5</i> | SPSA [13]                                           |

Table 14: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{14}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| $\Delta f_{target}$<br>$ERT_{best}/D$ | 14 Sum of different powers |            |            |            |            |            |            |            |            |                  |  | $\Delta f_{target}$<br>$ERT_{best}/D$ |
|---------------------------------------|----------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------------|--|---------------------------------------|
|                                       | 1e+03                      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07            |  |                                       |
| (1,2)-CMA-ES                          | <b>1</b>                   | <b>1.7</b> | 9.2        | 10         | 7.4        | 11         | 18         | 20         | 22         | 29               |  | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                   | <b>1.1</b> | <b>2.1</b> | <b>2.3</b> | 4.5        | 5.5        | 11         | 14         | 22         | 30               |  | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                   | <b>1</b>   | <b>1.7</b> | <b>2.6</b> | 3.9        | 4.7        | 10         | 13         | 19         | 24               |  | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                   | <b>1.9</b> | <b>1.9</b> | 3.9        | 8.3        | 13         | 29         | 56         | 64         | 86               |  | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                   | <b>2.0</b> | <b>2.6</b> | <b>2.8</b> | <b>2.8</b> | 4.3        | 4.8        | 5.8        | 7.3        | 8.7              |  | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                   | <b>1.4</b> | <b>1.9</b> | <b>1.3</b> | <b>3.0</b> | 3.8        | 6.1        | 6.3        | 7.9        | 10               |  | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                   | <b>1.2</b> | <b>1.9</b> | <b>2.3</b> | <b>2.5</b> | <b>3.1</b> | 4.1        | 4.4        | 5.3        | 7.0              |  | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                   | <b>1.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | 3.3        | 5.1        | 5.6        | 7.2        | 8.2              |  | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                   | <b>1</b>   | <b>1.8</b> | <b>2.1</b> | <b>2.7</b> | <b>3.2</b> | <b>3.1</b> | <b>4.0</b> | <b>4.5</b> | <b>5.0</b>       |  | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                   | <b>1.2</b> | <b>1.5</b> | <b>1.8</b> | 3.1        | 3.5        | <b>3.5</b> | <b>3.9</b> | <b>3.9</b> | <b>4.0</b>       |  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                   | <b>1.3</b> | <b>1.6</b> | 4.7        | 10         | 18         | 27         | 607        | 11891      | <i>22e-6/1e5</i> |  | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                   | <b>1.4</b> | 3.4        | <b>2.2</b> | <b>1.4</b> | <b>1.3</b> | <b>1.6</b> | <b>1.8</b> | <b>2.2</b> | 6.8              |  | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 4.3                        | 7.9        | 19         | 17         | 10         | 15         | 21         | 25         | 37         | 581              |  | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                   | <b>1.1</b> | <b>1.1</b> | 3.6        | 5.6        | 10         | 10         | 8.4        | 8.7        | 9.0              |  | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                   | <b>1.5</b> | <b>1.7</b> | 3.6        | 7.8        | 9.5        | 8.5        | 8.1        | 8.9        | 9.3              |  | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                   | <b>1.1</b> | <b>2.3</b> | <b>2.7</b> | 3.3        | 4.9        | 4.9        | 4.9        | 4.8        | <b>5.9</b>       |  | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                   | <b>1.3</b> | <b>2.2</b> | <b>2.9</b> | 4.6        | 5.1        | 4.7        | 5.2        | 6.0        | 7.2              |  | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                   | <b>1.2</b> | <b>1.8</b> | 4.3        | 13         | 17         | 18         | 18         | 19         | 20               |  | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                   | <b>1.3</b> | <b>2.0</b> | <b>2.9</b> | 11         | 17         | 14         | 13         | 16         | 22               |  | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                   | 185        | 213        | 74         | 67         | 141        | 165        | 177        | 246        | 2034             |  | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                   | <b>1.5</b> | <b>1.7</b> | <b>2.7</b> | 7.6        | 10         | 9.3        | 8.9        | 8.6        | 9.0              |  | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                   | <b>1.7</b> | <b>2.2</b> | 57         | 66         | 391        | 760        | 984        | 1037       | 1666             |  | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                   | <b>1.2</b> | <b>1.5</b> | 3.6        | 28         | 33         | 71         | 284        | 456        | 1630             |  | Basic RCGA [24]                       |
| SPSA                                  | 22                         | 57         | 242        | 984        | 530        | 452        | 850        | 5362       | 41592      | 31154            |  | SPSA [13]                             |

Table 15: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{15}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>15 Rastrigin</b>                   |            |            |             |            |             |                  |             |             |            |            |                                       |
|---------------------------------------|------------|------------|-------------|------------|-------------|------------------|-------------|-------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01       | 1e+00      | 1e-01       | 1e-02            | 1e-03       | 1e-04       | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1.1</b> | 4.2        | <b>2.9</b>  | 14         | 17          | 17               | 16          | 15          | 15         | 13         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1.3</b> | <b>2.9</b> | <b>0.83</b> | 7.8        | 10          | 13               | 13          | 13          | 12         | 11         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>   | 4.2        | <b>2.4</b>  | 6.8        | 9.5         | 9.2              | 8.9         | 8.5         | 8.1        | 7.1        | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>   | 5.6        | 9.5         | 15         | 20          | 24               | 23          | 22          | 21         | 18         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1.3</b> | 5.4        | <b>2.1</b>  | 3.6        | <b>2.7</b>  | <b>2.7</b>       | <b>2.6</b>  | <b>2.5</b>  | <b>2.4</b> | <b>2.1</b> | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1.1</b> | 4.4        | <b>1.1</b>  | <b>2.8</b> | 4.7         | 4.9              | 4.7         | 4.5         | 4.3        | 3.8        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1.5</b> | 3.4        | <b>2.2</b>  | 3.6        | 5.0         | 4.9              | 4.7         | 4.5         | 4.2        | 3.7        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1.1</b> | 4.7        | <b>2.4</b>  | 5.8        | 9.4         | 9.1              | 8.8         | 8.4         | 7.9        | 7.0        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>   | <b>2.8</b> | 3.1         | 4.0        | 6.5         | 6.3              | 6.1         | 5.8         | 5.5        | 4.9        | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1.1</b> | <b>2.8</b> | <b>1.6</b>  | 3.4        | 6.0         | 5.8              | 5.6         | 5.4         | 5.1        | 4.5        | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1.1</b> | <b>2.3</b> | <b>1.9</b>  | 8.8        | 17          | 75               | 164         | 309         | 495        | 672        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>   | <b>2.6</b> | <b>2.5</b>  | <b>2.5</b> | 3.3         | 3.2              | 3.1         | <b>2.9</b>  | <b>2.8</b> | <b>2.4</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 4.9        | 189        | 108         | 64         | 158         | 331              | 418         | 1128        | 1067       | 933        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1.2</b> | <b>2.4</b> | <b>1.8</b>  | <b>1.7</b> | <b>0.77</b> | <b>0.95</b>      | <b>0.98</b> | <b>1.0</b>  | <b>1.0</b> | <b>1.0</b> | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1.2</b> | <b>2.1</b> | <b>1.8</b>  | <b>1.5</b> | <b>0.67</b> | <b>0.88</b>      | <b>0.95</b> | <b>0.97</b> | <b>1.0</b> | <b>1.0</b> | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1.1</b> | 3.9        | <b>1.3</b>  | <b>2.6</b> | <b>2.5</b>  | <b>2.9</b>       | <b>2.8</b>  | <b>2.8</b>  | <b>2.7</b> | <b>2.4</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>   | <b>2.5</b> | <b>0.98</b> | <b>2.8</b> | <b>2.5</b>  | <b>2.5</b>       | <b>2.4</b>  | <b>2.4</b>  | <b>2.3</b> | <b>2.1</b> | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>   | <b>2.4</b> | <b>1.6</b>  | 4.0        | <b>2.7</b>  | 3.3              | 3.4         | 3.4         | 3.3        | 3.1        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1.1</b> | <b>2.8</b> | <b>2.2</b>  | <b>2.7</b> | 3.2         | 4.2              | 4.2         | 4.2         | 4.0        | 3.6        | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>   | 143        | 17          | 20         | 76          | 76               | 75          | 74          | 71         | 65         | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1.1</b> | <b>2.3</b> | <b>2.1</b>  | <b>1.7</b> | 15          | 14               | 14          | 13          | 13         | 11         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>   | 7.1        | 19          | 46         | 25          | 50               | 63          | 72          | 82         | 92         | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>   | <b>1.6</b> | 3.1         | 32         | 32          | 40               | 51          | 62          | 79         | 114        | Basic RCGA [24]                       |
| SPSA                                  | 28         | 962        | 39          | 1133       | 1352        | <i>11e-1/1e5</i> | .           | .           | .          | .          | SPSA [13]                             |



Table 16: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{16}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>16 Weierstrass</b>                 |            |            |            |            |            |            |            |                  |            |                  |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>   | <b>1.6</b> | 3.0        | 14         | 19         | 44         | 74         | 120              | 115        | 125              | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>   | <b>1.1</b> | 23         | 14         | 32         | 21         | 20         | 21               | 21         | 19               | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>   | <b>1.2</b> | 12         | 20         | 27         | 21         | 29         | 34               | 48         | 41               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>   | <b>1.5</b> | 23         | 39         | 41         | 74         | 107        | 725              | 696        | 530              | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>   | <b>1.9</b> | 10         | 13         | 7.1        | 4.2        | <b>4.4</b> | 4.9              | 4.8        | 4.0              | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>   | <b>1.4</b> | 4.0        | 9.1        | 5.4        | 4.3        | 4.4        | <b>4.2</b>       | 7.6        | 5.8              | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>   | <b>1.6</b> | <b>2.6</b> | 5.9        | <b>3.6</b> | 5.3        | 4.9        | 4.6              | 5.3        | 4.2              | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>   | <b>1.5</b> | 7.6        | 10         | 10         | 6.2        | 12         | 12               | 11         | 21               | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>   | <b>1.5</b> | 5.6        | 6.8        | 5.6        | 5.6        | 7.4        | 10               | 12         | 10               | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>   | <b>1.5</b> | 3.6        | 7.6        | 5.4        | 7.6        | 7.7        | 11               | 11         | 10               | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>   | <b>1.5</b> | <b>2.2</b> | <b>3.4</b> | 8.7        | 38         | 202        | 1036             | 4754       | 3686             | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>   | 12         | 15         | 9.1        | 5.5        | 6.8        | 13         | 21               | 37         | 73               | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1.7</b> | 8.5        | 166        | 134        | 236        | 489        | 2332       | <i>53e-4/1e5</i> | .          | .                | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>   | <b>1.6</b> | <b>1.5</b> | <b>4.9</b> | <b>3.5</b> | <b>3.6</b> | <b>4.0</b> | <b>4.1</b>       | <b>4.1</b> | <b>3.5</b>       | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>   | <b>1.2</b> | <b>2.8</b> | 6.8        | 4.0        | 3.8        | 4.6        | 4.6              | 4.7        | 4.0              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>   | <b>1.1</b> | 3.8        | 8.3        | 6.1        | <b>3.7</b> | <b>3.6</b> | <b>3.4</b>       | <b>3.3</b> | <b>2.7</b>       | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>   | <b>1.4</b> | <b>2.5</b> | 11         | 5.0        | <b>3.5</b> | 4.6        | 4.3              | <b>4.2</b> | <b>3.4</b>       | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>   | <b>1.6</b> | 5.3        | 6.0        | <b>3.8</b> | 5.0        | 5.8        | 5.7              | 6.5        | 6.5              | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>   | <b>1.5</b> | <b>2.4</b> | 5.3        | 12         | 17         | 22         | 21               | 23         | 19               | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>   | 100        | 67         | 152        | 81         | 137        | 132        | 126              | 125        | 103              | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>   | <b>1.2</b> | 3.1        | <b>4.2</b> | 4.6        | 47         | 44         | 41               | 39         | 30               | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>   | <b>1.6</b> | 39         | 22         | 58         | 106        | 162        | 229              | 264        | 283              | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>   | <b>1.5</b> | <b>1.8</b> | 5.2        | 68         | 73         | 87         | 160              | 219        | 290              | Basic RCGA [24]                       |
| SPSA                                  | 13         | 71         | 71         | 137        | 298        | 424        | 822        | 2207             | 7266       | <i>30e-4/1e5</i> | SPSA [13]                             |

Table 17: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{17}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| 17 Schaffer F7, condition 10 |            |            |            |            |            |            |                  |                  |                  |                  |                        |
|------------------------------|------------|------------|------------|------------|------------|------------|------------------|------------------|------------------|------------------|------------------------|
| $\Delta f_{target}$          | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04            | 1e-05            | 1e-07            | $\Delta f_{target}$    |
| $ERT_{best}/D$               | 0.50       | 0.50       | 1.3        | 30         | 66         | 138        | 198              | 372              | 543              | 828              | $ERT_{best}/D$         |
| (1,2)-CMA-ES                 | <b>1</b>   | <b>1.3</b> | 38         | 9.1        | 18         | 17         | 59               | 393              | <i>99e-5/1e4</i> | .                | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES                | <b>1</b>   | <b>1.3</b> | 3.7        | <b>1.6</b> | 4.6        | 5.2        | 7.4              | 11               | 60               | 84               | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES               | <b>1</b>   | <b>1.1</b> | <b>1.8</b> | <b>2.5</b> | <b>2.9</b> | 4.2        | 14               | 27               | 62               | 180              | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES                | <b>1</b>   | <b>2.9</b> | 7.4        | 4.5        | 17         | 48         | 332              | <i>33e-4/1e4</i> | .                | .                | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES                 | <b>1</b>   | <b>1.3</b> | 3.8        | <b>2.0</b> | 3.6        | 3.1        | 5.0              | 5.7              | 13               | 39               | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES                | <b>1</b>   | <b>1.3</b> | 3.2        | <b>1.8</b> | <b>2.6</b> | <b>2.6</b> | <b>2.9</b>       | 3.7              | 12               | 18               | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES               | <b>1.1</b> | <b>1.4</b> | <b>2.4</b> | 5.2        | 3.3        | <b>2.5</b> | 3.7              | 11               | 36               | 32               | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES                | <b>1</b>   | <b>1.3</b> | 6.2        | <b>1.8</b> | 3.7        | 5.3        | 10               | 27               | <i>30e-6/1e4</i> | .                | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES                 | <b>1</b>   | <b>2.5</b> | 4.0        | 3.3        | 4.5        | 12         | 19               | 19               | 33               | 22               | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES               | <b>1</b>   | <b>1.9</b> | 3.1        | <b>1.7</b> | <b>2.2</b> | 4.0        | 3.0              | 4.3              | 5.6              | 3.7              | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony             | <b>1.0</b> | <b>1.3</b> | <b>2.2</b> | <b>2.5</b> | 6.7        | 10         | 94               | 231              | 436              | <i>29e-6/1e5</i> | Artif Bee Colony [8]   |
| avg NEWUOA                   | <b>1.1</b> | <b>1.3</b> | 12         | 4.6        | 13         | 33         | 117              | <i>75e-4/5e3</i> | .                | .                | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)            | 5.3        | 17         | 14         | 6.5        | 61         | 310        | 811              | 3768             | <i>14e-4/1e5</i> | .                | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)              | <b>1</b>   | <b>1.1</b> | <b>2.9</b> | <b>1.9</b> | <b>2.5</b> | <b>2.0</b> | <b>2.1</b>       | <b>1.5</b>       | <b>1.3</b>       | <b>1.2</b>       | Adap DE (F-AUC) [10]   |
| DE (Uniform)                 | <b>1</b>   | <b>1.1</b> | <b>2.5</b> | <b>1.8</b> | <b>2.5</b> | <b>2.1</b> | <b>2.1</b>       | <b>1.5</b>       | <b>1.3</b>       | <b>1.2</b>       | DE (Uniform) [9]       |
| IPOP-aCMA-ES                 | <b>1</b>   | <b>1.3</b> | 5.4        | <b>2.6</b> | <b>2.2</b> | <b>1.8</b> | <b>1.5</b>       | <b>1.2</b>       | <b>1.3</b>       | <b>1.1</b>       | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES                  | <b>1</b>   | <b>1</b>   | 19         | <b>2.4</b> | <b>2.0</b> | <b>1.6</b> | <b>1.7</b>       | <b>1.4</b>       | <b>1.5</b>       | <b>1.1</b>       | IPOP-CMA-ES [22]       |
| CMA+DE-MOS                   | <b>1</b>   | <b>1.5</b> | <b>2.2</b> | 4.9        | 6.6        | 5.0        | 5.0              | 3.3              | 3.1              | <b>2.6</b>       | CMA+DE-MOS [18]        |
| NBC-CMA                      | <b>1</b>   | <b>1</b>   | <b>1.9</b> | <b>2.8</b> | 4.6        | <b>3.0</b> | <b>2.5</b>       | <b>1.7</b>       | <b>1.5</b>       | <b>2.1</b>       | NBC-CMA [21]           |
| POEMS                        | <b>1</b>   | 66         | 130        | 18         | 33         | 28         | 32               | 24               | 21               | 19               | POEMS [17]             |
| PM-AdapSS-DE                 | <b>1.1</b> | <b>1.2</b> | <b>2.5</b> | <b>1.6</b> | <b>2.2</b> | <b>2.0</b> | <b>2.1</b>       | <b>1.5</b>       | <b>1.4</b>       | <b>1.2</b>       | PM-AdapSS-DE [9, 10]   |
| pPOEMS                       | <b>1</b>   | <b>1.3</b> | 51         | 23         | 116        | 179        | 220              | 157              | 142              | 133              | pPOEMS [17, 20]        |
| Basic RCGA                   | <b>1</b>   | <b>1.2</b> | <b>2.9</b> | 5.0        | 47         | 61         | 103              | 77               | 124              | <i>23e-7/5e4</i> | Basic RCGA [24]        |
| SPSA                         | 1935       | 16834      | 27903      | 1683       | 771        | 1105       | <i>17e-3/1e5</i> | .                | .                | .                | SPSA [13]              |

Table 18: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{18}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| 18 Schaffer F7, condition 1000 |            |             |             |            |             |                  |                  |                  |                  |             |                        |
|--------------------------------|------------|-------------|-------------|------------|-------------|------------------|------------------|------------------|------------------|-------------|------------------------|
| $\Delta f_{target}$            | 1e+03      | 1e+02       | 1e+01       | 1e+00      | 1e-01       | 1e-02            | 1e-03            | 1e-04            | 1e-05            | 1e-07       | $\Delta f_{target}$    |
| $ERT_{best}/D$                 |            |             |             |            |             |                  |                  |                  | 1219             | 1429        | $ERT_{best}/D$         |
| (1,2)-CMA-ES                   | <b>1.1</b> | 17          | 8.4         | 7.7        | 16          | 72               | 82               | 144              | <i>28e-3/1e4</i> | .           | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES                  | <b>1.1</b> | 25          | 6.5         | 17         | 17          | 53               | 168              | 138              | <i>20e-3/1e4</i> | .           | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES                 | <b>1.5</b> | 4.3         | <b>1.7</b>  | 8.2        | 7.8         | 23               | <i>13e-3/1e4</i> | .                | .                | .           | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES                  | <b>1.3</b> | 3.1         | 74          | 41         | 39          | <i>98e-3/1e4</i> | .                | .                | .                | .           | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES                   | <b>1.1</b> | <b>2.4</b>  | 3.5         | 10         | 8.1         | 10               | 11               | 22               | 119              | 102         | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES                  | <b>1.1</b> | 16          | 3.5         | 5.7        | 3.7         | 4.2              | 6.9              | 15               | 37               | 31          | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES                 | <b>1.1</b> | <b>1.4</b>  | <b>0.70</b> | 4.1        | <b>2.6</b>  | 8.0              | 20               | 144              | <i>14e-4/1e4</i> | .           | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES                  | <b>1.6</b> | <b>1.3</b>  | <b>0.93</b> | 6.7        | 6.3         | 12               | 15               | 144              | <i>10e-4/1e4</i> | .           | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES                   | <b>1.7</b> | 8.1         | <b>2.4</b>  | 10         | 17          | 33               | 172              | <i>16e-3/1e4</i> | .                | .           | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES                 | <b>1</b>   | <b>1.3</b>  | <b>1.3</b>  | 7.6        | 12          | 39               | 173              | 143              | <i>16e-3/1e4</i> | .           | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony               | <b>1.2</b> | <b>1.1</b>  | <b>2.4</b>  | 8.2        | 20          | 596              | 2565             | <i>20e-3/1e5</i> | .                | .           | Artif Bee Colony [8]   |
| avg NEWUOA                     | <b>1.7</b> | 7.9         | 5.4         | 9.0        | 6.1         | 62               | <i>58e-3/6e3</i> | .                | .                | .           | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)              | 8.2        | 8.1         | 12          | 463        | 541         | <i>27e-2/1e5</i> | .                | .                | .                | .           | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)                | <b>1.1</b> | <b>1.3</b>  | <b>2.6</b>  | <b>1.4</b> | <b>0.73</b> | <b>0.62</b>      | <b>0.66</b>      | <b>0.68</b>      | <b>0.74</b>      | <b>0.81</b> | Adap DE (F-AUC) [10]   |
| DE (Uniform)                   | <b>1.1</b> | <b>0.98</b> | <b>2.9</b>  | <b>1.8</b> | <b>0.77</b> | <b>0.63</b>      | <b>0.63</b>      | <b>0.65</b>      | <b>0.71</b>      | <b>0.80</b> | DE (Uniform) [9]       |
| IPOP-aCMA-ES                   | <b>2.1</b> | <b>2.1</b>  | <b>1.4</b>  | 3.9        | <b>1.2</b>  | <b>0.78</b>      | <b>0.71</b>      | <b>0.71</b>      | <b>0.85</b>      | <b>0.92</b> | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES                    | <b>1</b>   | <b>2.9</b>  | 4.9         | 3.7        | <b>1.5</b>  | <b>1.1</b>       | <b>1.1</b>       | <b>1.1</b>       | <b>1.0</b>       | <b>1.1</b>  | IPOP-CMA-ES [22]       |
| CMA+DE-MOS                     | <b>1.5</b> | <b>1.3</b>  | <b>2.5</b>  | 3.8        | <b>2.6</b>  | <b>1.9</b>       | <b>2.1</b>       | <b>1.9</b>       | <b>2.6</b>       | <b>2.5</b>  | CMA+DE-MOS [18]        |
| NBC-CMA                        | <b>1.1</b> | <b>1.1</b>  | <b>2.4</b>  | 8.6        | <b>2.9</b>  | <b>2.3</b>       | <b>2.3</b>       | <b>2.1</b>       | <b>2.0</b>       | <b>2.2</b>  | NBC-CMA [21]           |
| POEMS                          | 36         | 84          | 31          | 17         | 10          | 8.9              | 8.9              | 33               | 32               | 30          | POEMS [17]             |
| PM-AdapSS-DE                   | <b>1.1</b> | <b>0.90</b> | <b>2.6</b>  | <b>1.5</b> | <b>0.71</b> | <b>0.65</b>      | <b>0.63</b>      | <b>0.65</b>      | <b>0.70</b>      | <b>0.77</b> | PM-AdapSS-DE [9, 10]   |
| pPOEMS                         | <b>1.1</b> | 11          | 29          | 37         | 56          | 57               | 63               | 70               | 77               | 94          | pPOEMS [17, 20]        |
| Basic RCGA                     | <b>1.1</b> | <b>1.4</b>  | <b>2.1</b>  | 114        | 137         | 352              | 836              | <i>71e-3/5e4</i> | .                | .           | Basic RCGA [24]        |
| SPSA                           | 24         | 6520        | 3903        | 2418       | 1211        | 2253             | <i>10e-1/1e5</i> | .                | .                | .           | SPSA [13]              |

Table 19: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{19}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>19 Griewank-Rosenbrock F8F2</b>    |          |            |            |           |            |            |            |            |            |                  |                                       |
|---------------------------------------|----------|------------|------------|-----------|------------|------------|------------|------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02      | 1e+01      | 1e+00     | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | <b>1</b>   | 3.9        | 128       | 18         | 21         | 31         | 44         | 52         | 49               | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | <b>1.1</b> | <b>2.7</b> | <b>30</b> | 21         | 19         | 39         | 43         | 58         | 54               | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | <b>1.2</b> | 3.7        | 56        | 17         | 13         | 23         | 30         | 37         | 40               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | <b>1</b>   | <b>3.1</b> | 68        | 12         | 32         | 41         | 50         | 56         | 53               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | <b>1.1</b> | 4.3        | <b>28</b> | 14         | 15         | 28         | 36         | 39         | 36               | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | <b>1</b>   | 4.8        | 35        | 11         | 9.1        | <b>10</b>  | 17         | 16         | <b>15</b>        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | <b>1.2</b> | 6.3        | 42        | 12         | 17         | 25         | 28         | 27         | 29               | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | <b>1</b>   | 9.4        | 57        | 25         | 14         | 22         | 22         | 24         | 22               | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | <b>1</b>   | <b>3.1</b> | 52        | 76         | 24         | 23         | 22         | 21         | 20               | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>1</b>   | 4.7        | 50        | 16         | 13         | <b>12</b>  | <b>12</b>  | <b>11</b>  | <b>10</b>        | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | <b>1.1</b> | 6.1        | 56        | 11         | <b>7.7</b> | 16         | 37         | 73         | 882              | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | <b>1.3</b> | 8.0        | 106       | 13         | 22         | 21         | 20         | 19         | 18               | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 4.9      | 8.7        | 87         | 144       | 24         | 118        | 281        | 493        | 1300       | 2054             | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | <b>1.3</b> | 6.5        | 63        | <b>8.3</b> | 147        | 143        | 138        | 132        | 122              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | <b>1.3</b> | 3.9        | 36        | 8.8        | 72         | 70         | 67         | 67         | 62               | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>1.4</b> | 5.1        | 32        | 9.2        | <b>8.7</b> | 14         | 19         | 19         | 18               | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>1.1</b> | 6.3        | <b>22</b> | 9.0        | 17         | 17         | 18         | 18         | 17               | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | <b>1.1</b> | 3.8        | <b>30</b> | <b>6.7</b> | <b>1.9</b> | <b>3.1</b> | <b>4.0</b> | <b>5.0</b> | <b>5.4</b>       | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | <b>1.3</b> | 5.4        | 36        | <b>7.9</b> | 11         | 13         | <b>16</b>  | <b>16</b>  | 18               | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | 102        | 310        | 549       | 46         | 464        | 451        | 432        | 415        | 389              | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | <b>2.1</b> | 5.5        | 43        | 10         | 341        | 327        | 312        | 299        | 276              | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | <b>1.3</b> | 68         | 539       | 49         | 38         | 81         | 122        | 185        | 258              | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | <b>1.1</b> | 5.7        | 47        | 8.9        | 18         | 22         | 71         | 107        | 453              | Basic RCGA [24]                       |
| SPSA                                  | 20       | 67         | 573        | 982       | 202        | 889        | 1595       | 2506       | 11291      | <i>48e-4/1e5</i> | SPSA [13]                             |

Table 20: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{20}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 20 Schwefel $x*\sin(x)$ |            |            |            |            |            |            |                  |                  |            |                                       |
|---------------------------------------|-------------------------|------------|------------|------------|------------|------------|------------|------------------|------------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                   | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05            | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 6.4                     | 4.8        | 6.0        | 15         | 24         | 37         | 37         | 37               | 37               | 37         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>2.3</b>              | <b>3.0</b> | 3.2        | 13         | 24         | 34         | 34         | 34               | 34               | 33         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>2.2</b>              | <b>2.2</b> | <b>2.1</b> | 17         | 31         | 54         | 54         | 54               | 54               | 53         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 5.7                     | 45         | 98         | 20         | 38         | 51         | 52         | 57               | 57               | 56         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 3.2                     | 3.4        | 3.1        | 9.3        | 6.9        | 7.8        | 7.8        | 7.9              | 7.9              | 7.9        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1.8</b>              | <b>2.3</b> | <b>2.4</b> | 10         | 12         | 13         | 13         | 13               | 13               | 13         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | 3.2                     | 3.6        | 3.7        | 11         | 14         | 15         | 17         | 17               | 17               | 17         | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>2.1</b>              | <b>1.7</b> | <b>1.6</b> | 8.4        | 10         | 11         | 12         | 12               | 12               | 12         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>3.0</b>              | 3.1        | 3.6        | 16         | 4.9        | 4.9        | <b>5.0</b> | <b>5.0</b>       | <b>5.1</b>       | <b>5.1</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1.6</b>              | <b>1.7</b> | <b>1.7</b> | 11         | 4.8        | <b>4.9</b> | <b>4.9</b> | <b>5.0</b>       | <b>5.0</b>       | <b>5.0</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>2.1</b>              | <b>2.6</b> | <b>2.6</b> | 4.6        | <b>2.2</b> | <b>4.1</b> | 6.0        | 7.8              | 10               | 16         | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>3.0</b>              | <b>2.2</b> | <b>2.1</b> | 10         | <b>4.0</b> | <b>4.0</b> | <b>4.0</b> | <b>4.0</b>       | <b>4.0</b>       | <b>3.9</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 22                      | 17         | 15         | 60         | 336        | 1100       | 3695       | <i>49e-3/1e5</i> | .                | .          | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>2.0</b>              | <b>2.9</b> | <b>2.9</b> | <b>4.6</b> | 482        | 481        | 481        | 480              | 476              | 470        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1.8</b>              | <b>2.9</b> | <b>2.9</b> | <b>4.2</b> | 276        | 276        | 276        | 276              | 274              | 270        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1.8</b>              | <b>1.4</b> | <b>1.8</b> | 12         | 10         | 11         | 12         | 12               | 12               | 12         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 4.5                     | 5.7        | 5.6        | 12         | 11         | 12         | 12         | 13               | 13               | 13         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>2.0</b>              | <b>2.6</b> | 3.2        | 10         | <b>4.8</b> | 6.7        | 7.8        | 8.4              | 9.0              | 12         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>2.2</b>              | 3.6        | 3.6        | 11         | 6.7        | 7.6        | 8.1        | 8.4              | 8.5              | 8.7        | NBC-CMA [21]                          |
| POEMS                                 | 190                     | 135        | 121        | 28         | 40         | 45         | 49         | 55               | 61               | 68         | POEMS [17]                            |
| PM-AdapSS-DE                          | 3.3                     | <b>2.5</b> | <b>2.2</b> | <b>4.0</b> | 628        | 627        | 627        | 626              | 620              | 612        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 75                      | 101        | 92         | 45         | 43         | 83         | 132        | 185              | 228              | 301        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>2.1</b>              | 3.7        | 3.6        | 33         | 38         | 143        | 335        | 641              | 849              | 1182       | Basic RCGA [24]                       |
| SPSA                                  | 65                      | 78         | 101        | 9123       | 7680       | 7652       | 7654       | 7639             | <i>11e-1/1e5</i> | .          | SPSA [13]                             |

Table 21: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{21}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>21 Gallagher 101 peaks</b>         |          |          |             |            |            |            |            |            |            |            |                                       |
|---------------------------------------|----------|----------|-------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02    | 1e+01       | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | <b>1</b> | <b>1.3</b>  | 15         | 14         | 16         | 16         | 17         | 17         | 17         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>1.6</b>  | 7.6        | 8.8        | 8.7        | 13         | 17         | 17         | 16         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>1.8</b>  | 5.5        | 13         | 13         | 16         | 16         | 15         | 15         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>1.5</b>  | 20         | 14         | 13         | 20         | 21         | 20         | 20         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | <b>1</b> | <b>1.4</b>  | 8.9        | 5.8        | 4.4        | 4.4        | 4.2        | 4.1        | 4.1        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>1.6</b>  | 5.6        | 4.9        | 4.2        | 6.7        | 6.6        | 6.3        | 6.3        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>1.4</b>  | 6.6        | 4.7        | 3.7        | <b>3.6</b> | <b>3.4</b> | <b>3.3</b> | <b>3.5</b> | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>1.4</b>  | 9.3        | 7.6        | 6.0        | 5.7        | 5.5        | 5.2        | 5.2        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | <b>1</b> | <b>1.6</b>  | 12         | 11         | 7.2        | 6.9        | 6.5        | 6.2        | 6.2        | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>1.3</b>  | 12         | 7.9        | 5.1        | 4.9        | 4.6        | 4.4        | 4.4        | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | <b>1</b> | <b>1.2</b>  | <b>2.0</b> | <b>1.8</b> | <b>2.6</b> | 5.5        | 10         | 26         | 59         | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | <b>1</b> | 6.1         | 6.5        | 4.6        | <b>2.9</b> | <b>2.8</b> | <b>2.7</b> | <b>2.6</b> | <b>2.7</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b> | 7.5      | 12          | 23         | 34         | 75         | 96         | 201        | 234        | 500        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | <b>1</b> | <b>1.3</b>  | 284        | 83         | 53         | 51         | 48         | 46         | 45         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | <b>1</b> | <b>1.5</b>  | <b>2.1</b> | <b>1.0</b> | <b>1.1</b> | <b>1.5</b> | <b>1.6</b> | <b>1.6</b> | <b>2.0</b> | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>1</b> | <b>1.5</b>  | 6.2        | 7.0        | 4.9        | 5.3        | 5.4        | 5.2        | 25         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>1</b> | <b>1.3</b>  | 13         | 7.7        | 5.4        | 13         | 13         | 13         | 14         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | <b>1</b> | <b>1.5</b>  | <b>1.8</b> | <b>4.3</b> | 4.9        | 5.3        | 6.5        | 10         | 12         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | <b>1</b> | <b>0.96</b> | <b>2.3</b> | 7.1        | 25         | 30         | 36         | 35         | 35         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | <b>1</b> | 111         | 143        | 309        | 198        | 191        | 182        | 178        | 178        | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | <b>1</b> | <b>1.7</b>  | <b>1.7</b> | 83         | 53         | 51         | 48         | 46         | 45         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | <b>1</b> | <b>1.8</b>  | 17         | 8.0        | 14         | 25         | 44         | 60         | 105        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | <b>1</b> | <b>1.4</b>  | 14         | 13         | 34         | 71         | 96         | 197        | 285        | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b> | 21       | 47          | 94         | 266        | 218        | 223        | 297        | 320        | 753        | SPSA [13]                             |

Table 22: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{22}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>22 Gallagher 21 peaks</b> |          |            |            |            |            |            |            |            |                  |                                       |
|---------------------------------------|------------------------------|----------|------------|------------|------------|------------|------------|------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                        | 1e+02    | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>                     | <b>1</b> | <b>2.1</b> | 17         | 6.1        | 9.1        | 8.6        | 8.3        | 12         | 12               | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                     | <b>1</b> | <b>1.4</b> | 34         | 19         | 24         | 25         | 22         | 23         | 22               | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                     | <b>1</b> | <b>1.3</b> | 15         | 10         | 11         | 14         | 20         | 23         | 22               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                     | <b>1</b> | <b>1.6</b> | 31         | 18         | 18         | 23         | 28         | 31         | 30               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                     | <b>1</b> | <b>2.2</b> | 10         | 8.3        | 7.0        | 6.5        | 5.9        | 6.6        | 6.3              | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                     | <b>1</b> | <b>1.6</b> | 14         | 11         | 11         | 11         | 10         | 9.5        | 9.1              | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                     | <b>1</b> | 3.2        | 19         | 6.5        | 5.7        | 5.3        | 4.7        | 4.6        | 4.4              | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                     | <b>1</b> | <b>1.5</b> | 16         | 5.1        | 6.0        | 5.5        | 4.9        | 5.3        | 5.1              | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                     | <b>1</b> | 6.6        | 19         | 4.4        | 3.6        | 3.3        | <b>3.0</b> | <b>3.0</b> | <b>2.9</b>       | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                     | <b>1</b> | <b>1</b>   | 8.5        | 4.4        | <b>3.5</b> | <b>3.2</b> | <b>2.8</b> | <b>2.8</b> | <b>2.7</b>       | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                     | <b>1</b> | <b>1.4</b> | <b>2.7</b> | <b>2.8</b> | 4.2        | 8.9        | 21         | 47         | 373              | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                     | <b>1</b> | <b>3.0</b> | 3.8        | <b>1.3</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | <b>1.3</b>       | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b>                     | 8.5      | 4.8        | 12         | 34         | 50         | 119        | 184        | 274        | 760              | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                     | <b>1</b> | <b>1.9</b> | <b>2.2</b> | 184        | 143        | 125        | 110        | 108        | 103              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                     | <b>1</b> | <b>1.3</b> | <b>2.2</b> | <b>1.0</b> | <b>1.3</b> | <b>1.5</b> | <b>1.7</b> | <b>1.8</b> | <b>2.2</b>       | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                     | <b>1</b> | <b>1.2</b> | 4.7        | 5.5        | 4.7        | 7.7        | 7.2        | 7.2        | 15               | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                     | <b>1</b> | <b>1.6</b> | 5.9        | 5.0        | 5.0        | 4.8        | 5.3        | 23         | 72               | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                     | <b>1</b> | <b>1.2</b> | 3.7        | <b>2.9</b> | 3.8        | 4.7        | 5.2        | 6.2        | 8.4              | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                     | <b>1</b> | <b>1.3</b> | <b>2.2</b> | 8.4        | 21         | 31         | 28         | 28         | 28               | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                     | <b>1</b> | 66         | 31         | 604        | 467        | 412        | 365        | 364        | 350              | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                     | <b>1</b> | <b>1.5</b> | <b>2.4</b> | 86         | 67         | 59         | 52         | 51         | 49               | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                     | <b>1</b> | 39         | 26         | 17         | 32         | 44         | 58         | 70         | 129              | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                     | <b>1</b> | <b>1.4</b> | <b>2.1</b> | 11         | 25         | 69         | 119        | 232        | 604              | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b>                     | 22       | 107        | 284        | 373        | 750        | 1930       | 9991       | 9800       | <i>38e-4/1e5</i> | SPSA [13]                             |

Table 23: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{23}$  in **2-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>23 Katsuuras</b> |            |            |            |                  |                  |            |                  |                  |            |                                       |
|---------------------------------------|---------------------|------------|------------|------------|------------------|------------------|------------|------------------|------------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03               | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03      | 1e-04            | 1e-05            | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>            | <b>1</b>   | <b>1.5</b> | 22         | 214              | 253              | 222        | 213              | 192              | 243        | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>            | <b>1</b>   | 4.2        | 10         | 76               | 81               | 71         | 68               | 62               | 57         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>            | <b>1</b>   | <b>2.2</b> | 18         | 90               | 99               | 90         | 86               | 78               | 72         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>            | <b>1</b>   | <b>1.6</b> | 14         | 103              | 225              | 288        | 276              | 249              | 770        | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>            | <b>1</b>   | <b>2.1</b> | 11         | 23               | 23               | 27         | 26               | 24               | 22         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>            | <b>1</b>   | 3.8        | 13         | 19               | 17               | 15         | 15               | 13               | 13         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>            | <b>1</b>   | 4.5        | 8.5        | 13               | 13               | 12         | <b>12</b>        | <b>11</b>        | <b>10</b>  | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>            | <b>1</b>   | <b>2.2</b> | 14         | 29               | 29               | 26         | 25               | 22               | 21         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>            | <b>1</b>   | 8.2        | 3.1        | <b>4.5</b>       | <b>4.5</b>       | <b>4.5</b> | <b>6.1</b>       | <b>5.6</b>       | <b>5.4</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>            | <b>1</b>   | <b>2.0</b> | <b>2.2</b> | 6.7              | 14               | 14         | 13               | <b>12</b>        | <b>11</b>  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>            | <b>1</b>   | <b>2.1</b> | 15         | 1791             | <i>13e-2/1e5</i> | .          | .                | .                | .          | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>            | <b>1</b>   | 4.2        | 6.7        | 25               | 103              | 262        | <i>49e-3/6e3</i> | .                | .          | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b>            | <b>2.5</b> | 4.0        | 12         | 2604             | <i>17e-2/1e5</i> | .          | .                | .                | .          | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>            | <b>1</b>   | <b>1.8</b> | <b>2.4</b> | <b>5.4</b>       | <b>7.6</b>       | <b>9.3</b> | <b>11</b>        | 13               | 15         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>            | <b>1</b>   | <b>2.5</b> | <b>2.3</b> | 6.0              | <b>8.2</b>       | 10         | 12               | 13               | 16         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>            | <b>1</b>   | <b>2.8</b> | 6.6        | 16               | 19               | 17         | 16               | 15               | 14         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>            | <b>1</b>   | <b>1.9</b> | 7.8        | 162              | 233              | 204        | 196              | 177              | 162        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>            | <b>1</b>   | <b>2.0</b> | 5.5        | 24               | 40               | 44         | 46               | 43               | 42         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>            | <b>1</b>   | <b>1.8</b> | 10         | 737              | 761              | 668        | 639              | 576              | 529        | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>            | <b>1</b>   | 13         | 41         | 253              | 245              | 233        | 234              | 225              | 230        | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>            | <b>1</b>   | <b>2.0</b> | <b>1.9</b> | <b>5.8</b>       | 8.5              | <b>10</b>  | 12               | 13               | 16         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>            | <b>1</b>   | 11         | 61         | 659              | 866              | 996        | 1160             | 1199             | 1404       | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>            | <b>1</b>   | <b>1.9</b> | 5.2        | 256              | 889              | 4692       | 4487             | <i>29e-3/5e4</i> | .          | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b>            | 13         | 18         | 264        | <i>49e-2/1e5</i> | .                | .          | .                | .                | .          | SPSA [13]                             |





Table 25: Running time excess  $ERT/ERT_{best}$  2009 on  $f_1$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>1 Sphere</b>                        |            |            |            |            |            |            |            |            |            |            |                                        |
|----------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|----------------------------------------|
| $\Delta ft_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta ft_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                           | <b>1</b>   | <b>1</b>   | 6.3        | 9.3        | 16         | 26         | 31         | 40         | 46         | 66         | (1,2)-CMA-ES [5, 3]                    |
| (1,2m)-CMA-ES                          | <b>1</b>   | <b>1</b>   | <b>2.9</b> | 5.2        | 12         | 18         | 24         | 31         | 38         | 51         | (1,2m)-CMA-ES [5]                      |
| (1,2ms)-CMA-ES                         | <b>1</b>   | <b>1</b>   | <b>1.9</b> | 4.0        | 8.2        | 13         | 19         | 23         | 30         | 41         | (1,2ms)-CMA-ES [5]                     |
| (1,2s)-CMA-ES                          | <b>1</b>   | <b>1</b>   | 5.5        | 6.7        | 12         | 19         | 28         | 34         | 42         | 60         | (1,2s)-CMA-ES [3]                      |
| (1,4)-CMA-ES                           | <b>1</b>   | <b>1</b>   | 3.1        | 4.5        | 10         | 14         | 19         | 24         | 29         | 37         | (1,4)-CMA-ES [6, 4]                    |
| (1,4m)-CMA-ES                          | <b>1</b>   | <b>1.1</b> | 3.4        | 4.5        | 8.3        | 12         | 17         | 22         | 27         | 35         | (1,4m)-CMA-ES [6]                      |
| (1,4ms)-CMA-ES                         | <b>1</b>   | <b>1</b>   | <b>2.4</b> | <b>3.4</b> | <b>5.8</b> | <b>8.8</b> | <b>12</b>  | <b>15</b>  | <b>20</b>  | <b>26</b>  | (1,4ms)-CMA-ES [1, 6]                  |
| (1,4s)-CMA-ES                          | <b>1</b>   | <b>1.2</b> | <b>2.7</b> | <b>3.7</b> | <b>6.7</b> | <b>11</b>  | <b>14</b>  | <b>18</b>  | 24         | 30         | (1,4s)-CMA-ES [4]                      |
| (1+1)-CMA-ES                           | <b>1</b>   | <b>1</b>   | <b>2.3</b> | 3.9        | 8.8        | 12         | 16         | 20         | 23         | 31         | (1+1)-CMA-ES [7]                       |
| (1+2ms)-CMA-ES                         | <b>1</b>   | <b>1</b>   | <b>2.9</b> | 4.8        | 8.4        | 12         | 15         | 19         | <b>23</b>  | <b>29</b>  | (1+2ms)-CMA-ES [2]                     |
| Artif Bee Colony                       | <b>1</b>   | <b>1</b>   | 5.4        | 20         | 41         | 64         | 88         | 118        | 147        | 210        | Artif Bee Colony [8]                   |
| avg NEWUOA                             | <b>1</b>   | <b>1.3</b> | <b>2.4</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | <b>1.1</b> | avg NEWUOA [23]                        |
| CMA-EGS (IPOP,r1)                      | <b>1.1</b> | 23         | 13         | 14         | 24         | 40         | 69         | 107        | 139        | 197        | CMA-EGS (IPOP,r1) [12]                 |
| Adap DE (F-AUC)                        | <b>1</b>   | <b>1.1</b> | <b>2.4</b> | 15         | 33         | 53         | 76         | 96         | 118        | 163        | Adap DE (F-AUC) [10]                   |
| DE (Uniform)                           | <b>1</b>   | <b>1</b>   | 3.4        | 14         | 35         | 57         | 79         | 105        | 126        | 174        | DE (Uniform) [9]                       |
| IPOP-aCMA-ES                           | <b>1</b>   | <b>1</b>   | 3.6        | 6.4        | 11         | 16         | 23         | 28         | 33         | 44         | IPOP-aCMA-ES [16]                      |
| IPOP-CMA-ES                            | <b>1</b>   | <b>1</b>   | 3.6        | 4.9        | 11         | 18         | 23         | 30         | 35         | 47         | IPOP-CMA-ES [22]                       |
| CMA+DE-MOS                             | <b>1</b>   | <b>1.1</b> | <b>2.5</b> | 18         | 48         | 72         | 100        | 128        | 152        | 208        | CMA+DE-MOS [18]                        |
| NBC-CMA                                | <b>1</b>   | <b>1</b>   | <b>2.3</b> | 16         | 45         | 57         | 66         | 79         | 90         | 112        | NBC-CMA [21]                           |
| POEMS                                  | <b>1</b>   | <b>1</b>   | 173        | 108        | 191        | 479        | 961        | 1309       | 1628       | 2506       | POEMS [17]                             |
| PM-AdapSS-DE                           | <b>1</b>   | <b>1.4</b> | <b>2.4</b> | 16         | 33         | 55         | 77         | 99         | 120        | 166        | PM-AdapSS-DE [9, 10]                   |
| pPOEMS                                 | <b>1</b>   | <b>1</b>   | 49         | 90         | 165        | 1519       | 3923       | 6568       | 9419       | 15398      | pPOEMS [17, 20]                        |
| Basic RCGA                             | <b>1</b>   | <b>1.1</b> | <b>2.0</b> | 20         | 77         | 152        | 268        | 497        | 693        | 1315       | Basic RCGA [24]                        |
| SPSA                                   | <b>1</b>   | 33         | 19         | 11         | 14         | 17         | 20         | 24         | 27         | 34         | SPSA [13]                              |









Table 30: Running time excess  $ERT/ERT_{best}$  2009 on  $f_6$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                        | 6 Attractive sector |            |            |            |            |                  |            |            |            |                  |                                        |
|----------------------------------------|---------------------|------------|------------|------------|------------|------------------|------------|------------|------------|------------------|----------------------------------------|
| $\Delta ft_{target}$<br>$ERT_{best}/D$ | 1e+03               | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03      | 1e-04      | 1e-05      | 1e-07            | $\Delta ft_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                           | 4.0                 | 3.3        | 5.0        | 7.6        | 6.3        | 6.1              | 5.8        | 5.3        | 5.0        | 5.5              | (1,2)-CMA-ES [5, 3]                    |
| (1,2m)-CMA-ES                          | <b>2.7</b>          | <b>2.6</b> | 3.8        | 4.4        | 4.1        | 4.4              | 4.8        | 4.4        | 4.1        | 4.1              | (1,2m)-CMA-ES [5]                      |
| (1,2ms)-CMA-ES                         | <b>2.3</b>          | <b>2.0</b> | <b>2.9</b> | 3.5        | 3.5        | 3.7              | 3.4        | 3.3        | 3.4        | 3.4              | (1,2ms)-CMA-ES [5]                     |
| (1,2s)-CMA-ES                          | 3.2                 | 4.6        | 8.2        | 8.4        | 6.9        | 8.0              | 7.5        | 6.8        | 6.8        | 7.2              | (1,2s)-CMA-ES [3]                      |
| (1,4)-CMA-ES                           | <b>3.0</b>          | <b>2.7</b> | <b>1.9</b> | <b>2.5</b> | <b>2.3</b> | <b>2.4</b>       | <b>2.5</b> | <b>2.3</b> | <b>2.4</b> | <b>2.5</b>       | (1,4)-CMA-ES [6, 4]                    |
| (1,4m)-CMA-ES                          | <b>2.3</b>          | <b>1.9</b> | <b>2.3</b> | <b>2.7</b> | <b>2.6</b> | <b>2.6</b>       | <b>2.6</b> | <b>2.3</b> | <b>2.4</b> | <b>2.5</b>       | (1,4m)-CMA-ES [6]                      |
| (1,4ms)-CMA-ES                         | <b>2.1</b>          | <b>1.7</b> | <b>1.5</b> | <b>1.8</b> | <b>1.8</b> | <b>1.8</b>       | <b>1.7</b> | <b>1.8</b> | <b>1.7</b> | <b>1.7</b>       | (1,4ms)-CMA-ES [1, 6]                  |
| (1,4s)-CMA-ES                          | 4.0                 | <b>2.5</b> | <b>1.7</b> | <b>2.1</b> | <b>1.9</b> | <b>2.0</b>       | <b>1.9</b> | <b>2.0</b> | <b>2.0</b> | <b>2.2</b>       | (1,4s)-CMA-ES [4]                      |
| (1+1)-CMA-ES                           | <b>1.7</b>          | <b>2.4</b> | <b>1.6</b> | <b>2.0</b> | <b>1.9</b> | <b>1.9</b>       | <b>1.8</b> | <b>1.8</b> | <b>1.8</b> | <b>1.9</b>       | (1+1)-CMA-ES [7]                       |
| (1+2ms)-CMA-ES                         | <b>1.9</b>          | <b>1.6</b> | <b>1.8</b> | <b>2.0</b> | <b>1.7</b> | <b>1.7</b>       | <b>1.6</b> | <b>1.5</b> | <b>1.5</b> | <b>1.6</b>       | (1+2ms)-CMA-ES [2]                     |
| Artif Bee Colony                       | 3.4                 | <b>2.2</b> | 3.8        | 13         | 43         | 163              | 445        | 490        | 592        | 524              | Artif Bee Colony [8]                   |
| avg NEWUOA                             | <b>1.2</b>          | <b>2.3</b> | <b>2.6</b> | <b>2.9</b> | <b>2.9</b> | 3.8              | 3.9        | 4.1        | 4.3        | 4.7              | avg NEWUOA [23]                        |
| CMA-EGS (IPOP,r1)                      | 7.3                 | 74         | 115        | 312        | 207        | 488              | 608        | 526        | 603        | 2355             | CMA-EGS (IPOP,r1) [12]                 |
| Adap DE (F-AUC)                        | 4.9                 | <b>2.8</b> | 5.3        | 8.8        | 8.9        | 9.0              | 8.9        | 9.1        | 8.7        | 9.5              | Adap DE (F-AUC) [10]                   |
| DE (Uniform)                           | 3.6                 | 4.1        | 4.3        | 9.2        | 9.5        | 10               | 10         | 10         | 10         | 10               | DE (Uniform) [9]                       |
| IPOP-aCMA-ES                           | 4.0                 | 4.3        | 3.3        | 3.3        | 3.2        | 3.3              | 3.2        | <b>2.9</b> | <b>3.0</b> | 3.0              | IPOP-aCMA-ES [16]                      |
| IPOP-CMA-ES                            | 3.9                 | <b>2.8</b> | <b>2.8</b> | 3.3        | 3.3        | 3.3              | 3.2        | <b>3.0</b> | <b>3.0</b> | 3.1              | IPOP-CMA-ES [22]                       |
| CMA+DE-MOS                             | 4.2                 | 3.4        | 5.8        | 14         | 13         | 15               | 14         | 13         | 13         | 14               | CMA+DE-MOS [18]                        |
| NBC-CMA                                | 6.0                 | 3.5        | 4.5        | 14         | 11         | 9.3              | 8.4        | 7.6        | 7.2        | 6.9              | NBC-CMA [21]                           |
| POEMS                                  | 150                 | 84         | 34         | 61         | 83         | 92               | 101        | 95         | 96         | 109              | POEMS [17]                             |
| PM-AdapSS-DE                           | 5.1                 | 3.3        | 3.7        | 8.6        | 8.7        | 9.2              | 9.4        | 9.3        | 9.4        | 10               | PM-AdapSS-DE [9, 10]                   |
| pPOEMS                                 | 89                  | 74         | 37         | 228        | 455        | 618              | 631        | 670        | 717        | 803              | pPOEMS [17, 20]                        |
| Basic RCGA                             | 23                  | 14         | 13         | 160        | 302        | 813              | 1494       | 3510       | 4760       | <i>18e-4/5e4</i> | Basic RCGA [24]                        |
| SPSA                                   | 23                  | 4689       | 11501      | 11802      | 14416      | <i>11e+0/1e5</i> | .          | .          | .          | .                | SPSA [13]                              |

Table 31: Running time excess  $ERT/ERT_{best}$  2009 on  $f_7$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>7 Step-ellipsoid</b>               |            |            |            |            |                  |             |            |            |            |            |                                       |
|---------------------------------------|------------|------------|------------|------------|------------------|-------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02       | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1.3</b> | 3.4        | 15         | 11         | 17               | 83          | 202        | 202        | 202        | 256        | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1.5</b> | 3.2        | 3.4        | 6.8        | 8.0              | 20          | 27         | 27         | 27         | 51         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1.3</b> | <b>2.4</b> | 3.9        | 3.4        | 5.2              | 25          | 44         | 44         | 44         | 59         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1.1</b> | <b>2.1</b> | 6.9        | 18         | 17               | 107         | 179        | 179        | 179        | 389        | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1.3</b> | 4.8        | 3.9        | <b>2.2</b> | 3.1              | 3.4         | 6.7        | 6.7        | 6.7        | 16         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1.3</b> | <b>2.1</b> | <b>2.2</b> | <b>2.1</b> | <b>1.9</b>       | 3.3         | 3.2        | 3.2        | 3.2        | 3.9        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1.4</b> | <b>1.9</b> | 14         | 3.8        | <b>1.6</b>       | <b>2.2</b>  | 3.9        | 3.9        | 3.9        | 6.8        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1.2</b> | <b>2.5</b> | 3.4        | <b>2.6</b> | <b>2.6</b>       | 3.3         | 5.6        | 5.6        | 5.6        | 10         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1.9</b> | <b>1.7</b> | <b>2.7</b> | <b>1.9</b> | <b>0.82</b>      | <b>2.2</b>  | <b>2.5</b> | <b>2.5</b> | <b>2.5</b> | <b>2.3</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1.5</b> | <b>2.1</b> | <b>2.2</b> | <b>2.2</b> | <b>1.3</b>       | <b>1.3</b>  | <b>1.5</b> | <b>1.5</b> | <b>1.5</b> | <b>1.4</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1.2</b> | <b>1.6</b> | 6.1        | 8.0        | 10               | 22          | 85         | 85         | 85         | 125        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.3</b> | 3.5        | <b>1.2</b> | 6.8        | 4.8              | 19          | 41         | 41         | 41         | 37         | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 17         | 164        | 246        | 781        | 2492             | 9087        | 8751       | 8751       | 8751       | 7880       | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1.3</b> | <b>1.5</b> | <b>2.4</b> | 3.4        | <b>1.1</b>       | <b>1.2</b>  | <b>1.4</b> | <b>1.4</b> | <b>1.4</b> | <b>1.5</b> | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1.3</b> | <b>1.5</b> | 5.5        | 4.2        | <b>1.3</b>       | <b>1.4</b>  | <b>1.6</b> | <b>1.6</b> | <b>1.6</b> | <b>1.6</b> | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1.3</b> | <b>2.6</b> | <b>2.9</b> | <b>1.7</b> | <b>0.93</b>      | <b>0.90</b> | <b>1.0</b> | <b>1.0</b> | <b>1.0</b> | <b>1.1</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1.5</b> | <b>2.4</b> | 3.5        | 7.2        | <b>2.0</b>       | <b>1.6</b>  | <b>1.9</b> | <b>1.9</b> | <b>1.9</b> | <b>1.8</b> | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1.1</b> | <b>2.2</b> | 3.0        | 4.4        | <b>2.3</b>       | <b>2.2</b>  | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.4</b> | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1.1</b> | <b>2.2</b> | 4.2        | 4.9        | <b>2.5</b>       | <b>2.2</b>  | <b>2.2</b> | <b>2.2</b> | <b>2.2</b> | <b>2.1</b> | NBC-CMA [21]                          |
| POEMS                                 | 92         | 240        | 76         | 28         | 27               | 26          | 28         | 28         | 28         | 28         | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1.5</b> | <b>1.8</b> | 4.3        | 3.5        | <b>1.2</b>       | <b>1.3</b>  | <b>1.6</b> | <b>1.6</b> | <b>1.6</b> | <b>1.6</b> | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1.6</b> | 33         | 61         | 30         | 40               | 67          | 91         | 91         | 91         | 106        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1.1</b> | <b>2.1</b> | 5.6        | 43         | 80               | 161         | 212        | 212        | 212        | 208        | Basic RCGA [24]                       |
| SPSA                                  | 59         | 193        | 20672      | 30144      | <i>69e-1/1e5</i> | .           | .          | .          | .          | .          | SPSA [13]                             |



Table 32: Running time excess  $ERT/ERT_{best}$  2009 on  $f_8$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>8 Rosenbrock original</b> |            |            |            |            |            |             |                  |                  |                  |            |                        |  |
|------------------------------|------------|------------|------------|------------|------------|-------------|------------------|------------------|------------------|------------|------------------------|--|
| $\Delta ft_{target}$         | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02       | 1e-03            | 1e-04            | 1e-05            | 1e-07      | $\Delta ft_{target}$   |  |
| $ERT_{best}/D$               |            |            |            |            |            |             |                  |                  |                  |            | $ERT_{best}/D$         |  |
| (1,2)-CMA-ES                 | 5.0        | 10         | 12         | 28         | 16         | 17          | 18               | 18               | 18               | 18         | (1,2)-CMA-ES [5, 3]    |  |
| (1,2m)-CMA-ES                | <b>2.8</b> | <b>2.2</b> | 10         | 20         | 9.3        | 10          | 11               | 11               | 11               | 11         | (1,2m)-CMA-ES [5]      |  |
| (1,2ms)-CMA-ES               | <b>2.6</b> | 6.2        | 12         | 29         | 12         | 12          | 13               | 13               | 13               | 13         | (1,2ms)-CMA-ES [5]     |  |
| (1,2s)-CMA-ES                | <b>1.8</b> | <b>2.2</b> | 3.9        | 50         | 23         | 25          | 28               | 29               | 29               | 29         | (1,2s)-CMA-ES [3]      |  |
| (1,4)-CMA-ES                 | 4.4        | 4.3        | 3.8        | 11         | 5.3        | 5.4         | 5.7              | 5.9              | 6.0              | 6.2        | (1,4)-CMA-ES [6, 4]    |  |
| (1,4m)-CMA-ES                | 3.9        | 3.3        | 3.5        | 13         | 6.7        | 6.7         | 6.8              | 6.8              | 6.9              | 7.0        | (1,4m)-CMA-ES [6]      |  |
| (1,4ms)-CMA-ES               | <b>2.4</b> | <b>2.6</b> | 3.5        | 10         | 4.3        | 4.4         | 4.6              | 4.6              | 4.7              | 4.8        | (1,4ms)-CMA-ES [1, 6]  |  |
| (1,4s)-CMA-ES                | <b>2.5</b> | <b>1.6</b> | <b>2.0</b> | 10         | 5.0        | 5.4         | 5.7              | 5.7              | 5.8              | 5.8        | (1,4s)-CMA-ES [4]      |  |
| (1+1)-CMA-ES                 | <b>2.5</b> | <b>2.6</b> | <b>2.5</b> | <b>6.5</b> | <b>2.9</b> | <b>3.0</b>  | <b>3.0</b>       | <b>3.1</b>       | <b>3.2</b>       | <b>3.4</b> | (1+1)-CMA-ES [7]       |  |
| (1+2ms)-CMA-ES               | <b>1.7</b> | <b>1.7</b> | <b>2.1</b> | <b>4.8</b> | <b>2.3</b> | <b>2.3</b>  | <b>2.5</b>       | <b>2.5</b>       | <b>2.7</b>       | <b>2.8</b> | (1+2ms)-CMA-ES [2]     |  |
| Artif Bee Colony             | <b>2.1</b> | 3.9        | 3.8        | 17         | 26         | 235         | 3088             | 21956            | <i>12e-4/1e5</i> | .          | Artif Bee Colony [8]   |  |
| avg NEWUOA                   | 3.1        | <b>1.9</b> | <b>1.9</b> | <b>2.6</b> | <b>1.0</b> | <b>0.98</b> | <b>0.98</b>      | <b>1.00</b>      | <b>1.0</b>       | <b>1.0</b> | avg NEWUOA [23]        |  |
| CMA-EGS (IPOP,r1)            | 35         | 17         | 25         | 50         | 21         | 22          | 22               | 22               | 24               | 25         | CMA-EGS (IPOP,r1) [12] |  |
| Adap DE (F-AUC)              | 3.5        | 4.7        | 9.1        | 13         | 7.2        | 7.9         | 8.5              | 9.1              | 10               | 11         | Adap DE (F-AUC) [10]   |  |
| DE (Uniform)                 | 5.1        | 5.2        | 8.4        | 16         | 9.5        | 11          | 12               | 13               | 14               | 15         | DE (Uniform) [9]       |  |
| IPOP-aCMA-ES                 | 3.6        | 4.1        | 3.5        | 7.4        | 3.8        | 4.1         | 4.2              | 4.3              | 4.5              | 4.7        | IPOP-aCMA-ES [16]      |  |
| IPOP-CMA-ES                  | 3.8        | 4.6        | 4.9        | 13         | 5.8        | 5.7         | 5.8              | 5.9              | 6.2              | 6.3        | IPOP-CMA-ES [22]       |  |
| CMA+DE-MOS                   | 3.4        | 6.1        | 11         | 19         | 12         | 13          | 13               | 14               | 15               | 16         | CMA+DE-MOS [18]        |  |
| NBC-CMA                      | 4.9        | 5.8        | 8.8        | 13         | 6.8        | 7.3         | 7.9              | 8.1              | 8.4              | 8.9        | NBC-CMA [21]           |  |
| POEMS                        | 147        | 55         | 44         | 88         | 55         | 74          | 163              | 283              | 300              | 380        | POEMS [17]             |  |
| PM-AdapSS-DE                 | <b>2.2</b> | 4.5        | 8.7        | 13         | 7.0        | 8.7         | 10               | 56               | 56               | 54         | PM-AdapSS-DE [9, 10]   |  |
| pPOEMS                       | 125        | 53         | 43         | 148        | 221        | 376         | 479              | 643              | 794              | 1066       | pPOEMS [17, 20]        |  |
| Basic RCGA                   | <b>2.6</b> | 7.0        | 13         | 61         | 640        | 1150        | 3462             | <i>14e-3/5e4</i> | .                | .          | Basic RCGA [24]        |  |
| SPSA                         | 490        | 275        | 267        | 8639       | 5825       | 24022       | <i>12e-1/1e5</i> | .                | .                | .          | SPSA [13]              |  |

Table 33: Running time excess  $ERT/ERT_{best}$  2009 on  $f_9$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 9 Rosenbrock rotated |           |            |            |                  |            |                  |            |                  |            |                                       |  |
|---------------------------------------|----------------------|-----------|------------|------------|------------------|------------|------------------|------------|------------------|------------|---------------------------------------|--|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                | 1e+02     | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03            | 1e-04      | 1e-05            | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |  |
| (1,2)-CMA-ES                          | 15                   | 86        | 11         | 14         | 16               | 17         | 18               | 18         | 18               | 19         | (1,2)-CMA-ES [5, 3]                   |  |
| (1,2m)-CMA-ES                         | 15                   | 42        | 5.2        | 10         | 10               | 11         | 11               | 12         | 12               | 12         | (1,2m)-CMA-ES [5]                     |  |
| (1,2ms)-CMA-ES                        | <b>7.8</b>           | 39        | 16         | 17         | 13               | 13         | 13               | 14         | 13               | 14         | (1,2ms)-CMA-ES [5]                    |  |
| (1,2s)-CMA-ES                         | 10                   | 54        | 4.8        | 6.7        | 16               | 21         | 22               | 24         | 24               | 25         | (1,2s)-CMA-ES [3]                     |  |
| (1,4)-CMA-ES                          | 10                   | 37        | 4.2        | 7.4        | 6.4              | 6.6        | 6.9              | 7.0        | 7.2              | 7.2        | (1,4)-CMA-ES [6, 4]                   |  |
| (1,4m)-CMA-ES                         | 11                   | 36        | 3.1        | 3.8        | 4.1              | 4.6        | 5.0              | 5.2        | 5.4              | 5.6        | (1,4m)-CMA-ES [6]                     |  |
| (1,4ms)-CMA-ES                        | 9.4                  | <b>23</b> | <b>2.5</b> | <b>3.1</b> | 3.5              | 3.9        | 4.1              | 4.2        | 4.3              | 4.4        | (1,4ms)-CMA-ES [1, 6]                 |  |
| (1,4s)-CMA-ES                         | 11                   | 39        | <b>2.7</b> | 9.1        | 7.2              | 7.3        | 7.3              | 7.3        | 7.3              | 7.3        | (1,4s)-CMA-ES [4]                     |  |
| (1+1)-CMA-ES                          | 10                   | 31        | <b>2.6</b> | <b>3.3</b> | <b>2.9</b>       | <b>3.1</b> | <b>3.1</b>       | <b>3.3</b> | <b>3.4</b>       | <b>3.6</b> | (1+1)-CMA-ES [7]                      |  |
| (1+2ms)-CMA-ES                        | 11                   | 26        | <b>2.8</b> | 3.9        | <b>3.3</b>       | <b>3.3</b> | <b>3.4</b>       | <b>3.5</b> | <b>3.6</b>       | <b>3.7</b> | (1+2ms)-CMA-ES [2]                    |  |
| Artif Bee Colony                      | 11                   | 54        | 5.2        | 7.3        | 93               | 473        | 4854             | 26815      | <i>24e-4/1e5</i> | .          | Artif Bee Colony [8]                  |  |
| avg NEWUOA                            | 11                   | <b>20</b> | <b>1.7</b> | <b>1.7</b> | <b>1.2</b>       | <b>1.1</b> | <b>1.1</b>       | <b>1.1</b> | <b>1.2</b>       | <b>1.2</b> | avg NEWUOA [23]                       |  |
| CMA-EGS (IPOP,r1)                     | 125                  | 163       | 26         | 37         | 29               | 27         | 27               | 28         | 28               | 29         | CMA-EGS (IPOP,r1) [12]                |  |
| Adap DE (F-AUC)                       | 14                   | 42        | 7.7        | 10         | 9.3              | 11         | 19               | 22         | 24               | 24         | Adap DE (F-AUC) [10]                  |  |
| DE (Uniform)                          | 11                   | 45        | 9.2        | 9.1        | 10               | 12         | 13               | 14         | 14               | 15         | DE (Uniform) [9]                      |  |
| IPOP-aCMA-ES                          | 10                   | 38        | 3.5        | 5.9        | 4.8              | 4.8        | 5.1              | 5.3        | 5.4              | 5.6        | IPOP-aCMA-ES [16]                     |  |
| IPOP-CMA-ES                           | <b>5.5</b>           | <b>19</b> | <b>3.0</b> | 4.8        | 4.4              | 4.8        | 5.0              | 5.2        | 5.5              | 5.7        | IPOP-CMA-ES [22]                      |  |
| CMA+DE-MOS                            | 10                   | 55        | 11         | 4.9        | 6.9              | 9.3        | 10               | 11         | 12               | 14         | CMA+DE-MOS [18]                       |  |
| NBC-CMA                               | 8.8                  | 56        | 10         | 9.1        | 8.7              | 9.3        | 10               | 10         | 10               | 11         | NBC-CMA [21]                          |  |
| POEMS                                 | 603                  | 753       | 55         | 213        | 138              | 176        | 252              | 352        | 461              | 604        | POEMS [17]                            |  |
| PM-AdapSS-DE                          | <b>7.7</b>           | 31        | 7.6        | 8.4        | 8.4              | 10         | 10               | 11         | 12               | 13         | PM-AdapSS-DE [9, 10]                  |  |
| pPOEMS                                | 466                  | 780       | 59         | 146        | 322              | 466        | 624              | 763        | 945              | 1276       | pPOEMS [17, 20]                       |  |
| Basic RCGA                            | 12                   | 69        | 12         | 181        | 1567             | 7119       | <i>94e-3/5e4</i> | .          | .                | .          | Basic RCGA [24]                       |  |
| SPSA                                  | 5984                 | 12372     | 1417       | 9774       | <i>12e-1/1e5</i> | .          | .                | .          | .                | .          | SPSA [13]                             |  |



Table 35: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{11}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                     | <b>11 Discus</b> |            |            |            |                  |                  |                  |            |            |            |                        |
|---------------------|------------------|------------|------------|------------|------------------|------------------|------------------|------------|------------|------------|------------------------|
| $\Delta f_{target}$ | 1e+03            | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03            | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$    |
| $ERT_{best}/D$      | 3.1              | 3.9        | 22         | 35         | 76               | 88               | 92               | 96         | 101        | 109        | $ERT_{best}/D$         |
| (1,2)-CMA-ES        | 10               | 74         | 36         | 27         | 14               | 12               | 12               | 12         | 12         | 11         | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES       | 18               | 80         | 28         | 23         | 12               | 10               | 10               | 10         | 10         | 9.4        | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES      | 16               | 44         | 20         | 19         | 9.5              | 8.5              | 8.3              | 8.2        | 8.2        | 8.0        | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES       | 34               | 119        | 36         | 36         | 19               | 17               | 17               | 17         | 16         | 15         | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES        | 5.2              | 18         | 10         | 8.8        | 4.7              | 4.3              | 4.3              | 4.3        | 4.2        | 4.2        | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES       | 4.2              | 24         | 12         | 9.3        | 4.7              | 4.3              | 4.3              | 4.3        | 4.3        | 4.2        | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES      | 6.7              | 11         | 7.0        | 6.9        | 3.6              | 3.2              | 3.1              | 3.1        | 3.1        | 3.0        | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES       | <b>3.7</b>       | 15         | 9.3        | 7.5        | 4.0              | 3.7              | 3.6              | 3.6        | 3.6        | 3.5        | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES        | <b>3.8</b>       | 13         | 5.9        | 5.3        | <b>2.8</b>       | <b>2.5</b>       | <b>2.5</b>       | <b>2.5</b> | <b>2.5</b> | <b>2.5</b> | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES      | 3.9              | <b>6.8</b> | <b>5.3</b> | <b>4.5</b> | <b>2.5</b>       | <b>2.3</b>       | <b>2.2</b>       | <b>2.2</b> | <b>2.2</b> | <b>2.2</b> | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony    | 7.0              | <b>8.2</b> | 28         | 262        | 2431             | <i>14e-2/1e5</i> | .                | .          | .          | .          | Artif Bee Colony [8]   |
| avg NEWUOA          | <b>1.9</b>       | <b>2.6</b> | <b>2.0</b> | <b>3.3</b> | <b>2.5</b>       | <b>2.7</b>       | 3.3              | 3.7        | 4.3        | 5.0        | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)   | 12               | 172        | 78         | 59         | 29               | 25               | 24               | 24         | 23         | 23         | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)     | 13               | 20         | 5.7        | 5.5        | 3.0              | 3.4              | 3.7              | 4.3        | 4.6        | 5.3        | Adap DE (F-AUC) [10]   |
| DE (Uniform)        | 10               | 15         | 5.9        | 5.6        | 3.3              | 3.5              | 3.9              | 4.4        | 4.9        | 5.7        | DE (Uniform) [9]       |
| IPOP-aCMA-ES        | 6.1              | 9.1        | <b>5.3</b> | <b>4.5</b> | <b>2.4</b>       | <b>2.3</b>       | <b>2.3</b>       | <b>2.4</b> | <b>2.5</b> | <b>2.5</b> | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES         | 6.0              | 13         | 9.2        | 7.5        | 4.0              | 3.7              | 3.7              | 3.7        | 3.7        | 3.7        | IPOP-CMA-ES [22]       |
| CMA+DE-MOS          | 13               | 23         | 17         | 17         | 8.8              | 8.5              | 8.7              | 9.0        | 9.0        | 9.4        | CMA+DE-MOS [18]        |
| NBC-CMA             | 11               | 25         | 11         | 16         | 9.1              | 8.8              | 9.2              | 9.1        | 9.0        | 9.1        | NBC-CMA [21]           |
| POEMS               | 79               | 81         | 138        | 716        | 641              | 891              | 1259             | 1627       | 1683       | 2371       | POEMS [17]             |
| PM-AdapSS-DE        | 11               | 17         | 6.1        | 5.6        | 3.4              | 3.6              | 4.1              | 4.5        | 4.9        | 5.6        | PM-AdapSS-DE [9, 10]   |
| pPOEMS              | 70               | 62         | 86         | 383        | 312              | 447              | 534              | 679        | 787        | 943        | pPOEMS [17, 20]        |
| Basic RCGA          | 11               | 17         | 342        | 1203       | 2947             | 8132             | <i>58e-2/5e4</i> | .          | .          | .          | Basic RCGA [24]        |
| SPSA                | 10               | 224        | 3544       | 18559      | <i>58e-1/1e5</i> | .                | .                | .          | .          | .          | SPSA [13]              |

Table 36: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{12}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 12 Bent cigar |            |            |            |            |                  |                  |            |                  |            |                                       |
|---------------------------------------|---------------|------------|------------|------------|------------|------------------|------------------|------------|------------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03         | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03            | 1e-04      | 1e-05            | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 23            | 43         | 55         | 39         | 27         | 28               | 27               | 23         | 22               | 21         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | 5.9           | 11         | 25         | 16         | 11         | 10               | 10               | 8.2        | 8.1              | 8.1        | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 10            | 15         | 25         | 17         | 11         | 10               | 9.4              | 7.3        | 6.9              | 6.7        | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 18            | 51         | 96         | 90         | 60         | 55               | 52               | 50         | 46               | 67         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 4.7           | 8.9        | 19         | 13         | 8.0        | 7.4              | 7.2              | 5.4        | 5.2              | 5.2        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 4.4           | 8.8        | 17         | 12         | 7.9        | 7.3              | 7.1              | 5.5        | 5.3              | 5.1        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>3.1</b>    | <b>3.0</b> | 13         | 10         | 6.8        | 6.4              | 6.2              | 4.9        | 4.7              | 4.6        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | 3.1           | <b>3.4</b> | <b>6.8</b> | 7.2        | 5.6        | 5.6              | 5.5              | 4.3        | 4.2              | 4.2        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>3.1</b>    | 3.8        | 10         | <b>6.2</b> | <b>4.1</b> | <b>3.9</b>       | <b>3.8</b>       | <b>2.9</b> | <b>2.9</b>       | <b>3.0</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | 3.1           | 3.6        | 10         | 7.9        | 5.1        | 5.0              | 4.7              | <b>3.6</b> | <b>3.5</b>       | <b>3.5</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 10            | 18         | 53         | 283        | 1651       | 10641            | <i>12e-2/1e5</i> | .          | .                | .          | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.1</b>    | <b>1.9</b> | <b>4.5</b> | <b>3.2</b> | <b>2.2</b> | <b>2.2</b>       | <b>1.8</b>       | <b>1.8</b> | <b>1.8</b>       | <b>1.9</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 25            | 33         | 1357       | 1390       | 1873       | 2084             | 2726             | 3153       | 2827             | 2491       | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 14            | 15         | 14         | 44         | 146        | 132              | 173              | 126        | 114              | 145        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 16            | 16         | 14         | 8.1        | 227        | 277              | 251              | 246        | 221              | 196        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | 4.7           | 4.7        | 10         | 7.8        | 6.2        | 6.0              | 5.9              | 4.7        | 4.6              | 4.5        | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 6.0           | 7.3        | <b>8.9</b> | <b>6.6</b> | <b>4.5</b> | <b>4.6</b>       | <b>4.6</b>       | 3.7        | 3.7              | 4.1        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 24            | 23         | 25         | 19         | 13         | 12               | 12               | 9.3        | 9.2              | 9.1        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 16            | 16         | 24         | 15         | 10         | 11               | 11               | 8.8        | 8.5              | 8.7        | NBC-CMA [21]                          |
| POEMS                                 | 122           | 173        | 2189       | 3753       | 4466       | 5469             | <i>22e-2/3e5</i> | .          | .                | .          | POEMS [17]                            |
| PM-AdapSS-DE                          | 14            | 17         | 344        | 284        | 229        | 505              | 456              | 360        | 324              | 286        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 190           | 430        | 852        | 604        | 443        | 539              | 618              | 543        | 582              | 650        | pPOEMS [17, 20]                       |
| Basic RCGA                            | 41            | 42         | 592        | 577        | 414        | 1104             | 1141             | 3519       | <i>96e-3/5e4</i> | .          | Basic RCGA [24]                       |
| SPSA                                  | 3876          | 5174       | 7183       | 11674      | 12506      | <i>21e+0/1e5</i> | .                | .          | .                | .          | SPSA [13]                             |

Table 37: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{13}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                     | <b>13 Sharp ridge</b> |            |            |            |            |                  |                  |                  |            |                  |  |                        |
|---------------------|-----------------------|------------|------------|------------|------------|------------------|------------------|------------------|------------|------------------|--|------------------------|
| $\Delta f_{target}$ | 1e+03                 | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03            | 1e-04            | 1e-05      | 1e-07            |  | $\Delta f_{target}$    |
| $ERT_{best}/D$      | 0.53                  | 5.6        | 16         | 28         | 36         | 45               | 72               | 85               | 94         | 122              |  | $ERT_{best}/D$         |
| (1,2)-CMA-ES        | <b>2.6</b>            | 7.3        | 21         | 29         | 27         | 29               | 26               | 23               | 24         | 41               |  | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES       | <b>0.92</b>           | <b>2.8</b> | 17         | 26         | 33         | 32               | 25               | 31               | 36         | 56               |  | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES      | <b>1.8</b>            | 4.2        | 15         | 19         | 21         | 22               | 20               | 19               | 28         | 72               |  | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES       | <b>1.8</b>            | 7.8        | 17         | 45         | 47         | 47               | 37               | 46               | 67         | 91               |  | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES        | <b>1.8</b>            | <b>2.9</b> | 6.6        | 8.1        | 8.7        | 7.9              | 6.1              | 6.9              | 6.9        | 8.1              |  | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES       | <b>1</b>              | 3.1        | 5.2        | 8.6        | 8.2        | 7.8              | 5.9              | 7.0              | 7.1        | 7.6              |  | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES      | <b>1.8</b>            | <b>2.1</b> | <b>3.4</b> | <b>5.1</b> | 5.9        | 6.1              | <b>4.6</b>       | 5.3              | 6.3        | 6.9              |  | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES       | <b>1.5</b>            | <b>2.3</b> | 7.3        | 7.7        | 7.6        | 7.2              | 5.6              | 5.8              | 6.0        | 5.5              |  | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES        | <b>1.3</b>            | <b>2.3</b> | 4.1        | 7.7        | 6.9        | 6.6              | 5.2              | 5.2              | 5.0        | 6.0              |  | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES      | <b>0.87</b>           | 3.6        | 5.2        | 5.1        | <b>5.1</b> | <b>4.8</b>       | <b>3.4</b>       | <b>3.6</b>       | <b>3.6</b> | <b>4.5</b>       |  | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony    | <b>1.1</b>            | 6.7        | 12         | 160        | 3803       | 31398            | <i>86e-3/1e5</i> | .                | .          | .                |  | Artif Bee Colony [8]   |
| avg NEWUOA          | <b>2.5</b>            | <b>1.0</b> | 5.6        | 14         | 42         | 114              | 159              | 277              | 256        | <i>36e-4/8e3</i> |  | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)   | 17                    | 8.4        | 1628       | 2638       | 18147      | <i>61e-2/1e5</i> | .                | .                | .          | .                |  | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)     | <b>1.6</b>            | 5.8        | 7.4        | 7.7        | 8.6        | 8.8              | 7.0              | 7.1              | 7.3        | 7.2              |  | Adap DE (F-AUC) [10]   |
| DE (Uniform)        | <b>1.4</b>            | 7.1        | 8.8        | 8.9        | 10         | 10               | 7.6              | 7.7              | 7.9        | 7.7              |  | DE (Uniform) [9]       |
| IPOP-aCMA-ES        | <b>2.2</b>            | <b>2.7</b> | <b>3.4</b> | <b>3.6</b> | <b>3.9</b> | <b>4.3</b>       | <b>3.3</b>       | <b>3.2</b>       | <b>3.4</b> | <b>3.4</b>       |  | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES         | <b>2.2</b>            | 3.0        | <b>3.4</b> | <b>5.0</b> | <b>5.9</b> | <b>5.7</b>       | 4.6              | <b>4.4</b>       | <b>4.6</b> | <b>4.5</b>       |  | IPOP-CMA-ES [22]       |
| CMA+DE-MOS          | <b>1.4</b>            | 4.5        | 14         | 15         | 15         | 15               | 11               | 11               | 11         | 10               |  | CMA+DE-MOS [18]        |
| NBC-CMA             | <b>1.5</b>            | 7.9        | 9.5        | 9.1        | 12         | 12               | 8.8              | 8.7              | 8.7        | 8.6              |  | NBC-CMA [21]           |
| POEMS               | 191                   | 48         | 67         | 1186       | 3456       | 4088             | 11632            | <i>43e-4/3e5</i> | .          | .                |  | POEMS [17]             |
| PM-AdapSS-DE        | <b>2.0</b>            | 5.8        | 7.8        | 8.1        | 9.5        | 10               | 7.5              | 7.6              | 7.8        | 7.7              |  | PM-AdapSS-DE [9, 10]   |
| pPOEMS              | <b>1.6</b>            | 51         | 101        | 595        | 922        | 1236             | 1020             | 1162             | 1390       | 1653             |  | pPOEMS [17, 20]        |
| Basic RCGA          | <b>1.2</b>            | 10         | 115        | 440        | 1252       | 3765             | 5106             | 4324             | 3914       | <i>46e-3/5e4</i> |  | Basic RCGA [24]        |
| SPSA                | 21                    | 34         | 110        | 2720       | 41486      | <i>67e-2/1e5</i> | .                | .                | .          | .                |  | SPSA [13]              |

Table 38: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{14}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| $\Delta f_{target}$<br>$ERT_{best}/D$ | 14 Sum of different powers |            |            |            |            |            |            |            |            |                  | $\Delta f_{target}$<br>$ERT_{best}/D$ |
|---------------------------------------|----------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------------|---------------------------------------|
|                                       | 1e+03                      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07            |                                       |
| (1,2)-CMA-ES                          | <b>1</b>                   | <b>1.2</b> | 13         | 6.3        | 6.5        | 7.3        | 12         | 17         | 21         | 18               | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                   | <b>1.1</b> | <b>1.6</b> | 4.2        | 4.4        | 4.9        | 6.8        | 10         | 15         | 16               | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                   | <b>1</b>   | <b>2.3</b> | <b>2.5</b> | 3.1        | 3.9        | 5.1        | 9.3        | 13         | 12               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                   | <b>1.3</b> | 3.5        | 3.3        | 5.1        | 8.5        | 12         | 25         | 31         | 27               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                   | <b>1.7</b> | 4.7        | <b>2.8</b> | 3.3        | 3.9        | 4.2        | 5.6        | 7.7        | 6.7              | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                   | <b>1.1</b> | <b>2.9</b> | <b>2.0</b> | <b>2.6</b> | <b>3.0</b> | 3.5        | 5.7        | 7.2        | 7.0              | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                   | <b>1.3</b> | <b>1.8</b> | <b>1.5</b> | <b>2.2</b> | <b>2.6</b> | <b>3.0</b> | <b>3.9</b> | 5.2        | 4.8              | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                   | <b>1.5</b> | 4.2        | <b>1.8</b> | <b>2.6</b> | 3.5        | 4.4        | 5.2        | 6.6        | 5.8              | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                   | <b>1.1</b> | 3.4        | <b>2.2</b> | <b>3.0</b> | <b>2.9</b> | 3.4        | 4.0        | <b>4.4</b> | <b>3.9</b>       | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                   | <b>1</b>   | <b>1.8</b> | <b>2.1</b> | <b>2.6</b> | <b>2.5</b> | <b>2.7</b> | <b>3.4</b> | <b>3.8</b> | <b>3.3</b>       | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                   | <b>1.2</b> | <b>1.5</b> | 8.9        | 14         | 26         | 315        | 2547       | 12654      | <i>55e-6/1e5</i> | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                   | <b>1.2</b> | 4.7        | <b>1.2</b> | <b>1.1</b> | <b>1.1</b> | <b>1.2</b> | <b>1.6</b> | <b>2.7</b> | 6.9              | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 5.7                        | 25         | 44         | 14         | 12         | 15         | 25         | 37         | 36         | 422              | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                   | <b>1.1</b> | <b>2.1</b> | 3.7        | 10         | 12         | 10         | 10         | 10         | 8.3              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                   | <b>1.1</b> | <b>1.6</b> | 4.4        | 11         | 14         | 11         | 12         | 12         | 8.8              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                   | <b>1</b>   | <b>2.3</b> | <b>2.7</b> | 3.7        | 4.2        | 3.7        | 4.5        | 5.0        | <b>4.2</b>       | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                   | <b>1.5</b> | <b>2.8</b> | 3.7        | 4.0        | 4.6        | 4.8        | 5.8        | 6.8        | 5.8              | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                   | <b>1.1</b> | <b>1.2</b> | 4.0        | 15         | 17         | 15         | 17         | 18         | 14               | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                   | <b>1.3</b> | <b>2.2</b> | 5.8        | 12         | 12         | 9.4        | 10         | 11         | 8.7              | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                   | 39         | 269        | 54         | 63         | 113        | 138        | 161        | 313        | 14624            | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                   | <b>1.6</b> | <b>1.9</b> | 5.4        | 12         | 12         | 11         | 11         | 11         | 8.7              | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                   | <b>1.1</b> | 41         | 43         | 91         | 467        | 735        | 1010       | 1223       | 1506             | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                   | <b>1.1</b> | <b>1.9</b> | 10         | 36         | 71         | 210        | 646        | 1886       | <i>51e-7/5e4</i> | Basic RCGA [24]                       |
| SPSA                                  | 10                         | 47         | 534        | 295        | 205        | 165        | 429        | 785        | 2270       | <i>48e-7/1e5</i> | SPSA [13]                             |

Table 39: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{15}$  in **3-D**, in *italics* is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>15 Rastrigin</b> |            |            |             |            |                  |             |                  |             |                  |             |                        |
|---------------------|------------|------------|-------------|------------|------------------|-------------|------------------|-------------|------------------|-------------|------------------------|
| $\Delta f_{target}$ | 1e+03      | 1e+02      | 1e+01       | 1e+00      | 1e-01            | 1e-02       | 1e-03            | 1e-04       | 1e-05            | 1e-07       | $\Delta f_{target}$    |
| $ERT_{best}/D$      | 0.33       | 0.78       | 40          | 457        | 2095             | 2761        | 2810             | 2863        | 2929             | 3014        | $ERT_{best}/D$         |
| (1,2)-CMA-ES        | <b>2.1</b> | 7.9        | 7.6         | 31         | 67               | 51          | 50               | 49          | 48               | 47          | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES       | <b>1.1</b> | 3.3        | <b>2.7</b>  | 8.2        | 12               | 9.0         | 8.8              | 8.7         | 8.5              | 8.3         | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES      | <b>1.6</b> | 3.7        | 3.6         | 10         | 11               | 8.4         | 8.3              | 8.1         | 7.9              | 7.7         | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES       | <b>1.4</b> | 4.7        | 9.0         | 39         | 33               | 25          | 25               | 24          | 24               | 23          | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES        | <b>1.8</b> | <b>2.5</b> | 3.9         | 5.7        | 7.0              | 5.3         | 5.2              | 5.1         | 5.0              | 4.9         | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES       | <b>1</b>   | <b>2.1</b> | <b>1.2</b>  | <b>2.9</b> | 8.3              | 6.3         | 6.2              | 6.1         | 6.0              | 5.8         | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES      | <b>1.5</b> | <b>2.7</b> | <b>2.2</b>  | <b>2.0</b> | <b>2.6</b>       | <b>2.0</b>  | <b>1.9</b>       | <b>1.9</b>  | <b>1.9</b>       | <b>1.8</b>  | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES       | <b>1.1</b> | 3.2        | 4.2         | 3.9        | 22               | 17          | 17               | 16          | 16               | 16          | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES        | <b>1.8</b> | 3.2        | <b>2.5</b>  | 3.8        | 11               | 8.3         | 8.2              | 8.1         | 7.9              | 7.7         | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES      | <b>1.4</b> | <b>2.5</b> | <b>2.1</b>  | 7.0        | 7.2              | 5.5         | 5.4              | 5.3         | 5.1              | 5.0         | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony    | <b>1.1</b> | <b>1.8</b> | 3.6         | 34         | 42               | 88          | 250              | 496         | <i>29e-3/1e5</i> | .           | Artif Bee Colony [8]   |
| avg NEWUOA          | <b>2.0</b> | 3.4        | 3.2         | 3.7        | 3.1              | <b>2.3</b>  | <b>2.3</b>       | <b>2.2</b>  | <b>2.2</b>       | <b>2.1</b>  | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)   | 18         | 23         | 12          | 36         | 325              | 519         | <i>99e-2/1e5</i> | .           | .                | .           | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)     | <b>1.3</b> | <b>1.9</b> | <b>1.8</b>  | <b>1.4</b> | <b>0.41</b>      | <b>0.37</b> | <b>0.38</b>      | <b>0.40</b> | <b>0.40</b>      | <b>0.43</b> | Adap DE (F-AUC) [10]   |
| DE (Uniform)        | <b>1</b>   | 3.9        | <b>2.3</b>  | <b>1.6</b> | 3.9              | 3.0         | <b>3.0</b>       | <b>3.0</b>  | <b>2.9</b>       | <b>2.9</b>  | DE (Uniform) [9]       |
| IPOP-aCMA-ES        | <b>2.5</b> | 4.2        | <b>0.98</b> | <b>1.6</b> | <b>1.0</b>       | <b>0.85</b> | <b>0.85</b>      | <b>0.85</b> | <b>0.85</b>      | <b>0.85</b> | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES         | <b>1.3</b> | <b>2.9</b> | <b>2.4</b>  | <b>1.4</b> | <b>1.2</b>       | <b>0.93</b> | <b>0.93</b>      | <b>0.93</b> | <b>0.92</b>      | <b>0.93</b> | IPOP-CMA-ES [22]       |
| CMA+DE-MOS          | <b>1.3</b> | <b>1.5</b> | 4.9         | 3.8        | <b>1.5</b>       | <b>1.6</b>  | <b>1.6</b>       | <b>1.6</b>  | <b>1.6</b>       | <b>1.6</b>  | CMA+DE-MOS [18]        |
| NBC-CMA             | <b>1.2</b> | <b>1.3</b> | 3.2         | 3.1        | 3.1              | <b>2.4</b>  | <b>2.3</b>       | <b>2.3</b>  | <b>2.3</b>       | <b>2.2</b>  | NBC-CMA [21]           |
| POEMS               | <b>1</b>   | 217        | 15          | 26         | 85               | 65          | 65               | 64          | 63               | 62          | POEMS [17]             |
| PM-AdapSS-DE        | <b>1.4</b> | <b>2.6</b> | <b>2.3</b>  | <b>1.5</b> | 3.9              | 3.0         | <b>3.0</b>       | <b>3.0</b>  | <b>2.9</b>       | <b>2.9</b>  | PM-AdapSS-DE [9, 10]   |
| pPOEMS              | <b>1.1</b> | 20         | 17          | 46         | 23               | 21          | 23               | 26          | 28               | 32          | pPOEMS [17, 20]        |
| Basic RCGA          | <b>1.3</b> | <b>2.0</b> | 5.3         | 24         | 9.3              | 7.5         | 9.4              | 12          | 17               | 39          | Basic RCGA [24]        |
| SPSA                | 282        | 9719       | 473         | 3249       | <i>21e-1/1e5</i> | .           | .                | .           | .                | .           | SPSA [13]              |



Table 40: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{16}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>16 Weierstrass</b>                 |            |            |            |            |            |                  |                  |                  |                  |             |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|------------------|------------------|------------------|------------------|-------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03            | 1e-04            | 1e-05            | 1e-07       | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>   | <b>1.5</b> | 19         | 37         | 96         | 160              | 68               | 92               | <i>25e-2/1e4</i> | .           | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>   | <b>1</b>   | <b>2.4</b> | 12         | 21         | 40               | 26               | 27               | 23               | 42          | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>   | <b>1.7</b> | <b>2.5</b> | 11         | 19         | 25               | 17               | 22               | 16               | 64          | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>   | <b>1.4</b> | 27         | 33         | 97         | 129              | 115              | <i>17e-2/1e4</i> | .                | .           | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>   | <b>1.5</b> | 3.3        | 13         | 15         | 19               | 10               | 9.2              | 8.7              | 61          | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>   | <b>1.3</b> | 5.4        | 5.3        | 8.1        | 8.6              | 5.6              | 5.4              | 5.0              | 5.0         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>   | <b>1.2</b> | <b>1.9</b> | 4.5        | 5.3        | 6.5              | 7.3              | 10               | 6.9              | 6.9         | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>   | <b>1.8</b> | 6.2        | 8.1        | 12         | 18               | 14               | 19               | 16               | 22          | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>   | <b>1.4</b> | 3.1        | 3.7        | 10         | 20               | 28               | 30               | 27               | 66          | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>   | <b>1.2</b> | <b>1.9</b> | 3.4        | 4.7        | 13               | 12               | 34               | 41               | 60          | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>   | <b>1.8</b> | <b>1.2</b> | <b>3.1</b> | 19         | 142              | 2272             | <i>45e-4/1e5</i> | .                | .           | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>   | <b>1.3</b> | 3.7        | 6.1        | 23         | 59               | 73               | <i>19e-3/7e3</i> | .                | .           | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1.2</b> | 15         | 14         | 91         | 445        | 5699             | <i>80e-3/1e5</i> | .                | .                | .           | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>   | <b>1.3</b> | <b>2.5</b> | 4.4        | 6.7        | 5.8              | <b>2.7</b>       | 12               | 8.5              | 8.2         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>   | <b>1.2</b> | <b>2.2</b> | 4.5        | 7.3        | 7.5              | 3.4              | 3.1              | <b>2.2</b>       | <b>2.2</b>  | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>   | <b>1.2</b> | <b>1.5</b> | <b>3.2</b> | <b>2.7</b> | <b>3.1</b>       | <b>1.5</b>       | <b>1.3</b>       | <b>0.93</b>      | <b>0.93</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>   | <b>1.7</b> | <b>2.2</b> | <b>3.2</b> | <b>3.8</b> | <b>3.3</b>       | <b>1.4</b>       | <b>1.3</b>       | <b>0.88</b>      | <b>1.1</b>  | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>   | <b>1.2</b> | <b>1.5</b> | 5.3        | <b>4.4</b> | <b>3.8</b>       | <b>1.9</b>       | <b>1.8</b>       | <b>1.3</b>       | <b>1.4</b>  | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>   | <b>1.5</b> | <b>1.5</b> | 7.5        | 7.1        | 8.6              | 3.8              | 3.4              | <b>2.4</b>       | <b>2.4</b>  | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>   | 20         | 18         | 28         | 523        | 521              | 225              | 195              | 133              | 128         | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>   | <b>1.4</b> | <b>1.6</b> | 6.4        | 11         | 11               | 17               | 15               | 10               | 10          | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>   | <b>1.4</b> | 18         | 15         | 85         | 112              | 105              | 139              | 103              | 119         | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>   | <b>1</b>   | <b>1.6</b> | 17         | 45         | 117              | 125              | 135              | 117              | 199         | Basic RCGA [24]                       |
| SPSA                                  | <b>2.7</b> | 107        | 106        | 312        | 1571       | <i>28e-2/1e5</i> | .                | .                | .                | .           | SPSA [13]                             |

Table 41: Running time excess  $ERT/ERT_{\text{best}}^{2009}$  on  $f_{17}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                                     | 17 Schaffer F7, condition 10 |            |            |            |            |            |                  |                  |                  |                  |                                                     |
|-----------------------------------------------------|------------------------------|------------|------------|------------|------------|------------|------------------|------------------|------------------|------------------|-----------------------------------------------------|
| $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ | 1e+03                        | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04            | 1e-05            | 1e-07            | $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ |
| (1,2)-CMA-ES                                        | <b>1</b>                     | <b>1.7</b> | 6.4        | 11         | 25         | 138        | <i>14e-3/1e4</i> | .                | .                | .                | (1,2)-CMA-ES [5, 3]                                 |
| (1,2m)-CMA-ES                                       | <b>1</b>                     | <b>1.3</b> | 4.0        | 5.1        | 3.9        | 4.3        | 11               | 54               | 187              | <i>26e-5/1e4</i> | (1,2m)-CMA-ES [5]                                   |
| (1,2ms)-CMA-ES                                      | <b>1</b>                     | <b>1.5</b> | 3.8        | <b>1.3</b> | 5.1        | 7.5        | 22               | 119              | 184              | 124              | (1,2ms)-CMA-ES [5]                                  |
| (1,2s)-CMA-ES                                       | <b>1</b>                     | 388        | 113        | 30         | 50         | 859        | <i>44e-3/1e4</i> | .                | .                | .                | (1,2s)-CMA-ES [3]                                   |
| (1,4)-CMA-ES                                        | <b>1</b>                     | <b>1.3</b> | 19         | 7.4        | 8.4        | 16         | 19               | 28               | 91               | <i>12e-5/1e4</i> | (1,4)-CMA-ES [6, 4]                                 |
| (1,4m)-CMA-ES                                       | <b>1</b>                     | <b>1.6</b> | 4.1        | 4.5        | 3.3        | 5.9        | 4.2              | 15               | 61               | 129              | (1,4m)-CMA-ES [6]                                   |
| (1,4ms)-CMA-ES                                      | <b>1</b>                     | <b>1.7</b> | 13         | 3.6        | 3.8        | 3.8        | 6.5              | 17               | 87               | <i>58e-6/1e4</i> | (1,4ms)-CMA-ES [1, 6]                               |
| (1,4s)-CMA-ES                                       | <b>1</b>                     | <b>1.1</b> | 3.9        | 4.9        | 6.9        | 12         | 18               | <i>54e-5/1e4</i> | .                | .                | (1,4s)-CMA-ES [4]                                   |
| (1+1)-CMA-ES                                        | <b>1</b>                     | <b>1.4</b> | 12         | 5.2        | 15         | 36         | 88               | 243              | <i>26e-4/1e4</i> | .                | (1+1)-CMA-ES [7]                                    |
| (1+2ms)-CMA-ES                                      | <b>1</b>                     | <b>1.2</b> | 10         | 6.3        | 6.3        | 13         | 17               | 55               | 92               | 125              | (1+2ms)-CMA-ES [2]                                  |
| Artif Bee Colony                                    | <b>1</b>                     | <b>1.5</b> | 3.2        | 6.6        | 11         | 42         | 469              | 2342             | 1803             | <i>11e-4/1e5</i> | Artif Bee Colony [8]                                |
| avg NEWUOA                                          | <b>1</b>                     | <b>1.9</b> | 3.3        | 8.0        | 13         | 153        | <i>32e-3/5e3</i> | .                | .                | .                | avg NEWUOA [23]                                     |
| CMA-EGS (IPOP,r1)                                   | 6.9                          | 19         | 16         | 17         | 12         | 243        | 739              | 2328             | 1793             | <i>61e-4/1e5</i> | CMA-EGS (IPOP,r1) [12]                              |
| Adap DE (F-AUC)                                     | <b>1</b>                     | <b>1.3</b> | 4.3        | <b>3.3</b> | <b>2.7</b> | <b>2.6</b> | <b>1.6</b>       | <b>1.4</b>       | <b>1.3</b>       | <b>1.2</b>       | Adap DE (F-AUC) [10]                                |
| DE (Uniform)                                        | <b>1</b>                     | <b>1.3</b> | <b>2.2</b> | 3.6        | <b>2.8</b> | <b>2.7</b> | <b>1.7</b>       | <b>1.4</b>       | <b>1.4</b>       | <b>1.3</b>       | DE (Uniform) [9]                                    |
| IPOP-aCMA-ES                                        | <b>1.1</b>                   | <b>2.3</b> | 4.5        | 6.6        | <b>2.8</b> | <b>2.1</b> | <b>1.6</b>       | <b>1.2</b>       | <b>1.2</b>       | <b>0.95</b>      | IPOP-aCMA-ES [16]                                   |
| IPOP-CMA-ES                                         | <b>1</b>                     | 3.5        | 20         | <b>2.2</b> | <b>1.1</b> | <b>1.8</b> | <b>1.2</b>       | <b>1.1</b>       | <b>1.1</b>       | <b>1.0</b>       | IPOP-CMA-ES [22]                                    |
| CMA+DE-MOS                                          | <b>1</b>                     | <b>1.3</b> | <b>2.4</b> | 5.9        | 6.8        | 6.2        | 5.2              | 4.3              | 3.7              | 3.4              | CMA+DE-MOS [18]                                     |
| NBC-CMA                                             | <b>1</b>                     | <b>1.4</b> | <b>2.6</b> | 4.0        | <b>2.1</b> | <b>1.7</b> | <b>0.93</b>      | <b>0.72</b>      | <b>1.4</b>       | <b>1.2</b>       | NBC-CMA [21]                                        |
| POEMS                                               | <b>1</b>                     | 164        | 184        | 22         | 26         | 28         | 18               | 15               | 15               | 30               | POEMS [17]                                          |
| PM-AdapSS-DE                                        | <b>1</b>                     | <b>1.5</b> | <b>1.9</b> | 3.7        | <b>2.5</b> | <b>2.7</b> | <b>1.7</b>       | <b>1.3</b>       | <b>1.3</b>       | <b>1.2</b>       | PM-AdapSS-DE [9, 10]                                |
| pPOEMS                                              | <b>1.1</b>                   | <b>1.2</b> | 16         | 19         | 129        | 185        | 125              | 108              | 106              | 105              | pPOEMS [17, 20]                                     |
| Basic RCGA                                          | <b>1</b>                     | <b>1.3</b> | 3.1        | 25         | 72         | 81         | 51               | 111              | 155              | <i>63e-6/5e4</i> | Basic RCGA [24]                                     |
| SPSA                                                | 57                           | 21735      | 32080      | 4518       | 1302       | 2511       | <i>11e-1/1e5</i> | .                | .                | .                | SPSA [13]                                           |

Table 42: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{18}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                     | 18 Schaffer F7, condition 1000 |            |            |            |             |                  |                  |                  |                  |             |                        |
|---------------------|--------------------------------|------------|------------|------------|-------------|------------------|------------------|------------------|------------------|-------------|------------------------|
| $\Delta f_{target}$ | 1e+03                          | 1e+02      | 1e+01      | 1e+00      | 1e-01       | 1e-02            | 1e-03            | 1e-04            | 1e-05            | 1e-07       | $\Delta f_{target}$    |
| $ERT_{best}/D$      |                                |            |            |            |             |                  |                  |                  |                  |             | $ERT_{best}/D$         |
| (1,2)-CMA-ES        | <b>1.2</b>                     | 5.9        | 9.0        | 29         | 23          | 137              | <i>69e-3/1e4</i> | .                | .                | .           | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES       | <b>1</b>                       | 3.6        | <b>1.3</b> | 10         | 14          | 26               | <i>42e-3/1e4</i> | .                | .                | .           | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES      | <b>1</b>                       | 5.4        | <b>1.4</b> | 4.2        | 6.1         | 20               | <i>11e-3/1e4</i> | .                | .                | .           | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES       | <b>1</b>                       | 5.8        | 15         | 46         | 103         | <i>24e-2/1e4</i> | .                | .                | .                | .           | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES        | <b>1.1</b>                     | 4.1        | 5.4        | 7.2        | 5.5         | 16               | 120              | <i>12e-3/1e4</i> | .                | .           | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES       | <b>1.1</b>                     | 48         | 4.6        | 5.0        | 3.1         | 6.2              | 18               | <i>24e-4/1e4</i> | .                | .           | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES      | <b>1</b>                       | 4.2        | 4.0        | 4.7        | 5.8         | 8.7              | 17               | 107              | <i>15e-4/1e4</i> | .           | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES       | <b>1.2</b>                     | 4.6        | 5.2        | 12         | 8.8         | 19               | 125              | <i>15e-3/1e4</i> | .                | .           | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES        | <b>1</b>                       | 3.6        | 6.0        | 21         | 11          | 35               | <i>42e-3/1e4</i> | .                | .                | .           | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES      | <b>1</b>                       | 61         | 5.8        | 11         | 9.5         | 26               | 128              | <i>24e-3/1e4</i> | .                | .           | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony    | <b>1</b>                       | 3.1        | 3.4        | 15         | 70          | 315              | <i>23e-3/1e5</i> | .                | .                | .           | Artif Bee Colony [8]   |
| avg NEWUOA          | <b>1.3</b>                     | 4.8        | 11         | 30         | 15          | 89               | <i>76e-3/6e3</i> | .                | .                | .           | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)   | 12                             | 38         | 13         | 62         | 284         | <i>19e-2/1e5</i> | .                | .                | .                | .           | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)     | <b>1.1</b>                     | <b>2.6</b> | <b>2.9</b> | 3.7        | <b>0.86</b> | <b>0.57</b>      | <b>0.67</b>      | <b>0.76</b>      | <b>0.78</b>      | <b>0.86</b> | Adap DE (F-AUC) [10]   |
| DE (Uniform)        | <b>1.5</b>                     | <b>2.8</b> | 3.5        | 3.6        | <b>0.86</b> | <b>0.57</b>      | <b>0.68</b>      | <b>0.77</b>      | <b>0.78</b>      | <b>0.86</b> | DE (Uniform) [9]       |
| IPOP-aCMA-ES        | <b>1</b>                       | 7.4        | <b>1.3</b> | <b>1.3</b> | <b>0.61</b> | <b>0.91</b>      | <b>0.90</b>      | <b>0.86</b>      | <b>0.92</b>      | <b>0.94</b> | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES         | <b>1.3</b>                     | 6.4        | <b>1.4</b> | <b>1.8</b> | <b>1.2</b>  | <b>1.0</b>       | <b>1.2</b>       | <b>1.3</b>       | <b>1.4</b>       | <b>1.3</b>  | IPOP-CMA-ES [22]       |
| CMA+DE-MOS          | <b>1.1</b>                     | <b>1.8</b> | <b>2.9</b> | 7.8        | <b>2.1</b>  | <b>1.7</b>       | <b>2.0</b>       | <b>1.9</b>       | <b>1.8</b>       | <b>2.0</b>  | CMA+DE-MOS [18]        |
| NBC-CMA             | <b>1.3</b>                     | 3.4        | <b>2.3</b> | 4.8        | 19          | 8.1              | 7.1              | 6.6              | 5.8              | 5.4         | NBC-CMA [21]           |
| POEMS               | 43                             | 260        | 23         | 27         | 8.9         | 50               | 110              | 107              | 158              | 226         | POEMS [17]             |
| PM-AdapSS-DE        | <b>1.5</b>                     | 3.6        | <b>2.1</b> | <b>3.6</b> | <b>0.86</b> | <b>0.55</b>      | <b>0.66</b>      | <b>0.76</b>      | <b>0.77</b>      | <b>0.85</b> | PM-AdapSS-DE [9, 10]   |
| pPOEMS              | <b>1.1</b>                     | 54         | 28         | 82         | 55          | 42               | 53               | 67               | 68               | 83          | pPOEMS [17, 20]        |
| Basic RCGA          | <b>1</b>                       | <b>1.6</b> | 24         | 86         | 61          | 327              | <i>33e-3/5e4</i> | .                | .                | .           | Basic RCGA [24]        |
| SPSA                | 43                             | 1240       | 3787       | 3149       | 1547        | <i>20e-1/1e5</i> | .                | .                | .                | .           | SPSA [13]              |

Table 43: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{19}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>19 Griewank-Rosenbrock F8F2</b> |            |            |            |            |            |                  |            |            |                  |                                       |
|---------------------------------------|------------------------------------|------------|------------|------------|------------|------------|------------------|------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                              | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04      | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | <b>4.8</b> | 469        | 177        | 30         | <i>32e-3/1e4</i> | .          | .          | .                | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                           | <b>1</b>   | 6.7        | 239        | 132        | 20         | <i>39e-3/1e4</i> | .          | .          | .                | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                           | <b>1</b>   | 8.5        | 556        | 87         | 21         | 29               | 29         | 29         | 29               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                           | <b>1</b>   | 31         | 550        | 173        | 31         | 58               | 58         | 58         | 58               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | <b>5.5</b> | 329        | 99         | 6.7        | 12               | 12         | 12         | 12               | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                           | <b>1.1</b> | 10         | 420        | 60         | 10         | 13               | 13         | 13         | 12               | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                           | <b>1</b>   | 10         | <b>171</b> | 89         | 6.7        | 28               | 28         | 27         | 27               | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                           | <b>1</b>   | 11         | 251        | 123        | 65         | <i>58e-3/1e4</i> | .          | .          | .                | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | 7.4        | 415        | 186        | 20         | 18               | 18         | 18         | 18               | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                           | <b>1.1</b> | 12         | 364        | 121        | 14         | 28               | 28         | 28         | 28               | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                           | <b>1.1</b> | 12         | 391        | 52         | 8.0        | 24               | 72         | 295        | <i>14e-5/1e5</i> | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                           | <b>1.5</b> | 13         | 319        | 122        | 39         | 76               | 76         | 76         | 76               | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 6.2                                | 15         | 47         | 346        | 150        | 49         | 98               | 266        | 265        | 566              | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                           | <b>1.1</b> | 12         | 218        | 27         | 5.0        | 12               | 12         | 12         | 12               | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                           | <b>1.1</b> | 7.3        | 335        | 32         | 5.5        | 13               | 13         | 13         | 13               | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                           | <b>1</b>   | <b>6.0</b> | 234        | 41         | 4.0        | 4.6              | 4.6        | 4.7        | 4.7              | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                           | <b>1.1</b> | 11         | <b>196</b> | 67         | 4.4        | <b>4.1</b>       | <b>4.1</b> | <b>4.1</b> | <b>4.1</b>       | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                           | <b>1.1</b> | 11         | <b>213</b> | <b>5.8</b> | <b>3.7</b> | <b>3.6</b>       | <b>3.7</b> | <b>3.7</b> | <b>3.8</b>       | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                           | <b>1.2</b> | 8.9        | 235        | 29         | <b>3.2</b> | <b>4.3</b>       | <b>4.3</b> | <b>4.3</b> | <b>4.3</b>       | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                           | 42         | 611        | 1680       | 251        | 81         | 168              | 167        | 169        | 169              | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                           | <b>1.9</b> | 7.9        | 237        | <b>25</b>  | <b>2.3</b> | 12               | 12         | 12         | 14               | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                           | <b>1.5</b> | 260        | 1717       | 259        | 10         | 11               | 13         | 15         | 21               | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                           | <b>1.1</b> | 10         | 273        | <b>16</b>  | 8.7        | 24               | 51         | 141        | 289              | Basic RCGA [24]                       |
| SPSA                                  | 18                                 | 71         | 258        | 10394      | 2974       | 637        | <i>83e-3/1e5</i> | .          | .          | .                | SPSA [13]                             |

Table 44: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{20}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                   | 20 Schwefel $x*\sin(x)$ |            |            |            |                  |            |            |                  |            |            |                                   |
|-----------------------------------|-------------------------|------------|------------|------------|------------------|------------|------------|------------------|------------|------------|-----------------------------------|
| $\Delta$ target<br>$ERT_{best}/D$ | 1e+03                   | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03      | 1e-04            | 1e-05      | 1e-07      | $\Delta$ target<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                      | 4.5                     | 4.2        | 4.9        | 4.1        | 16               | 15         | 17         | 17               | 16         | 15         | (1,2)-CMA-ES [5, 3]               |
| (1,2m)-CMA-ES                     | <b>2.4</b>              | <b>2.8</b> | 3.2        | 8.1        | 41               | 39         | 38         | 37               | 36         | 34         | (1,2m)-CMA-ES [5]                 |
| (1,2ms)-CMA-ES                    | <b>2.6</b>              | 3.2        | 3.9        | 7.9        | 91               | 87         | 84         | 83               | 81         | 75         | (1,2ms)-CMA-ES [5]                |
| (1,2s)-CMA-ES                     | 4.3                     | 7.9        | 7.7        | 11         | 32               | 32         | 31         | 31               | 30         | 28         | (1,2s)-CMA-ES [3]                 |
| (1,4)-CMA-ES                      | <b>1.8</b>              | <b>2.0</b> | <b>2.8</b> | 4.1        | 11               | 11         | 10         | 10               | 10         | 9.2        | (1,4)-CMA-ES [6, 4]               |
| (1,4m)-CMA-ES                     | <b>1.3</b>              | <b>1.3</b> | <b>2.0</b> | 7.8        | 18               | 17         | 16         | 16               | 16         | 15         | (1,4m)-CMA-ES [6]                 |
| (1,4ms)-CMA-ES                    | <b>1.2</b>              | <b>1.6</b> | <b>1.7</b> | 4.7        | 54               | 52         | 50         | 49               | 48         | 45         | (1,4ms)-CMA-ES [1, 6]             |
| (1,4s)-CMA-ES                     | <b>0.95</b>             | <b>1.4</b> | <b>1.9</b> | 6.0        | 21               | 20         | 19         | 19               | 19         | 17         | (1,4s)-CMA-ES [4]                 |
| (1+1)-CMA-ES                      | <b>2.1</b>              | <b>2.1</b> | <b>2.4</b> | <b>3.0</b> | 10               | 10         | 9.5        | 9.3              | 9.1        | 8.5        | (1+1)-CMA-ES [7]                  |
| (1+2ms)-CMA-ES                    | <b>1.3</b>              | <b>1.4</b> | <b>1.8</b> | <b>2.0</b> | 9.2              | 8.8        | 8.5        | 8.4              | 8.3        | <b>7.7</b> | (1+2ms)-CMA-ES [2]                |
| Artif Bee Colony                  | <b>2.6</b>              | 5.0        | 5.6        | <b>1.1</b> | <b>1.3</b>       | <b>1.8</b> | <b>3.7</b> | 6.0              | 6.9        | 9.3        | Artif Bee Colony [8]              |
| avg NEWUOA                        | <b>1.5</b>              | <b>1.3</b> | <b>1.3</b> | <b>2.3</b> | 10               | 9.5        | 9.2        | 9.0              | 8.9        | 8.2        | avg NEWUOA [23]                   |
| CMA-EGS (IPOP,r1)                 | 10                      | 12         | 13         | 158        | <i>45e-2/1e5</i> | .          | .          | .                | .          | .          | CMA-EGS (IPOP,r1) [12]            |
| Adap DE (F-AUC)                   | <b>1.6</b>              | <b>2.9</b> | 4.5        | 3.7        | 34               | 33         | 32         | 31               | 31         | 28         | Adap DE (F-AUC) [10]              |
| DE (Uniform)                      | <b>2.9</b>              | 3.4        | 4.6        | <b>2.8</b> | 34               | 32         | 32         | 31               | 31         | 28         | DE (Uniform) [9]                  |
| IPOP-aCMA-ES                      | <b>2.3</b>              | <b>1.9</b> | <b>2.0</b> | 5.1        | 5.8              | 5.9        | 5.9        | <b>5.9</b>       | <b>5.9</b> | <b>5.6</b> | IPOP-aCMA-ES [16]                 |
| IPOP-CMA-ES                       | <b>2.1</b>              | <b>2.8</b> | <b>2.9</b> | 4.5        | <b>5.6</b>       | <b>5.7</b> | <b>5.6</b> | <b>5.7</b>       | <b>5.7</b> | <b>5.4</b> | IPOP-CMA-ES [22]                  |
| CMA+DE-MOS                        | <b>3.0</b>              | 3.9        | 4.5        | 4.3        | <b>3.5</b>       | <b>4.0</b> | <b>4.8</b> | <b>4.9</b>       | <b>5.1</b> | 7.8        | CMA+DE-MOS [18]                   |
| NBC-CMA                           | <b>1.9</b>              | 4.0        | 4.9        | 3.8        | 13               | 12         | 12         | 12               | 12         | 11         | NBC-CMA [21]                      |
| POEMS                             | 110                     | 83         | 80         | 8.2        | 146              | 141        | 138        | 137              | 135        | 128        | POEMS [17]                        |
| PM-AdapSS-DE                      | <b>1.9</b>              | <b>2.5</b> | <b>2.8</b> | <b>2.8</b> | 21               | 20         | 20         | 19               | 19         | 18         | PM-AdapSS-DE [9, 10]              |
| pPOEMS                            | 63                      | 60         | 65         | 20         | 17               | 27         | 36         | 44               | 52         | 64         | pPOEMS [17, 20]                   |
| Basic RCGA                        | <b>2.2</b>              | 3.2        | 4.6        | 64         | 217              | 916        | 887        | <i>41e-2/5e4</i> | .          | .          | Basic RCGA [24]                   |
| SPSA                              | 34                      | 39         | 51         | 5071       | <i>15e-1/1e5</i> | .          | .          | .                | .          | .          | SPSA [13]                         |

Table 45: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{21}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>21 Gallagher 101 peaks</b>         |          |          |            |            |            |            |            |            |            |            |                                       |
|---------------------------------------|----------|----------|------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02    | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | <b>1</b> | 6.8        | 11         | 25         | 28         | 27         | 27         | 27         | 26         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>1.6</b> | 7.7        | 7.7        | 11         | 11         | 11         | 11         | 11         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>1.8</b> | 8.1        | 12         | 13         | 18         | 17         | 17         | 17         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | <b>1</b> | 4.1        | 21         | 40         | 42         | 40         | 40         | 40         | 39         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | <b>1</b> | <b>1.4</b> | 7.4        | 13         | 13         | 12         | 12         | 12         | 12         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>1.1</b> | 5.4        | 21         | 26         | 27         | 27         | 27         | 26         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>2.6</b> | 5.1        | 7.4        | 7.3        | 7.0        | 6.9        | 6.9        | 6.8        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | <b>1</b> | <b>2.4</b> | 8.0        | 11         | 11         | 11         | 11         | 11         | 10         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | <b>1</b> | <b>2.5</b> | 5.3        | 10         | 10         | 9.4        | 9.2        | 9.2        | 9.0        | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>1.7</b> | 7.4        | 8.9        | 8.7        | 8.4        | 8.3        | 8.2        | 8.1        | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | <b>1</b> | <b>2.4</b> | <b>2.5</b> | 3.7        | 5.9        | 10         | 26         | 60         | 145        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | <b>1</b> | 4.0        | <b>2.5</b> | <b>2.1</b> | <b>2.0</b> | <b>2.0</b> | <b>2.0</b> | <b>2.0</b> | <b>2.0</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b> | 19       | 10         | 35         | 220        | 305        | 293        | 577        | 573        | 559        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | <b>1</b> | <b>2.0</b> | <b>2.1</b> | <b>1.6</b> | <b>2.0</b> | <b>2.4</b> | <b>2.7</b> | <b>2.9</b> | <b>3.1</b> | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | <b>1</b> | <b>1.3</b> | <b>1.9</b> | <b>1.9</b> | <b>2.3</b> | <b>2.6</b> | <b>2.8</b> | <b>3.0</b> | <b>3.3</b> | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>1</b> | <b>1.8</b> | 6.6        | 10         | 10         | 10         | 10         | 11         | 11         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>1</b> | <b>1.5</b> | 11         | 10         | 11         | 11         | 11         | 11         | 11         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | <b>1</b> | <b>1.7</b> | 13         | 22         | 106        | 488        | 746        | 744        | 860        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | <b>1</b> | <b>1.3</b> | 5.1        | 31         | 55         | 52         | 52         | 51         | 50         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | <b>1</b> | 90         | 1001       | 800        | 777        | 745        | 739        | 735        | 722        | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | <b>1</b> | <b>1.1</b> | <b>1.7</b> | 52         | 51         | 49         | 48         | 48         | 47         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | <b>1</b> | 31         | 12         | 11         | 24         | 39         | 57         | 92         | 145        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | <b>1</b> | <b>1.8</b> | 21         | 59         | 162        | 164        | 216        | 269        | 293        | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b> | 30       | 30         | 439        | 1223       | 1188       | 1139       | 1134       | 1155       | 2915       | SPSA [13]                             |

Table 46: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{22}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>22 Gallagher 21 peaks</b> |          |            |            |            |            |                  |            |            |            |                                       |
|---------------------------------------|------------------------------|----------|------------|------------|------------|------------|------------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                        | 1e+02    | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03            | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>                     | <b>1</b> | 4.0        | 17         | 28         | 35         | 34               | 33         | 33         | 32         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                     | <b>1</b> | 15         | 11         | 22         | 25         | 25               | 25         | 25         | 24         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                     | <b>1</b> | 7.1        | 7.6        | 20         | 31         | 30               | 35         | 34         | 33         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                     | <b>1</b> | 18         | 16         | 26         | 26         | 27               | 27         | 27         | 27         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                     | <b>1</b> | 4.0        | 7.8        | 7.8        | 7.9        | 7.6              | 7.5        | 7.4        | 7.3        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                     | <b>1</b> | 3.6        | 6.8        | 7.3        | 7.4        | 7.2              | 7.2        | 7.1        | 7.1        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                     | <b>1</b> | <b>2.8</b> | 10         | 15         | 16         | 15               | 15         | 15         | 14         | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                     | <b>1</b> | 9.0        | 7.0        | 10         | 10         | 10               | 9.4        | 9.3        | 9.1        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                     | <b>1</b> | 6.4        | 8.7        | 7.2        | <b>7.2</b> | <b>6.9</b>       | <b>6.8</b> | <b>6.7</b> | <b>6.6</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                     | <b>1</b> | 3.1        | <b>2.7</b> | <b>3.4</b> | <b>3.5</b> | <b>3.3</b>       | <b>3.3</b> | <b>3.3</b> | <b>3.3</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                     | <b>1</b> | <b>2.5</b> | <b>1.7</b> | <b>4.3</b> | 29         | 105              | 241        | 329        | 4862       | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                     | <b>1</b> | <b>2.8</b> | <b>2.0</b> | <b>2.9</b> | <b>2.9</b> | <b>2.8</b>       | <b>2.9</b> | <b>2.9</b> | <b>3.1</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b>                     | 16       | 3.6        | 43         | 237        | 523        | 798              | 1172       | 1152       | 1117       | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                     | <b>1</b> | <b>2.1</b> | <b>2.2</b> | 132        | 130        | 123              | 120        | 118        | 115        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                     | <b>1</b> | <b>1.3</b> | <b>1.5</b> | 132        | 130        | 123              | 120        | 118        | 115        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                     | <b>1</b> | 6.6        | 7.1        | 27         | 83         | 228              | 224        | 222        | 217        | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                     | <b>1</b> | <b>1.2</b> | 5.0        | 21         | 90         | 247              | 290        | 286        | 281        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                     | <b>1</b> | <b>1.5</b> | 16         | 22         | 28         | 31               | 42         | 44         | 193        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                     | <b>1</b> | <b>1.4</b> | 109        | 174        | 225        | 213              | 208        | 204        | 198        | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                     | <b>1</b> | 2130       | 623        | 989        | 974        | 921              | 901        | 889        | 868        | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                     | <b>1</b> | <b>1.3</b> | 127        | 213        | 209        | 198              | 193        | 190        | 184        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                     | <b>1</b> | 29         | 12         | 211        | 227        | 234              | 266        | 298        | 361        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                     | <b>1</b> | <b>1.3</b> | 32         | 111        | 389        | 518              | 601        | 1218       | 5387       | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b>                     | 28       | 31         | 320        | 5903       | 12219      | <i>40e-2/1e5</i> | .          | .          | .          | SPSA [13]                             |

Table 47: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{23}$  in **3-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>23 Katsuuras</b> |          |            |            |                  |            |                  |                  |            |                  |                                       |
|---------------------------------------|---------------------|----------|------------|------------|------------------|------------|------------------|------------------|------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03               | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03            | 1e-04            | 1e-05      | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>            | <b>1</b> | 7.2        | 37         | 237              | 177        | 197              | 194              | 190        | <i>68e-2/1e4</i> | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>            | <b>1</b> | 6.5        | 12         | 48               | 104        | 57               | 89               | 87         | <i>22e-2/1e4</i> | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>            | <b>1</b> | 5.3        | 18         | 69               | 81         | 45               | 64               | 63         | 61               | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>            | <b>1</b> | 10         | 54         | 231              | 180        | 199              | <i>66e-2/1e4</i> | .          | .                | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>            | <b>1</b> | <b>2.5</b> | 7.3        | 20               | 16         | 10               | 10               | 10         | 11               | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>            | <b>1</b> | <b>3.0</b> | 6.2        | 19               | 21         | 14               | 14               | 14         | 13               | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>            | <b>1</b> | 6.1        | 8.2        | 30               | 27         | 15               | 14               | 14         | 14               | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>            | <b>1</b> | 9.5        | 16         | 40               | 41         | 34               | 43               | 43         | 55               | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>            | <b>1</b> | 5.6        | 3.4        | 13               | 19         | 13               | 15               | 20         | 29               | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>            | <b>1</b> | 4.9        | 3.6        | 10               | 21         | 16               | 25               | 24         | 23               | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>            | <b>1</b> | 4.2        | 10         | <i>24e-2/1e5</i> | .          | .                | .                | .          | .                | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>            | <b>1</b> | 11         | <b>2.5</b> | 22               | 85         | 147              | <i>46e-3/7e3</i> | .          | .                | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b>            | 7.1      | 16         | 11         | <i>29e-2/1e5</i> | .          | .                | .                | .          | .                | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>            | <b>1</b> | 3.1        | 3.1        | <b>5.1</b>       | <b>6.6</b> | <b>5.1</b>       | <b>6.4</b>       | <b>7.8</b> | <b>10</b>        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>            | <b>1</b> | 4.0        | <b>2.4</b> | <b>5.3</b>       | <b>7.2</b> | 5.5              | 6.9              | 8.4        | 11               | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>            | <b>1</b> | 7.2        | 5.3        | 10               | <b>7.7</b> | <b>4.3</b>       | <b>5.4</b>       | <b>5.4</b> | <b>5.4</b>       | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>            | <b>1</b> | 4.9        | 5.2        | 80               | 60         | 33               | 32               | 32         | 31               | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>            | <b>1</b> | 3.9        | 7.5        | 10               | 8.6        | <b>5.2</b>       | <b>5.2</b>       | <b>5.3</b> | <b>5.4</b>       | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>            | <b>1</b> | <b>2.7</b> | 15         | 353              | 263        | 145              | 142              | 140        | 134              | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>            | <b>1</b> | 20         | 21         | 106              | 141        | 83               | 85               | 86         | 88               | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>            | <b>1</b> | 4.1        | <b>2.5</b> | <b>5.7</b>       | 26         | 16               | 17               | 19         | 20               | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>            | <b>1</b> | 14         | 64         | 264              | 276        | 189              | 227              | 255        | 328              | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>            | <b>1</b> | 5.4        | 16         | 271              | 837        | <i>15e-2/5e4</i> | .                | .          | .                | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b>            | 26       | 113        | 946        | <i>99e-2/1e5</i> | .          | .                | .                | .          | .                | SPSA [13]                             |





Table 49: Running time excess  $ERT/ERT_{best}$  2009 on  $f_1$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>1 Sphere</b>                       |            |            |            |            |            |            |            |            |            |            |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>   | 3.1        | 7.4        | 15         | 27         | 37         | 47         | 54         | 63         | 80         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>   | <b>1</b>   | 3.2        | 10         | 15         | 21         | 28         | 35         | 40         | 53         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>   | <b>1.3</b> | <b>2.1</b> | 7.2        | 13         | 18         | 24         | 30         | 35         | 45         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>   | <b>1.3</b> | 4.5        | 12         | 22         | 29         | 38         | 48         | 55         | 71         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>   | <b>1.1</b> | <b>2.5</b> | 6.9        | 11         | 16         | 21         | 25         | 30         | 40         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>   | <b>1.1</b> | <b>2.2</b> | 6.2        | 10         | 15         | 19         | 23         | 27         | 37         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>   | <b>1</b>   | <b>2.0</b> | <b>5.0</b> | <b>8.3</b> | <b>12</b>  | <b>15</b>  | <b>18</b>  | <b>22</b>  | <b>30</b>  | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>   | <b>1.9</b> | <b>2.5</b> | 6.5        | 10         | 15         | 18         | 22         | 26         | 34         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>   | <b>1.1</b> | <b>2.1</b> | 5.6        | 10         | 13         | 17         | 21         | 24         | 32         | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>   | <b>1</b>   | <b>1.5</b> | <b>4.9</b> | <b>8.0</b> | <b>12</b>  | <b>15</b>  | <b>18</b>  | <b>21</b>  | <b>28</b>  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>   | <b>1.4</b> | 12         | 32         | 62         | 89         | 122        | 156        | 191        | 255        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>   | 3.3        | <b>1.5</b> | <b>1.3</b> | <b>1.3</b> | <b>1.3</b> | <b>1.3</b> | <b>1.3</b> | <b>1.3</b> | <b>1.3</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>2.3</b> | 27         | 7.2        | 16         | 24         | 34         | 43         | 55         | 67         | 87         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>   | <b>1.3</b> | 5.9        | 37         | 67         | 104        | 132        | 166        | 203        | 266        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>   | <b>1.3</b> | 8.6        | 42         | 80         | 117        | 155        | 194        | 236        | 313        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>   | <b>1.3</b> | 3.2        | 8.9        | 15         | 22         | 27         | 33         | 39         | 51         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>   | <b>1.1</b> | <b>2.5</b> | 8.0        | 14         | 20         | 27         | 32         | 39         | 51         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>   | <b>1.1</b> | 6.5        | 33         | 66         | 90         | 121        | 142        | 169        | 217        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>   | <b>1.3</b> | 5.6        | 26         | 42         | 53         | 65         | 74         | 85         | 108        | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>   | 263        | 102        | 136        | 329        | 766        | 1195       | 1592       | 2001       | 2796       | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>   | <b>2.1</b> | 4.8        | 39         | 74         | 111        | 145        | 182        | 223        | 292        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>   | <b>1.2</b> | 97         | 129        | 614        | 2849       | 5775       | 8274       | 12299      | 18337      | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>   | <b>1.1</b> | 8.7        | 72         | 155        | 329        | 561        | 831        | 1141       | 1741       | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b>   | 43         | 11         | 15         | 19         | 22         | 27         | 31         | 36         | 44         | SPSA [13]                             |









Table 54: Running time excess  $ERT/ERT_{best}$  2009 on  $f_6$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 6 Attractive sector |            |            |            |            |                  |             |                  |             |             |                                       |
|---------------------------------------|---------------------|------------|------------|------------|------------|------------------|-------------|------------------|-------------|-------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03               | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03       | 1e-04            | 1e-05       | 1e-07       | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>2.6</b>          | 13         | 5.9        | 5.1        | 5.0        | 4.8              | 4.3         | 4.2              | 3.9         | 4.0         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1.5</b>          | 6.4        | <b>2.7</b> | <b>2.4</b> | <b>2.5</b> | <b>2.1</b>       | <b>1.8</b>  | <b>1.7</b>       | <b>1.4</b>  | <b>1.4</b>  | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1.5</b>          | 4.2        | <b>2.2</b> | <b>2.0</b> | <b>2.1</b> | <b>1.9</b>       | <b>1.6</b>  | <b>1.4</b>       | <b>1.1</b>  | <b>1.1</b>  | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 4.8                 | 11         | 6.5        | 6.6        | 7.7        | 7.3              | 6.8         | 6.5              | 5.8         | 5.9         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>2.2</b>          | <b>2.4</b> | <b>1.6</b> | <b>1.8</b> | <b>1.8</b> | <b>1.7</b>       | <b>1.5</b>  | <b>1.4</b>       | <b>1.3</b>  | <b>1.2</b>  | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>2.2</b>          | 4.7        | <b>1.8</b> | <b>1.6</b> | <b>1.7</b> | <b>1.5</b>       | <b>1.3</b>  | <b>1.2</b>       | <b>1.00</b> | <b>0.96</b> | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1.9</b>          | <b>2.8</b> | <b>1.1</b> | <b>1.1</b> | <b>1.2</b> | <b>1.1</b>       | <b>0.91</b> | <b>0.83</b>      | <b>0.70</b> | <b>0.69</b> | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>2.0</b>          | 5.0        | <b>1.8</b> | <b>1.9</b> | <b>1.9</b> | <b>1.8</b>       | <b>1.5</b>  | <b>1.4</b>       | <b>1.1</b>  | <b>1.1</b>  | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1.8</b>          | 3.5        | <b>1.8</b> | <b>1.5</b> | <b>1.9</b> | <b>1.7</b>       | <b>1.4</b>  | <b>1.3</b>       | <b>1.1</b>  | <b>1.4</b>  | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1.2</b>          | <b>2.3</b> | <b>1.1</b> | <b>1.2</b> | <b>1.6</b> | <b>1.4</b>       | <b>1.4</b>  | <b>1.6</b>       | <b>1.6</b>  | <b>2.2</b>  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 7.7                 | 8.3        | 4.9        | 15         | 365        | 408              | 619         | 522              | 498         | 507         | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1.2</b>          | <b>2.6</b> | <b>1.3</b> | <b>1.6</b> | <b>2.6</b> | <b>2.6</b>       | <b>2.6</b>  | <b>2.6</b>       | <b>2.4</b>  | <b>2.5</b>  | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 5.0                 | 54         | 241        | 657        | 518        | 518              | 372         | 300              | 220         | 230         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 4.8                 | 7.1        | 6.5        | 7.6        | 8.5        | 8.1              | 7.0         | 6.5              | 5.3         | 5.4         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 4.7                 | 7.2        | 9.0        | 9.2        | 10         | 9.2              | 7.8         | 7.3              | 6.1         | 6.1         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>2.6</b>          | 5.3        | <b>2.5</b> | <b>2.1</b> | <b>2.2</b> | <b>2.0</b>       | <b>1.6</b>  | <b>1.5</b>       | <b>1.2</b>  | <b>1.2</b>  | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1.9</b>          | 3.2        | <b>2.5</b> | <b>2.1</b> | <b>2.2</b> | <b>2.0</b>       | <b>1.7</b>  | <b>1.5</b>       | <b>1.3</b>  | <b>1.2</b>  | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 11                  | 11         | 8.0        | 8.6        | 8.8        | 7.7              | 6.3         | 5.7              | 4.8         | 4.6         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 9.2                 | 8.5        | 8.2        | 19         | 16         | 11               | 8.4         | 6.8              | 5.1         | 4.3         | NBC-CMA [21]                          |
| POEMS                                 | 102                 | 81         | 26         | 46         | 54         | 51               | 45          | 43               | 36          | 37          | POEMS [17]                            |
| PM-AdapSS-DE                          | 6.0                 | 7.4        | 8.1        | 8.1        | 9.0        | 8.3              | 7.3         | 6.7              | 5.7         | 5.7         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 91                  | 76         | 31         | 202        | 313        | 323              | 306         | 300              | 266         | 282         | pPOEMS [17, 20]                       |
| Basic RCGA                            | 29                  | 28         | 26         | 72         | 255        | 434              | 598         | <i>47e-4/5e4</i> | .           | .           | Basic RCGA [24]                       |
| SPSA                                  | 521                 | 13582      | 28485      | 32769      | 25181      | <i>44e+0/1e5</i> | .           | .                | .           | .           | SPSA [13]                             |





Table 56: Running time excess  $ERT/ERT_{\text{best}} 2009$  on  $f_8$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                            | <b>8 Rosenbrock original</b> |            |            |            |                  |            |            |                  |                  |            |                            |
|----------------------------|------------------------------|------------|------------|------------|------------------|------------|------------|------------------|------------------|------------|----------------------------|
| $\Delta f_{\text{target}}$ | 1e+03                        | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03      | 1e-04            | 1e-05            | 1e-07      | $\Delta f_{\text{target}}$ |
| $ERT_{\text{best}}/D$      | 3.6                          | 8.8        | 15         | 55         | 67               | 74         | 78         | 80               | 82               | 84         | $ERT_{\text{best}}/D$      |
| (1,2)-CMA-ES               | 6.5                          | 12         | 10         | 10         | 14               | 14         | 15         | 15               | 15               | 15         | (1,2)-CMA-ES [5, 3]        |
| (1,2m)-CMA-ES              | 4.1                          | 5.7        | 5.6        | 5.7        | 7.2              | 7.8        | 8.1        | 8.3              | 8.4              | 8.7        | (1,2m)-CMA-ES [5]          |
| (1,2ms)-CMA-ES             | 5.2                          | 4.5        | 4.2        | 5.8        | 6.8              | 7.3        | 7.5        | 7.6              | 7.6              | 7.8        | (1,2ms)-CMA-ES [5]         |
| (1,2s)-CMA-ES              | 7.8                          | 15         | 12         | 14         | 19               | 19         | 20         | 20               | 21               | 21         | (1,2s)-CMA-ES [3]          |
| (1,4)-CMA-ES               | <b>2.6</b>                   | <b>2.9</b> | <b>2.6</b> | 4.9        | 5.7              | 5.8        | 5.9        | 6.1              | 6.2              | 6.3        | (1,4)-CMA-ES [6, 4]        |
| (1,4m)-CMA-ES              | <b>2.0</b>                   | 3.2        | <b>2.9</b> | 3.6        | 4.3              | 4.7        | 4.8        | 5.0              | 5.0              | 5.2        | (1,4m)-CMA-ES [6]          |
| (1,4ms)-CMA-ES             | <b>1.4</b>                   | <b>2.6</b> | <b>2.3</b> | <b>2.9</b> | <b>3.5</b>       | <b>3.6</b> | <b>3.7</b> | <b>3.8</b>       | <b>3.8</b>       | <b>4.0</b> | (1,4ms)-CMA-ES [1, 6]      |
| (1,4s)-CMA-ES              | <b>1.5</b>                   | <b>2.3</b> | <b>2.4</b> | 4.1        | 5.0              | 5.2        | 5.4        | 5.4              | 5.5              | 5.6        | (1,4s)-CMA-ES [4]          |
| (1+1)-CMA-ES               | <b>2.5</b>                   | <b>2.5</b> | <b>2.3</b> | 3.5        | 3.8              | 3.8        | 3.8        | 3.9              | 4.0              | 4.1        | (1+1)-CMA-ES [7]           |
| (1+2ms)-CMA-ES             | <b>1.7</b>                   | <b>2.0</b> | <b>1.9</b> | 3.0        | <b>3.2</b>       | <b>3.2</b> | <b>3.3</b> | <b>3.4</b>       | <b>3.4</b>       | <b>3.5</b> | (1+2ms)-CMA-ES [2]         |
| Artif Bee Colony           | 4.4                          | 5.0        | 6.0        | 12         | 52               | 449        | 2509       | <i>10e-4/1e5</i> | .                | .          | Artif Bee Colony [8]       |
| avg NEWUOA                 | <b>1.3</b>                   | <b>1.6</b> | <b>1.2</b> | <b>1.2</b> | <b>1.1</b>       | <b>1.1</b> | <b>1.1</b> | <b>1.1</b>       | <b>1.1</b>       | <b>1.1</b> | avg NEWUOA [23]            |
| CMA-EGS (IPOP,r1)          | 11                           | 9.0        | 8.2        | 7.6        | 8.2              | 8.5        | 8.8        | 9.3              | 10               | 11         | CMA-EGS (IPOP,r1) [12]     |
| Adap DE (F-AUC)            | 6.5                          | 11         | 13         | 8.9        | 11               | 11         | 11         | 12               | 13               | 14         | Adap DE (F-AUC) [10]       |
| DE (Uniform)               | 7.2                          | 12         | 15         | 10         | 14               | 16         | 17         | 17               | 18               | 20         | DE (Uniform) [9]           |
| IPOP-aCMA-ES               | <b>2.1</b>                   | <b>2.4</b> | <b>2.8</b> | <b>3.0</b> | 3.6              | 3.8        | 4.0        | 4.1              | 4.2              | 4.5        | IPOP-aCMA-ES [16]          |
| IPOP-CMA-ES                | <b>2.6</b>                   | 3.8        | 3.5        | 4.8        | 5.3              | 5.5        | 5.6        | 5.7              | 5.8              | 6.1        | IPOP-CMA-ES [22]           |
| CMA+DE-MOS                 | 6.3                          | 6.8        | 11         | 11         | 12               | 13         | 13         | 14               | 14               | 15         | CMA+DE-MOS [18]            |
| NBC-CMA                    | 4.4                          | 7.5        | 7.1        | 7.0        | 8.1              | 8.4        | 8.6        | 8.8              | 8.9              | 9.3        | NBC-CMA [21]               |
| POEMS                      | 66                           | 40         | 58         | 52         | 117              | 380        | 689        | 1132             | 1485             | 2230       | POEMS [17]                 |
| PM-AdapSS-DE               | 5.5                          | 11         | 13         | 9.4        | 15               | 18         | 19         | 19               | 20               | 21         | PM-AdapSS-DE [9, 10]       |
| pPOEMS                     | 56                           | 36         | 84         | 262        | 365              | 482        | 583        | 689              | 795              | 1052       | pPOEMS [17, 20]            |
| Basic RCGA                 | 5.7                          | 12         | 32         | 558        | 1450             | 2992       | 2983       | 9295             | <i>54e-2/5e4</i> | .          | Basic RCGA [24]            |
| SPSA                       | 360                          | 1473       | 3764       | 12308      | <i>50e-1/1e5</i> | .          | .          | .                | .                | .          | SPSA [13]                  |

Table 57: Running time excess  $ERT/ERT_{best}$  2009 on  $f_9$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>9 Rosenbrock rotated</b> |           |            |            |                  |            |                  |            |            |            |                                       |
|---------------------------------------|-----------------------------|-----------|------------|------------|------------------|------------|------------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                       | 1e+02     | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03            | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | 131                         | 285       | 12         | 27         | 24               | 23         | 21               | 21         | 20         | 19         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | 62                          | 164       | 7.4        | 14         | 12               | 12         | 11               | 11         | 11         | 10         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | 57                          | 273       | 14         | 12         | 11               | 10         | 10               | 9.3        | 9.2        | 8.8        | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | 98                          | 382       | 16         | 51         | 40               | 37         | 34               | 33         | 33         | 31         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | 31                          | 218       | 9.0        | 14         | 11               | 10         | 9.4              | 9.1        | 9.0        | 8.6        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | 30                          | 111       | 5.2        | 9.5        | 8.2              | 7.6        | 7.2              | 7.0        | 7.0        | 6.7        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | 26                          | 117       | 5.4        | 10         | 7.7              | 6.8        | 6.3              | 6.1        | 6.0        | 5.8        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | 28                          | 128       | 5.7        | 11         | 9.2              | 8.3        | 7.7              | 7.4        | 7.3        | 6.9        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>22</b>                   | <b>65</b> | <b>3.3</b> | 13         | 9.0              | 7.8        | 7.2              | 6.8        | 6.8        | 6.4        | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>25</b>                   | 102       | <b>4.6</b> | <b>6.2</b> | <b>5.0</b>       | <b>4.4</b> | <b>4.2</b>       | <b>4.0</b> | <b>4.0</b> | <b>3.9</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | 86                          | 259       | 14         | 69         | 699              | 3988       | <i>13e-3/1e5</i> | .          | .          | .          | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>20</b>                   | <b>56</b> | <b>2.4</b> | <b>3.1</b> | <b>2.1</b>       | <b>1.8</b> | <b>1.7</b>       | <b>1.6</b> | <b>1.6</b> | <b>1.5</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 276                         | 692       | 48         | 79         | 56               | 50         | 45               | 46         | 46         | 45         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 97                          | 393       | 24         | 18         | 16               | 16         | 16               | 16         | 16         | 17         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 143                         | 444       | 30         | 23         | 21               | 22         | 21               | 21         | 22         | 22         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | 28                          | 97        | 5.4        | <b>6.2</b> | <b>5.7</b>       | <b>5.3</b> | <b>5.0</b>       | <b>4.9</b> | <b>5.0</b> | <b>4.9</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 29                          | <b>92</b> | 6.0        | 11         | 8.7              | 7.9        | 7.5              | 7.3        | 7.3        | 7.2        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 98                          | 367       | 13         | 10         | 17               | 18         | 17               | 17         | 17         | 17         | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 84                          | 281       | 15         | 11         | 11               | 10         | 10               | 9.5        | 10         | 9.5        | NBC-CMA [21]                          |
| POEMS                                 | 1148                        | 1606      | 109        | 116        | 176              | 616        | 1039             | 1473       | 1856       | 2809       | POEMS [17]                            |
| PM-AdapSS-DE                          | 90                          | 374       | 25         | 22         | 21               | 22         | 21               | 21         | 21         | 22         | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | 1126                        | 1981      | 287        | 563        | 596              | 630        | 722              | 850        | 994        | 1200       | pPOEMS [17, 20]                       |
| Basic RCGA                            | 118                         | 318       | 40         | 8950       | <i>17e-1/5e4</i> | .          | .                | .          | .          | .          | Basic RCGA [24]                       |
| SPSA                                  | 8379                        | 1.78e5    | 13128      | 56959      | <i>54e-1/1e5</i> | .          | .                | .          | .          | .          | SPSA [13]                             |

Table 58: Running time excess  $ERT/ERT_{best, 2009}$  on  $f_{10}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                     | <b>10 Ellipsoid</b> |                  |            |                  |            |                  |            |            |            |            |                     |          |
|---------------------|---------------------|------------------|------------|------------------|------------|------------------|------------|------------|------------|------------|---------------------|----------|
| $\Delta f_{target}$ | 1e+03               | 1e+02            | 1e+01      | 1e+00            | 1e-01      | 1e-02            | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$ |          |
| $ERT_{best}/D$      | 21                  | 34               | 70         | 100              | 115        | 121              | 125        | 129        | 166        | 176        | $ERT_{best}/D$      |          |
| (1,2)-CMA-ES        | 21                  | 23               | 16         | 12               | 11         | 10               | 10         | 10         | 8.2        | 8.0        | (1,2)-CMA-ES        | [5, 3]   |
| (1,2m)-CMA-ES       | 15                  | 13               | 9.4        | 7.6              | 6.8        | 6.6              | 6.5        | 6.5        | 5.1        | 5.1        | (1,2m)-CMA-ES       | [5]      |
| (1,2ms)-CMA-ES      | 12                  | 11               | 7.3        | 5.8              | 5.4        | 5.2              | 5.2        | 5.1        | 4.1        | 4.0        | (1,2ms)-CMA-ES      | [5]      |
| (1,2s)-CMA-ES       | 21                  | 25               | 19         | 14               | 13         | 13               | 13         | 12         | 10         | 10         | (1,2s)-CMA-ES       | [3]      |
| (1,4)-CMA-ES        | 6.3                 | 6.4              | 5.0        | 4.1              | 3.9        | 3.9              | 3.9        | 3.8        | 3.1        | 3.0        | (1,4)-CMA-ES        | [6, 4]   |
| (1,4m)-CMA-ES       | 7.2                 | 7.3              | 4.5        | 3.6              | 3.3        | 3.3              | 3.4        | 3.4        | <b>2.7</b> | <b>2.7</b> | (1,4m)-CMA-ES       | [6]      |
| (1,4ms)-CMA-ES      | 4.7                 | 3.8              | 3.1        | <b>2.6</b>       | <b>2.6</b> | <b>2.5</b>       | <b>2.5</b> | <b>2.5</b> | <b>2.0</b> | <b>2.0</b> | (1,4ms)-CMA-ES      | [1, 6]   |
| (1,4s)-CMA-ES       | 4.3                 | 5.5              | 3.7        | 3.2              | 3.1        | 3.1              | 3.1        | 3.1        | <b>2.5</b> | <b>2.5</b> | (1,4s)-CMA-ES       | [4]      |
| (1+1)-CMA-ES        | <b>3.7</b>          | <b>3.4</b>       | <b>2.6</b> | <b>2.1</b>       | <b>2.1</b> | <b>2.0</b>       | <b>2.0</b> | <b>2.1</b> | <b>1.7</b> | <b>1.7</b> | (1+1)-CMA-ES        | [7]      |
| (1+2ms)-CMA-ES      | <b>2.4</b>          | <b>2.9</b>       | <b>2.2</b> | <b>1.7</b>       | <b>1.7</b> | <b>1.7</b>       | <b>1.7</b> | <b>1.7</b> | <b>1.4</b> | <b>1.4</b> | (1+2ms)-CMA-ES      | [2]      |
| Artif Bee Colony    | 195                 | 2201             | 21228      | <i>55e+0/1e5</i> | .          | .                | .          | .          | .          | .          | Artif Bee Colony    | [8]      |
| avg NEWUOA          | <b>1.2</b>          | <b>2.2</b>       | 3.1        | 4.6              | 6.6        | 8.1              | 10         | 12         | 11         | 14         | avg NEWUOA          | [23]     |
| CMA-EGS (IPOP,r1)   | 22                  | 23               | 16         | 12               | 11         | 11               | 10         | 10         | 8.2        | 8.1        | CMA-EGS (IPOP,r1)   | [12]     |
| Adap DE (F-AUC)     | 7.1                 | 6.5              | 4.5        | 3.9              | 4.0        | 4.5              | 4.9        | 5.4        | 4.7        | 5.3        | Adap DE (F-AUC)     | [10]     |
| DE (Uniform)        | 7.7                 | 6.9              | 4.5        | 4.2              | 4.6        | 5.1              | 5.5        | 6.1        | 5.4        | 6.2        | DE (Uniform)        | [9]      |
| IPOP-aCMA-ES        | 3.8                 | 3.7              | <b>2.5</b> | <b>2.2</b>       | <b>2.1</b> | <b>2.1</b>       | <b>2.2</b> | <b>2.2</b> | <b>1.8</b> | <b>1.9</b> | IPOP-aCMA-ES        | [16]     |
| IPOP-CMA-ES         | 4.6                 | 4.3              | 3.6        | <b>2.9</b>       | <b>2.7</b> | <b>2.7</b>       | <b>2.8</b> | <b>2.8</b> | <b>2.3</b> | <b>2.3</b> | IPOP-CMA-ES         | [22]     |
| CMA+DE-MOS          | 13                  | 13               | 10         | 8.1              | 7.6        | 7.6              | 7.7        | 7.9        | 6.4        | 6.5        | CMA+DE-MOS          | [18]     |
| NBC-CMA             | 6.2                 | 6.7              | 4.6        | 4.5              | 4.4        | 4.4              | 4.5        | 4.6        | 3.8        | 3.8        | NBC-CMA             | [21]     |
| POEMS               | 54                  | 408              | 1411       | 4129             | 17335      | <i>24e-1/3e5</i> | .          | .          | .          | .          | POEMS               | [17]     |
| PM-AdapSS-DE        | 6.6                 | 6.5              | 4.6        | 4.0              | 4.3        | 4.8              | 5.3        | 5.9        | 5.2        | 5.9        | PM-AdapSS-DE        | [9, 10]  |
| pPOEMS              | 59                  | 343              | 552        | 639              | 738        | 844              | 1002       | 1180       | 1040       | 1238       | pPOEMS              | [17, 20] |
| Basic RCGA          | 460                 | 1563             | 3242       | <i>72e+0/5e4</i> | .          | .                | .          | .          | .          | .          | Basic RCGA          | [24]     |
| SPSA                | 5248                | <i>73e+1/1e5</i> | .          | .                | .          | .                | .          | .          | .          | .          | SPSA                | [13]     |

Table 59: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{11}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                     | <b>11 Discus</b> |            |            |                  |                  |                  |            |             |             |             |                        |  |
|---------------------|------------------|------------|------------|------------------|------------------|------------------|------------|-------------|-------------|-------------|------------------------|--|
| $\Delta f_{target}$ | 1e+03            | 1e+02      | 1e+01      | 1e+00            | 1e-01            | 1e-02            | 1e-03      | 1e-04       | 1e-05       | 1e-07       | $\Delta f_{target}$    |  |
| $ERT_{best}/D$      |                  |            |            |                  |                  |                  |            |             |             |             | $ERT_{best}/D$         |  |
| (1,2)-CMA-ES        | 31               | 91         | 28         | 25               | 7.3              | 6.0              | 5.1        | 4.5         | 4.3         | 3.9         | (1,2)-CMA-ES [5, 3]    |  |
| (1,2m)-CMA-ES       | 25               | 91         | 24         | 20               | 5.6              | 4.6              | 3.9        | 3.5         | 3.3         | <b>3.0</b>  | (1,2m)-CMA-ES [5]      |  |
| (1,2ms)-CMA-ES      | 37               | 59         | 19         | 16               | 4.8              | 3.9              | 3.3        | <b>3.0</b>  | <b>2.8</b>  | <b>2.6</b>  | (1,2ms)-CMA-ES [5]     |  |
| (1,2s)-CMA-ES       | 6.8              | 88         | 31         | 29               | 9.1              | 7.3              | 6.3        | 5.6         | 5.3         | 4.9         | (1,2s)-CMA-ES [3]      |  |
| (1,4)-CMA-ES        | <b>3.9</b>       | 20         | 10         | 10               | <b>2.9</b>       | <b>2.3</b>       | <b>2.0</b> | <b>1.8</b>  | <b>1.7</b>  | <b>1.6</b>  | (1,4)-CMA-ES [6, 4]    |  |
| (1,4m)-CMA-ES       | 5.7              | 39         | 12         | 10               | <b>2.8</b>       | <b>2.3</b>       | <b>2.0</b> | <b>1.8</b>  | <b>1.7</b>  | <b>1.6</b>  | (1,4m)-CMA-ES [6]      |  |
| (1,4ms)-CMA-ES      | 5.7              | 37         | 10         | 7.9              | <b>2.2</b>       | <b>1.8</b>       | <b>1.5</b> | <b>1.4</b>  | <b>1.3</b>  | <b>1.2</b>  | (1,4ms)-CMA-ES [1, 6]  |  |
| (1,4s)-CMA-ES       | 17               | 31         | 10         | 8.1              | <b>2.3</b>       | <b>1.9</b>       | <b>1.7</b> | <b>1.5</b>  | <b>1.4</b>  | <b>1.3</b>  | (1,4s)-CMA-ES [4]      |  |
| (1+1)-CMA-ES        | 4.0              | 12         | 5.8        | 6.9              | <b>2.1</b>       | <b>1.8</b>       | <b>1.5</b> | <b>1.3</b>  | <b>1.3</b>  | <b>1.2</b>  | (1+1)-CMA-ES [7]       |  |
| (1+2ms)-CMA-ES      | <b>4.0</b>       | <b>7.7</b> | <b>4.9</b> | <b>5.2</b>       | <b>1.7</b>       | <b>1.4</b>       | <b>1.2</b> | <b>1.1</b>  | <b>1.1</b>  | <b>0.98</b> | (1+2ms)-CMA-ES [2]     |  |
| Artif Bee Colony    | 6.1              | <b>8.5</b> | 160        | 6088             | 9336             | <i>15e-1/1e5</i> | .          | .           | .           | .           | Artif Bee Colony [8]   |  |
| avg NEWUOA          | <b>2.6</b>       | 11         | <b>5.4</b> | 7.2              | <b>2.7</b>       | <b>2.6</b>       | <b>2.8</b> | <b>2.9</b>  | 3.1         | 3.4         | avg NEWUOA [23]        |  |
| CMA-EGS (IPOP,r1)   | 10               | 180        | 61         | 51               | 14               | 11               | 9.0        | 8.0         | 7.4         | 6.7         | CMA-EGS (IPOP,r1) [12] |  |
| Adap DE (F-AUC)     | 12               | 12         | 6.2        | 6.6              | <b>2.2</b>       | <b>2.1</b>       | <b>2.0</b> | <b>2.1</b>  | <b>2.2</b>  | <b>2.4</b>  | Adap DE (F-AUC) [10]   |  |
| DE (Uniform)        | 10               | 14         | 6.2        | 6.6              | <b>2.4</b>       | <b>2.3</b>       | <b>2.4</b> | <b>2.4</b>  | <b>2.6</b>  | <b>2.8</b>  | DE (Uniform) [9]       |  |
| IPOP-aCMA-ES        | 7.1              | 12         | <b>5.6</b> | <b>4.7</b>       | <b>1.4</b>       | <b>1.2</b>       | <b>1.0</b> | <b>0.97</b> | <b>0.95</b> | <b>0.92</b> | IPOP-aCMA-ES [16]      |  |
| IPOP-CMA-ES         | 5.9              | 17         | 8.6        | 7.3              | <b>2.1</b>       | <b>1.8</b>       | <b>1.6</b> | <b>1.4</b>  | <b>1.4</b>  | <b>1.3</b>  | IPOP-CMA-ES [22]       |  |
| CMA+DE-MOS          | 8.0              | 13         | 18         | 17               | 4.9              | 4.2              | 3.7        | 3.4         | 3.3         | 3.2         | CMA+DE-MOS [18]        |  |
| NBC-CMA             | 8.4              | 13         | 13         | 14               | 4.1              | 3.4              | <b>3.0</b> | <b>2.7</b>  | <b>2.6</b>  | <b>2.4</b>  | NBC-CMA [21]           |  |
| POEMS               | 78               | 44         | 558        | 918              | 466              | 496              | 571        | 571         | 680         | 739         | POEMS [17]             |  |
| PM-AdapSS-DE        | 11               | 15         | 6.3        | <b>6.5</b>       | <b>2.3</b>       | <b>2.2</b>       | <b>2.3</b> | <b>2.3</b>  | <b>2.4</b>  | <b>2.7</b>  | PM-AdapSS-DE [9, 10]   |  |
| pPOEMS              | 80               | 50         | 95         | 393              | 204              | 232              | 251        | 261         | 291         | 341         | pPOEMS [17, 20]        |  |
| Basic RCGA          | 10               | <b>11</b>  | 473        | 5466             | <i>26e-1/5e4</i> | .                | .          | .           | .           | .           | Basic RCGA [24]        |  |
| SPSA                | 21               | 8415       | 49100      | <i>63e+0/1e5</i> | .                | .                | .          | .           | .           | .           | SPSA [13]              |  |



Table 61: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{13}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                     | 13 Sharp ridge |            |            |                  |            |                  |                  |                  |                  |                  |                     |          |
|---------------------|----------------|------------|------------|------------------|------------|------------------|------------------|------------------|------------------|------------------|---------------------|----------|
| $\Delta f_{target}$ | 1e+03          | 1e+02      | 1e+01      | 1e+00            | 1e-01      | 1e-02            | 1e-03            | 1e-04            | 1e-05            | 1e-07            | $\Delta f_{target}$ |          |
| $ERT_{best}/D$      |                |            |            |                  |            |                  |                  |                  |                  |                  | $ERT_{best}/D$      |          |
| (1,2)-CMA-ES        | 7.1            | 15         | 25         | 27               | 37         | 65               | 22               | 22               | 28               | 98               | (1,2)-CMA-ES        | [5, 3]   |
| (1,2m)-CMA-ES       | <b>2.0</b>     | 4.2        | 9.4        | 30               | 34         | 34               | 14               | 16               | 27               | 37               | (1,2m)-CMA-ES       | [5]      |
| (1,2ms)-CMA-ES      | 5.9            | 3.1        | 4.6        | 17               | 21         | 24               | 14               | 16               | 18               | 36               | (1,2ms)-CMA-ES      | [5]      |
| (1,2s)-CMA-ES       | 7.7            | 7.6        | 16         | 32               | 44         | 60               | 23               | 24               | 46               | 153              | (1,2s)-CMA-ES       | [3]      |
| (1,4)-CMA-ES        | <b>2.6</b>     | 3.6        | 7.0        | 10               | 11         | 10               | 3.0              | 3.1              | 4.2              | 5.1              | (1,4)-CMA-ES        | [6, 4]   |
| (1,4m)-CMA-ES       | 5.8            | 3.3        | 6.4        | 11               | 10         | 9.1              | <b>2.8</b>       | 3.1              | 3.2              | 3.9              | (1,4m)-CMA-ES       | [6]      |
| (1,4ms)-CMA-ES      | <b>2.5</b>     | 4.3        | <b>2.9</b> | <b>4.9</b>       | 7.7        | 6.7              | <b>2.5</b>       | 3.5              | 3.1              | 3.1              | (1,4ms)-CMA-ES      | [1, 6]   |
| (1,4s)-CMA-ES       | 3.1            | 3.1        | 5.0        | 10               | 10         | 8.8              | 3.3              | 3.1              | 3.1              | 5.0              | (1,4s)-CMA-ES       | [4]      |
| (1+1)-CMA-ES        | <b>2.4</b>     | <b>2.2</b> | 3.7        | 7.1              | 8.3        | 7.9              | <b>2.4</b>       | <b>2.2</b>       | <b>2.2</b>       | 3.1              | (1+1)-CMA-ES        | [7]      |
| (1+2ms)-CMA-ES      | <b>1.9</b>     | <b>2.1</b> | <b>3.1</b> | 7.9              | <b>7.1</b> | <b>6.1</b>       | <b>1.9</b>       | <b>2.0</b>       | <b>2.0</b>       | <b>2.3</b>       | (1+2ms)-CMA-ES      | [2]      |
| Artif Bee Colony    | <b>1.9</b>     | 11         | 18         | 187              | 6618       | <i>15e-2/1e5</i> | .                | .                | .                | .                | Artif Bee Colony    | [8]      |
| avg NEWUOA          | 4.0            | <b>1.0</b> | 4.5        | 8.1              | 42         | 67               | 68               | 450              | 391              | <i>15e-4/9e3</i> | avg NEWUOA          | [23]     |
| CMA-EGS (IPOP,r1)   | 28             | <b>30</b>  | 506        | 1310             | 8016       | 10188            | 5347             | <i>38e-2/1e5</i> | .                | .                | CMA-EGS (IPOP,r1)   | [12]     |
| Adap DE (F-AUC)     | <b>2.9</b>     | 14         | 10         | 11               | 11         | 11               | 3.2              | 3.3              | 3.2              | 3.1              | Adap DE (F-AUC)     | [10]     |
| DE (Uniform)        | <b>2.3</b>     | 15         | 11         | 12               | 13         | 13               | 3.7              | 3.8              | 3.8              | 3.7              | DE (Uniform)        | [9]      |
| IPOP-aCMA-ES        | <b>2.6</b>     | 3.3        | <b>3.0</b> | <b>4.1</b>       | <b>4.2</b> | <b>4.0</b>       | <b>1.2</b>       | <b>1.2</b>       | <b>1.2</b>       | <b>1.1</b>       | IPOP-aCMA-ES        | [16]     |
| IPOP-CMA-ES         | 3.8            | 4.0        | 3.1        | <b>5.0</b>       | <b>5.3</b> | <b>5.1</b>       | <b>1.4</b>       | <b>1.6</b>       | <b>1.6</b>       | <b>1.6</b>       | IPOP-CMA-ES         | [22]     |
| CMA+DE-MOS          | <b>1.7</b>     | 15         | 11         | 12               | 14         | 13               | 3.5              | 3.4              | 3.4              | 3.2              | CMA+DE-MOS          | [18]     |
| NBC-CMA             | <b>1.8</b>     | 9.5        | 6.2        | 7.5              | 9.3        | 9.3              | <b>2.6</b>       | <b>2.6</b>       | <b>2.7</b>       | <b>2.6</b>       | NBC-CMA             | [21]     |
| POEMS               | 286            | 52         | 904        | 2912             | 9139       | 18912            | 16068            | 13841            | <i>12e-2/3e5</i> | .                | POEMS               | [17]     |
| PM-AdapSS-DE        | <b>2.1</b>     | 13         | 10         | 11               | 12         | 12               | 3.4              | 3.5              | 3.5              | 3.4              | PM-AdapSS-DE        | [9, 10]  |
| pPOEMS              | 26             | 57         | 446        | 793              | 1067       | 1220             | 390              | 472              | 1316             | 9956             | pPOEMS              | [17, 20] |
| Basic RCGA          | <b>2.4</b>     | 34         | 282        | 1074             | 6915       | 11505            | <i>50e-2/5e4</i> | .                | .                | .                | Basic RCGA          | [24]     |
| SPSA                | 22             | 55         | 2055       | <i>43e-1/1e5</i> | .          | .                | .                | .                | .                | .                | SPSA                | [13]     |

Table 62: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{14}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| $\Delta f_{target}$<br>$ERT_{best}/D$ | 14 Sum of different powers |            |             |            |            |            |            |            |                  |                  | $\Delta f_{target}$<br>$ERT_{best}/D$ |
|---------------------------------------|----------------------------|------------|-------------|------------|------------|------------|------------|------------|------------------|------------------|---------------------------------------|
|                                       | 1e+03                      | 1e+02      | 1e+01       | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05            | 1e-07            |                                       |
| (1,2)-CMA-ES                          | <b>1</b>                   | <b>1.8</b> | <b>2.3</b>  | 5.0        | 5.9        | 6.3        | 8.3        | 11         | 13               | 13               | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                   | <b>1</b>   | 4.3         | 3.5        | 3.9        | 4.3        | 5.8        | 8.2        | 11               | 9.3              | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                   | <b>1.8</b> | 3.1         | 3.2        | 3.3        | 3.6        | 4.8        | 6.9        | 9.2              | 8.1              | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                   | <b>1.2</b> | 3.5         | 6.4        | 6.4        | 6.3        | 11         | 14         | 17               | 16               | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                   | <b>1.6</b> | <b>1.7</b>  | <b>1.9</b> | 3.1        | 3.2        | 4.2        | 5.0        | 6.8              | 5.4              | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                   | <b>1.6</b> | <b>2.3</b>  | <b>2.1</b> | <b>2.9</b> | 3.3        | 3.9        | 4.6        | 6.0              | 5.3              | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                   | <b>1.5</b> | <b>1.7</b>  | <b>1.8</b> | <b>2.3</b> | <b>2.3</b> | <b>2.9</b> | 3.6        | 4.5              | 4.0              | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                   | <b>2.5</b> | <b>2.0</b>  | <b>2.0</b> | <b>2.5</b> | 3.0        | 3.8        | 4.2        | 5.2              | 4.7              | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                   | <b>1.6</b> | <b>1.2</b>  | <b>1.8</b> | <b>2.3</b> | <b>2.5</b> | <b>2.7</b> | <b>3.1</b> | <b>4.1</b>       | <b>3.3</b>       | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                   | <b>1.6</b> | <b>0.82</b> | <b>1.4</b> | <b>1.7</b> | <b>2.0</b> | <b>2.7</b> | <b>2.9</b> | <b>3.2</b>       | <b>2.7</b>       | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                   | <b>1.9</b> | 3.5         | 11         | 19         | 29         | 679        | 33788      | <i>27e-5/1e5</i> | .                | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                   | <b>1.7</b> | <b>2.1</b>  | <b>1.0</b> | <b>1.0</b> | <b>1.0</b> | <b>1.2</b> | <b>1.8</b> | 5.0              | 1029             | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 4.1                        | 25         | 14          | 7.3        | 7.5        | 8.8        | 17         | 21         | 27               | 203              | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                   | <b>1.3</b> | <b>2.2</b>  | 9.4        | 15         | 15         | 13         | 11         | 11               | 8.2              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                   | <b>1.2</b> | <b>2.3</b>  | 10         | 16         | 18         | 15         | 13         | 13               | 9.3              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                   | <b>2.3</b> | <b>1.5</b>  | <b>2.2</b> | 3.2        | 3.6        | 3.6        | 3.4        | <b>3.8</b>       | <b>2.9</b>       | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                   | <b>1.3</b> | <b>2.2</b>  | <b>2.9</b> | 3.8        | 4.3        | 4.7        | 4.7        | 5.4              | 4.4              | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                   | <b>1.2</b> | <b>2.9</b>  | 13         | 14         | 15         | 14         | 13         | 14               | 11               | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                   | <b>1.3</b> | <b>1.4</b>  | 7.0        | 8.7        | 8.1        | 7.4        | 6.6        | 7.7              | 6.4              | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                   | 280        | 111         | 43         | 79         | 124        | 136        | 130        | 501              | <i>46e-8/3e5</i> | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                   | <b>1.5</b> | <b>1</b>    | 9.4        | 17         | 17         | 15         | 12         | 12               | 8.9              | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                   | 69         | 61          | 47         | 140        | 597        | 798        | 868        | 1057             | 2134             | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                   | <b>1.1</b> | <b>1.5</b>  | 23         | 40         | 59         | 273        | 1453       | 14895            | <i>90e-6/5e4</i> | Basic RCGA [24]                       |
| SPSA                                  | 24                         | 120        | 167         | 106        | 86         | 69         | 99         | 601        | 2141             | <i>60e-7/1e5</i> | SPSA [13]                             |





Table 64: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{16}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>16 Weierstrass</b>             |            |            |            |            |                  |                  |                  |                  |                  |                  |                                   |
|-----------------------------------|------------|------------|------------|------------|------------------|------------------|------------------|------------------|------------------|------------------|-----------------------------------|
| $\Delta$ target<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03            | 1e-04            | 1e-05            | 1e-07            | $\Delta$ target<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                      | <b>1</b>   | <b>1.4</b> | 42         | 259        | <i>14e-1/1e4</i> | .                | .                | .                | .                | .                | (1,2)-CMA-ES [5, 3]               |
| (1,2m)-CMA-ES                     | <b>1</b>   | <b>1</b>   | 16         | 29         | 45               | 70               | 69               | 63               | 62               | <i>18e-2/1e4</i> | (1,2m)-CMA-ES [5]                 |
| (1,2ms)-CMA-ES                    | <b>1</b>   | <b>1.2</b> | 15         | 43         | 38               | 36               | <i>17e-2/1e4</i> | .                | .                | .                | (1,2ms)-CMA-ES [5]                |
| (1,2s)-CMA-ES                     | <b>1</b>   | <b>1.3</b> | 58         | 589        | <i>28e-1/1e4</i> | .                | .                | .                | .                | .                | (1,2s)-CMA-ES [3]                 |
| (1,4)-CMA-ES                      | <b>1</b>   | <b>1.1</b> | 7.2        | 27         | 31               | 34               | <i>22e-2/1e4</i> | .                | .                | .                | (1,4)-CMA-ES [6, 4]               |
| (1,4m)-CMA-ES                     | <b>1</b>   | <b>1.3</b> | <b>2.9</b> | 5.8        | 12               | 6.1              | 11               | 29               | <i>98e-4/1e4</i> | .                | (1,4m)-CMA-ES [6]                 |
| (1,4ms)-CMA-ES                    | <b>1</b>   | <b>1.5</b> | 5.6        | 16         | 19               | 15               | 33               | <i>39e-3/1e4</i> | .                | .                | (1,4ms)-CMA-ES [1, 6]             |
| (1,4s)-CMA-ES                     | <b>1</b>   | <b>1.8</b> | 8.1        | 20         | 33               | 72               | <i>14e-2/1e4</i> | .                | .                | .                | (1,4s)-CMA-ES [4]                 |
| (1+1)-CMA-ES                      | <b>1</b>   | <b>1.2</b> | <b>2.0</b> | 21         | 19               | 33               | <i>71e-3/1e4</i> | .                | .                | .                | (1+1)-CMA-ES [7]                  |
| (1+2ms)-CMA-ES                    | <b>1</b>   | <b>1.2</b> | <b>1.7</b> | 7.7        | 16               | <i>62e-3/1e4</i> | .                | .                | .                | .                | (1+2ms)-CMA-ES [2]                |
| Artif Bee Colony                  | <b>1</b>   | <b>1.7</b> | <b>2.3</b> | 10         | 95               | <i>48e-3/1e5</i> | .                | .                | .                | .                | Artif Bee Colony [8]              |
| avg NEWUOA                        | <b>1</b>   | <b>1.2</b> | <b>2.6</b> | 12         | 47               | <i>35e-2/8e3</i> | .                | .                | .                | .                | avg NEWUOA [23]                   |
| CMA-EGS (IPOP,r1)                 | <b>1.3</b> | 20         | 7.8        | 179        | 409              | 324              | 671              | <i>15e-2/1e5</i> | .                | .                | CMA-EGS (IPOP,r1) [12]            |
| Adap DE (F-AUC)                   | <b>1</b>   | <b>1.2</b> | 6.4        | 39         | 31               | 8.2              | 12               | 11               | 11               | 10               | Adap DE (F-AUC) [10]              |
| DE (Uniform)                      | <b>1</b>   | <b>1.2</b> | 4.3        | 44         | 20               | 13               | 17               | 16               | 16               | 15               | DE (Uniform) [9]                  |
| IPOP-aCMA-ES                      | <b>1</b>   | <b>1.1</b> | 3.9        | <b>2.4</b> | <b>1.7</b>       | <b>0.56</b>      | <b>0.82</b>      | <b>0.84</b>      | <b>0.84</b>      | <b>0.85</b>      | IPOP-aCMA-ES [16]                 |
| IPOP-CMA-ES                       | <b>1</b>   | <b>1.3</b> | <b>2.5</b> | <b>2.3</b> | <b>1.7</b>       | <b>0.55</b>      | <b>0.96</b>      | <b>0.94</b>      | <b>0.94</b>      | <b>0.95</b>      | IPOP-CMA-ES [22]                  |
| CMA+DE-MOS                        | <b>1</b>   | <b>1.6</b> | <b>1.6</b> | <b>2.9</b> | <b>2.6</b>       | <b>1.2</b>       | <b>1.2</b>       | <b>1.2</b>       | <b>7.7</b>       | 7.7              | CMA+DE-MOS [18]                   |
| NBC-CMA                           | <b>1</b>   | <b>1.3</b> | 3.0        | 4.0        | <b>1.3</b>       | <b>0.81</b>      | <b>0.86</b>      | <b>0.84</b>      | <b>0.83</b>      | <b>0.83</b>      | NBC-CMA [21]                      |
| POEMS                             | <b>1</b>   | 57         | 11         | 14         | 92               | 56               | 74               | 68               | 68               | 66               | POEMS [17]                        |
| PM-AdapSS-DE                      | <b>1</b>   | <b>1.3</b> | 3.9        | 124        | 55               | 16               | 20               | 18               | 28               | 27               | PM-AdapSS-DE [9, 10]              |
| pPOEMS                            | <b>1</b>   | <b>1.5</b> | 10         | 52         | 40               | 53               | 116              | 110              | 113              | 116              | pPOEMS [17, 20]                   |
| Basic RCGA                        | <b>1</b>   | <b>1.4</b> | <b>2.4</b> | 60         | 49               | 80               | 351              | 322              | <i>16e-3/5e4</i> | .                | Basic RCGA [24]                   |
| SPSA                              | 4.3        | 280        | 548        | 1367       | 594              | 349              | 695              | <i>12e-1/1e5</i> | .                | .                | SPSA [13]                         |

Table 65: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{17}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>17 Schaffer F7, condition 10</b> |          |            |            |             |             |                  |                  |                  |             |                  |                        |
|-------------------------------------|----------|------------|------------|-------------|-------------|------------------|------------------|------------------|-------------|------------------|------------------------|
| $\Delta f_{target}$                 | 1e+03    | 1e+02      | 1e+01      | 1e+00       | 1e-01       | 1e-02            | 1e-03            | 1e-04            | 1e-05       | 1e-07            | $\Delta f_{target}$    |
| $ERT_{best}/D$                      | 0.20     | 0.20       | 1.0        | 43          | 180         | 572              | 734              | 959              | 1270        | 1587             | $ERT_{best}/D$         |
| (1,2)-CMA-ES                        | <b>1</b> | <b>1.1</b> | 52         | 54          | 404         | <i>14e-2/1e4</i> | .                | .                | .           | .                | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES                       | <b>1</b> | <b>1.3</b> | 6.7        | 5.3         | 6.2         | 13               | 64               | <i>51e-4/1e4</i> | .           | .                | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES                      | <b>1</b> | <b>1.3</b> | 5.3        | 5.0         | 13          | 22               | <i>87e-4/1e4</i> | .                | .           | .                | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES                       | <b>1</b> | <b>1.3</b> | 52         | 87          | 397         | <i>36e-2/1e4</i> | .                | .                | .           | .                | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES                        | <b>1</b> | <b>1</b>   | 116        | 20          | 18          | 31               | <i>27e-3/1e4</i> | .                | .           | .                | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES                       | <b>1</b> | <b>1</b>   | 20         | <b>2.3</b>  | 4.1         | 7.2              | 90               | <i>34e-4/1e4</i> | .           | .                | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES                      | <b>1</b> | <b>1.1</b> | 5.1        | <b>0.71</b> | 4.5         | 28               | <i>12e-3/1e4</i> | .                | .           | .                | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES                       | <b>1</b> | <b>1</b>   | 4.2        | 3.6         | 18          | 54               | <i>23e-3/1e4</i> | .                | .           | .                | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES                        | <b>1</b> | <b>1</b>   | 15         | 25          | 94          | <i>14e-2/1e4</i> | .                | .                | .           | .                | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES                      | <b>1</b> | <b>1.2</b> | 15         | 17          | 24          | <i>38e-3/1e4</i> | .                | .                | .           | .                | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony                    | <b>1</b> | <b>1.1</b> | 6.5        | 15          | 64          | 1259             | <i>31e-3/1e5</i> | .                | .           | .                | Artif Bee Colony [8]   |
| avg NEWUOA                          | <b>1</b> | <b>1.2</b> | <b>3.1</b> | 42          | 405         | <i>24e-2/1e4</i> | .                | .                | .           | .                | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)                   | 17       | 37         | 17         | 3.3         | <b>2.5</b>  | 40               | 62               | 120              | 1104        | <i>36e-5/1e5</i> | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)                     | <b>1</b> | <b>1.2</b> | 5.7        | 3.9         | <b>2.3</b>  | <b>1.2</b>       | <b>1.3</b>       | <b>1.3</b>       | <b>1.3</b>  | <b>1.4</b>       | Adap DE (F-AUC) [10]   |
| DE (Uniform)                        | <b>1</b> | <b>1</b>   | 3.8        | 4.3         | <b>2.7</b>  | <b>1.4</b>       | <b>1.6</b>       | <b>1.6</b>       | <b>1.5</b>  | <b>1.6</b>       | DE (Uniform) [9]       |
| IPOP-aCMA-ES                        | <b>1</b> | <b>1.3</b> | 4.3        | <b>0.89</b> | <b>0.53</b> | <b>0.59</b>      | <b>0.77</b>      | <b>0.74</b>      | <b>1.00</b> | <b>1.1</b>       | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES                         | <b>1</b> | <b>1.1</b> | 4.8        | <b>1.1</b>  | <b>0.97</b> | <b>0.61</b>      | <b>0.77</b>      | <b>0.80</b>      | <b>0.81</b> | <b>1.0</b>       | IPOP-CMA-ES [22]       |
| CMA+DE-MOS                          | <b>1</b> | <b>1.1</b> | <b>2.8</b> | 5.8         | 5.2         | 3.9              | 5.4              | 4.7              | 3.9         | 4.0              | CMA+DE-MOS [18]        |
| NBC-CMA                             | <b>1</b> | <b>1.2</b> | 5.6        | <b>2.2</b>  | <b>1.9</b>  | <b>0.74</b>      | <b>0.68</b>      | <b>0.68</b>      | <b>1.6</b>  | 3.3              | NBC-CMA [21]           |
| POEMS                               | <b>1</b> | 78         | 221        | 17          | 15          | 8.2              | 14               | 61               | 98          | 139              | POEMS [17]             |
| PM-AdapSS-DE                        | <b>1</b> | <b>1.3</b> | 4.2        | 4.0         | <b>2.3</b>  | <b>1.2</b>       | <b>1.4</b>       | <b>1.4</b>       | <b>1.3</b>  | <b>1.4</b>       | PM-AdapSS-DE [9, 10]   |
| pPOEMS                              | <b>1</b> | <b>1.3</b> | 169        | 22          | 88          | 57               | 71               | 75               | 73          | 82               | pPOEMS [17, 20]        |
| Basic RCGA                          | <b>1</b> | <b>1.1</b> | <b>2.9</b> | 57          | 48          | 35               | 56               | 124              | 173         | <i>30e-5/5e4</i> | Basic RCGA [24]        |
| SPSA                                | 35977    | 77306      | 48618      | 2098        | 2228        | 2447             | <i>85e-2/1e5</i> | .                | .           | .                | SPSA [13]              |

Table 66: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{18}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| 18 Schaffer F7, condition 1000    |            |            |            |            |                  |                  |                  |             |                  |             |                                   |
|-----------------------------------|------------|------------|------------|------------|------------------|------------------|------------------|-------------|------------------|-------------|-----------------------------------|
| $\Delta target$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03            | 1e-04       | 1e-05            | 1e-07       | $\Delta target$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                      | <b>1.1</b> | <b>2.4</b> | 36         | 201        | <i>11e-1/1e4</i> | .                | .                | .           | .                | .           | (1,2)-CMA-ES [5, 3]               |
| (1,2m)-CMA-ES                     | <b>1</b>   | 4.7        | 3.7        | 28         | 23               | <i>16e-2/1e4</i> | .                | .           | .                | .           | (1,2m)-CMA-ES [5]                 |
| (1,2ms)-CMA-ES                    | <b>1</b>   | 5.4        | 8.2        | 27         | 21               | 83               | <i>13e-2/1e4</i> | .           | .                | .           | (1,2ms)-CMA-ES [5]                |
| (1,2s)-CMA-ES                     | <b>1</b>   | 7.6        | 29         | 601        | <i>19e-1/1e4</i> | .                | .                | .           | .                | .           | (1,2s)-CMA-ES [3]                 |
| (1,4)-CMA-ES                      | <b>1</b>   | 3.5        | <b>3.0</b> | 31         | 21               | 84               | <i>14e-2/1e4</i> | .           | .                | .           | (1,4)-CMA-ES [6, 4]               |
| (1,4m)-CMA-ES                     | <b>1</b>   | <b>2.1</b> | <b>1.9</b> | 5.9        | 9.2              | 19               | <i>67e-3/1e4</i> | .           | .                | .           | (1,4m)-CMA-ES [6]                 |
| (1,4ms)-CMA-ES                    | <b>1</b>   | <b>2.7</b> | 3.1        | 18         | 6.4              | 84               | <i>39e-3/1e4</i> | .           | .                | .           | (1,4ms)-CMA-ES [1, 6]             |
| (1,4s)-CMA-ES                     | <b>1</b>   | 5.4        | 8.8        | 35         | 20               | <i>13e-2/1e4</i> | .                | .           | .                | .           | (1,4s)-CMA-ES [4]                 |
| (1+1)-CMA-ES                      | <b>1</b>   | 4.1        | 8.6        | 52         | 87               | <i>42e-2/1e4</i> | .                | .           | .                | .           | (1+1)-CMA-ES [7]                  |
| (1+2ms)-CMA-ES                    | <b>1.1</b> | 3.6        | 15         | 48         | 33               | 85               | <i>14e-2/1e4</i> | .           | .                | .           | (1+2ms)-CMA-ES [2]                |
| Artif Bee Colony                  | <b>1.1</b> | <b>1.6</b> | 5.0        | 27         | 300              | <i>14e-2/1e5</i> | .                | .           | .                | .           | Artif Bee Colony [8]              |
| avg NEWUOA                        | <b>1</b>   | 5.4        | 10         | 272        | <i>57e-2/3e4</i> | .                | .                | .           | .                | .           | avg NEWUOA [23]                   |
| CMA-EGS (IPOP,r1)                 | 28         | 53         | <b>2.2</b> | 7.2        | 25               | 122              | <i>22e-3/1e5</i> | .           | .                | .           | CMA-EGS (IPOP,r1) [12]            |
| Adap DE (F-AUC)                   | <b>1</b>   | <b>2.4</b> | 4.3        | 3.8        | <b>0.75</b>      | <b>0.55</b>      | <b>0.69</b>      | <b>0.75</b> | <b>0.88</b>      | <b>0.98</b> | Adap DE (F-AUC) [10]              |
| DE (Uniform)                      | <b>1</b>   | <b>2.7</b> | 4.0        | 4.3        | <b>0.81</b>      | <b>0.58</b>      | <b>0.73</b>      | <b>0.80</b> | <b>0.95</b>      | <b>1.1</b>  | DE (Uniform) [9]                  |
| IPOP-aCMA-ES                      | <b>1</b>   | 5.8        | 3.5        | <b>1.6</b> | <b>0.70</b>      | <b>0.69</b>      | <b>0.77</b>      | <b>0.73</b> | <b>0.80</b>      | <b>0.84</b> | IPOP-aCMA-ES [16]                 |
| IPOP-CMA-ES                       | <b>1.6</b> | 7.5        | <b>1.2</b> | <b>2.7</b> | <b>0.87</b>      | <b>1.1</b>       | <b>1.0</b>       | <b>0.98</b> | <b>1.0</b>       | <b>0.99</b> | IPOP-CMA-ES [22]                  |
| CMA+DE-MOS                        | <b>1.1</b> | <b>1.7</b> | 4.9        | 6.7        | <b>2.9</b>       | <b>1.7</b>       | <b>1.7</b>       | <b>1.6</b>  | <b>1.6</b>       | <b>2.0</b>  | CMA+DE-MOS [18]                   |
| NBC-CMA                           | <b>1</b>   | <b>2.3</b> | 3.1        | <b>3.0</b> | <b>0.41</b>      | <b>0.48</b>      | <b>1.2</b>       | 3.4         | 6.2              | 15          | NBC-CMA [21]                      |
| POEMS                             | <b>2.5</b> | 260        | 19         | 23         | 33               | 207              | 449              | 2029        | <i>15e-3/3e5</i> | .           | POEMS [17]                        |
| PM-AdapSS-DE                      | <b>1.1</b> | 4.4        | 4.3        | 4.1        | <b>0.76</b>      | <b>0.54</b>      | <b>0.67</b>      | <b>0.74</b> | <b>0.89</b>      | <b>1.0</b>  | PM-AdapSS-DE [9, 10]              |
| pPOEMS                            | <b>1.1</b> | 77         | 18         | 95         | 34               | 30               | 39               | 46          | 55               | 69          | pPOEMS [17, 20]                   |
| Basic RCGA                        | <b>1</b>   | 3.5        | 7.9        | 88         | 23               | 35               | 187              | 347         | <i>53e-4/5e4</i> | .           | Basic RCGA [24]                   |
| SPSA                              | 3.33e5     | 6.26e5     | 19476      | 18540      | <i>31e+1/1e5</i> | .                | .                | .           | .                | .           | SPSA [13]                         |

Table 67: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{19}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                        | <b>19 Griewank-Rosenbrock F8F2</b> |            |           |             |                  |                  |                  |             |             |             |                                        |
|----------------------------------------|------------------------------------|------------|-----------|-------------|------------------|------------------|------------------|-------------|-------------|-------------|----------------------------------------|
| $\Delta ft_{target}$<br>$ERT_{best}/D$ | 1e+03                              | 1e+02      | 1e+01     | 1e+00       | 1e-01            | 1e-02            | 1e-03            | 1e-04       | 1e-05       | 1e-07       | $\Delta ft_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                           | <b>1</b>                           | <b>1</b>   | 31        | 16363       | <i>56e-2/1e4</i> | .                | .                | .           | .           | .           | (1,2)-CMA-ES [5, 3]                    |
| (1,2m)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | 62        | 4556        | 945              | <i>27e-2/1e4</i> | .                | .           | .           | .           | (1,2m)-CMA-ES [5]                      |
| (1,2ms)-CMA-ES                         | <b>1</b>                           | <b>1.4</b> | 22        | 8527        | 1393             | <i>39e-2/1e4</i> | .                | .           | .           | .           | (1,2ms)-CMA-ES [5]                     |
| (1,2s)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | 55        | 25341       | <i>59e-2/1e4</i> | .                | .                | .           | .           | .           | (1,2s)-CMA-ES [3]                      |
| (1,4)-CMA-ES                           | <b>1</b>                           | <b>1</b>   | 21        | 6463        | <i>39e-2/1e4</i> | .                | .                | .           | .           | .           | (1,4)-CMA-ES [6, 4]                    |
| (1,4m)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | 20        | 8960        | 659              | <i>19e-2/1e4</i> | .                | .           | .           | .           | (1,4m)-CMA-ES [6]                      |
| (1,4ms)-CMA-ES                         | <b>1</b>                           | <b>1</b>   | <b>17</b> | 3093        | 478              | 7.0              | 6.1              | 6.1         | 6.0         | 6.0         | (1,4ms)-CMA-ES [1, 6]                  |
| (1,4s)-CMA-ES                          | <b>1</b>                           | <b>1</b>   | 25        | 10110       | <i>34e-2/1e4</i> | .                | .                | .           | .           | .           | (1,4s)-CMA-ES [4]                      |
| (1+1)-CMA-ES                           | <b>1</b>                           | <b>1</b>   | <b>13</b> | 5123        | 1482             | <i>20e-2/1e4</i> | .                | .           | .           | .           | (1+1)-CMA-ES [7]                       |
| (1+2ms)-CMA-ES                         | <b>1</b>                           | <b>1</b>   | <b>17</b> | 6018        | 233              | <i>98e-3/1e4</i> | .                | .           | .           | .           | (1+2ms)-CMA-ES [2]                     |
| Artif Bee Colony                       | <b>1</b>                           | <b>1.2</b> | 34        | 2898        | 3823             | 69               | <i>12e-2/1e5</i> | .           | .           | .           | Artif Bee Colony [8]                   |
| avg NEWUOA                             | <b>1</b>                           | <b>1</b>   | 24        | 15619       | 995              | <i>55e-3/1e5</i> | .                | .           | .           | .           | avg NEWUOA [23]                        |
| CMA-EGS (IPOP,r1)                      | 17                                 | 37         | 97        | 5695        | 2016             | 33               | <i>73e-3/1e5</i> | .           | .           | .           | CMA-EGS (IPOP,r1) [12]                 |
| Adap DE (F-AUC)                        | <b>1</b>                           | <b>1.1</b> | 29        | 2586        | 1726             | 10               | 11               | 11          | 11          | 10          | Adap DE (F-AUC) [10]                   |
| DE (Uniform)                           | <b>1</b>                           | <b>1.2</b> | 35        | 3449        | 1630             | 15               | 13               | 13          | 13          | 13          | DE (Uniform) [9]                       |
| IPOP-aCMA-ES                           | <b>1</b>                           | <b>1</b>   | <b>14</b> | <b>1207</b> | <b>123</b>       | <b>0.84</b>      | <b>0.95</b>      | <b>0.95</b> | <b>0.96</b> | <b>0.96</b> | IPOP-aCMA-ES [16]                      |
| IPOP-CMA-ES                            | <b>1</b>                           | <b>1</b>   | 21        | 1720        | <b>125</b>       | <b>1.2</b>       | <b>1.1</b>       | <b>1.1</b>  | <b>1.1</b>  | <b>1.1</b>  | IPOP-CMA-ES [22]                       |
| CMA+DE-MOS                             | <b>1</b>                           | <b>1.2</b> | 27        | <b>658</b>  | <b>108</b>       | <b>3.9</b>       | <b>4.8</b>       | <b>4.8</b>  | <b>4.8</b>  | <b>4.8</b>  | CMA+DE-MOS [18]                        |
| NBC-CMA                                | <b>1</b>                           | <b>1.1</b> | 39        | 2946        | 2141             | 40               | 35               | 35          | 35          | 35          | NBC-CMA [21]                           |
| POEMS                                  | <b>1</b>                           | 202        | 1047      | 30587       | 10531            | 98               | 87               | 86          | 86          | 86          | POEMS [17]                             |
| PM-AdapSS-DE                           | <b>1</b>                           | <b>1.7</b> | 37        | 2000        | 2054             | 22               | 19               | 19          | 19          | 29          | PM-AdapSS-DE [9, 10]                   |
| pPOEMS                                 | <b>1</b>                           | <b>1.1</b> | 982       | 18467       | 1645             | 12               | 27               | 27          | 27          | 27          | pPOEMS [17, 20]                        |
| Basic RCGA                             | <b>1</b>                           | <b>1.1</b> | 33        | <b>1019</b> | 463              | <i>63e-3/5e4</i> | .                | .           | .           | .           | Basic RCGA [24]                        |
| SPSA                                   | 36                                 | 97         | 422       | 2.10e5      | 29091            | <i>59e-2/1e5</i> | .                | .           | .           | .           | SPSA [13]                              |



Table 69: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{21}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>21 Gallagher 101 peaks</b> |          |            |            |            |            |            |            |            |            |                                       |
|---------------------------------------|-------------------------------|----------|------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                         | 1e+02    | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>                      | <b>1</b> | 6.9        | 8.6        | 13         | 13         | 13         | 13         | 13         | 12         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                      | <b>1</b> | 5.7        | 5.8        | 9.0        | 9.0        | 8.9        | 8.9        | 8.9        | 8.8        | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                      | <b>1</b> | <b>2.4</b> | 5.0        | 10         | 9.4        | 9.4        | 9.4        | 9.3        | 9.2        | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                      | <b>1</b> | 24         | 14         | 23         | 23         | 23         | 23         | 23         | 22         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                      | <b>1</b> | 5.7        | <b>2.9</b> | 6.9        | 6.8        | 6.8        | 6.8        | 6.8        | 6.7        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                      | <b>1</b> | 3.5        | 3.4        | 6.1        | 6.1        | 6.1        | 6.0        | 6.0        | 6.0        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                      | <b>1</b> | <b>1.2</b> | <b>1.7</b> | <b>3.1</b> | <b>3.1</b> | <b>3.1</b> | <b>3.1</b> | <b>3.1</b> | <b>3.1</b> | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                      | <b>1</b> | 5.1        | 4.3        | <b>5.3</b> | <b>5.3</b> | <b>5.3</b> | <b>5.2</b> | <b>5.2</b> | <b>5.2</b> | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                      | <b>1</b> | <b>2.7</b> | 3.4        | 5.6        | 5.5        | 5.5        | 5.5        | 5.5        | 5.4        | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                      | <b>1</b> | 7.6        | 3.8        | 7.5        | 7.4        | 7.4        | 7.3        | 7.3        | 7.2        | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                      | <b>1</b> | 3.2        | <b>1.8</b> | 6.7        | 10         | 13         | 24         | 84         | 265        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                      | <b>1</b> | <b>1.7</b> | <b>2.5</b> | <b>3.6</b> | <b>3.5</b> | <b>3.5</b> | <b>3.5</b> | <b>3.5</b> | <b>3.5</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b>                      | 21       | 3.4        | 114        | 217        | 267        | 287        | 327        | 374        | 458        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                      | <b>1</b> | 5.2        | <b>1.7</b> | 110        | 109        | 109        | 108        | 107        | 106        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                      | <b>1</b> | 4.5        | 33         | 76         | 76         | 75         | 75         | 74         | 74         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                      | <b>1</b> | 3.5        | 7.3        | 32         | 33         | 33         | 33         | 33         | 33         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                      | <b>1</b> | 6.3        | 5.6        | 30         | 30         | 31         | 31         | 31         | 31         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                      | <b>1</b> | 4.6        | 69         | 280        | 478        | 485        | 485        | 483        | 527        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                      | <b>1</b> | <b>2.5</b> | 96         | 119        | 118        | 117        | 116        | 115        | 114        | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                      | <b>1</b> | 25         | 744        | 1429       | 1415       | 1405       | 1397       | 1389       | 1371       | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                      | <b>1</b> | 4.0        | 33         | 201        | 199        | 198        | 196        | 195        | 192        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                      | <b>1</b> | 28         | 11         | 214        | 238        | 243        | 254        | 263        | 283        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                      | <b>1</b> | <b>2.5</b> | 84         | 105        | 129        | 129        | 134        | 135        | 140        | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b>                      | 34       | 34         | 299        | 1985       | 1967       | 1958       | 1997       | 4056       | 3995       | SPSA [13]                             |

Table 70: Running time excess  $ERT/ERT_{\text{best}}^{2009}$  on  $f_{22}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                                     | <b>22 Gallagher 21 peaks</b> |          |            |            |            |                  |            |            |            |            |                                                     |
|-----------------------------------------------------|------------------------------|----------|------------|------------|------------|------------------|------------|------------|------------|------------|-----------------------------------------------------|
| $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ | 1e+03                        | 1e+02    | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ |
| (1,2)-CMA-ES                                        | <b>1</b>                     | <b>1</b> | 18         | 31         | 31         | 30               | 30         | 29         | 29         | 29         | (1,2)-CMA-ES [5, 3]                                 |
| (1,2m)-CMA-ES                                       | <b>1</b>                     | <b>1</b> | 10         | 11         | 20         | 19               | 19         | 19         | 18         | 18         | (1,2m)-CMA-ES [5]                                   |
| (1,2ms)-CMA-ES                                      | <b>1</b>                     | <b>1</b> | 15         | 21         | 51         | 49               | 48         | 47         | 47         | 46         | (1,2ms)-CMA-ES [5]                                  |
| (1,2s)-CMA-ES                                       | <b>1</b>                     | <b>1</b> | 23         | 32         | 49         | 47               | 46         | 46         | 45         | 44         | (1,2s)-CMA-ES [3]                                   |
| (1,4)-CMA-ES                                        | <b>1</b>                     | <b>1</b> | 6.9        | 13         | 16         | 16               | 15         | 15         | 15         | 15         | (1,4)-CMA-ES [6, 4]                                 |
| (1,4m)-CMA-ES                                       | <b>1</b>                     | <b>1</b> | 12         | 10         | 12         | 12               | 12         | 12         | 12         | 11         | (1,4m)-CMA-ES [6]                                   |
| (1,4ms)-CMA-ES                                      | <b>1</b>                     | <b>1</b> | 10         | 12         | 15         | 15               | 14         | 14         | 14         | 14         | (1,4ms)-CMA-ES [1, 6]                               |
| (1,4s)-CMA-ES                                       | <b>1</b>                     | <b>1</b> | 16         | 18         | 12         | 11               | 11         | 11         | 11         | 11         | (1,4s)-CMA-ES [4]                                   |
| (1+1)-CMA-ES                                        | <b>1</b>                     | <b>1</b> | 3.7        | 8.0        | <b>8.5</b> | <b>8.2</b>       | <b>8.0</b> | <b>8.0</b> | <b>7.9</b> | <b>7.8</b> | (1+1)-CMA-ES [7]                                    |
| (1+2ms)-CMA-ES                                      | <b>1</b>                     | <b>1</b> | <b>3.1</b> | <b>6.5</b> | <b>4.9</b> | <b>4.7</b>       | <b>4.6</b> | <b>4.6</b> | <b>4.6</b> | <b>4.5</b> | (1+2ms)-CMA-ES [2]                                  |
| Artif Bee Colony                                    | <b>1</b>                     | <b>1</b> | 5.1        | 7.6        | 35         | 237              | 374        | 1160       | 3311       | 6900       | Artif Bee Colony [8]                                |
| avg NEWUOA                                          | <b>1</b>                     | <b>1</b> | <b>3.4</b> | <b>2.6</b> | <b>2.3</b> | <b>2.3</b>       | <b>2.3</b> | <b>2.3</b> | <b>2.4</b> | <b>2.4</b> | avg NEWUOA [23]                                     |
| CMA-EGS (IPOP,r1)                                   | <b>1</b>                     | 27       | 58         | 336        | 1483       | 1421             | 1384       | 1364       | 1933       | 1885       | CMA-EGS (IPOP,r1) [12]                              |
| Adap DE (F-AUC)                                     | <b>1</b>                     | <b>1</b> | 4.8        | 203        | 803        | 768              | 747        | 734        | 724        | 706        | Adap DE (F-AUC) [10]                                |
| DE (Uniform)                                        | <b>1</b>                     | <b>1</b> | 6.6        | 203        | 469        | 450              | 437        | 430        | 424        | 414        | DE (Uniform) [9]                                    |
| IPOP-aCMA-ES                                        | <b>1</b>                     | <b>1</b> | 8.8        | 21         | 65         | 276              | 270        | 265        | 262        | 257        | IPOP-aCMA-ES [16]                                   |
| IPOP-CMA-ES                                         | <b>1</b>                     | <b>1</b> | 12         | 48         | 166        | 165              | 161        | 159        | 158        | 155        | IPOP-CMA-ES [22]                                    |
| CMA+DE-MOS                                          | <b>1</b>                     | <b>1</b> | 3.7        | 24         | 299        | 483              | 557        | 551        | 549        | 541        | CMA+DE-MOS [18]                                     |
| NBC-CMA                                             | <b>1</b>                     | <b>1</b> | <b>3.0</b> | 264        | 289        | 360              | 350        | 343        | 339        | 331        | NBC-CMA [21]                                        |
| POEMS                                               | <b>1</b>                     | <b>1</b> | 1137       | 2347       | 2593       | 2485             | 2417       | 2377       | 2348       | 2292       | POEMS [17]                                          |
| PM-AdapSS-DE                                        | <b>1</b>                     | <b>1</b> | 4.1        | <b>4.6</b> | 469        | 449              | 437        | 430        | 424        | 414        | PM-AdapSS-DE [9, 10]                                |
| pPOEMS                                              | <b>1</b>                     | <b>1</b> | 29         | 24         | 268        | 276              | 284        | 305        | 326        | 362        | pPOEMS [17, 20]                                     |
| Basic RCGA                                          | <b>1</b>                     | <b>1</b> | 6.2        | 154        | 365        | 857              | 1697       | 1716       | 1706       | 3410       | Basic RCGA [24]                                     |
| SPSA                                                | <b>1</b>                     | 42       | 676        | 1318       | 7823       | <i>69e-2/1e5</i> | .          | .          | .          | .          | SPSA [13]                                           |

Table 71: Running time excess  $ERT/ERT_{\text{best}}^{2009}$  on  $f_{23}$  in **5-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>23 Katsuuras</b>                                 |       |       |            |            |                  |                  |                  |            |            |            |                                                     |
|-----------------------------------------------------|-------|-------|------------|------------|------------------|------------------|------------------|------------|------------|------------|-----------------------------------------------------|
| $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ | 1e+03 | 1e+02 | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03            | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ |
| (1,2)-CMA-ES                                        | 1     | 1     | <b>2.8</b> | 101        | <i>97e-2/1e4</i> | .                | .                | .          | .          | .          | (1,2)-CMA-ES [5, 3]                                 |
| (1,2m)-CMA-ES                                       | 1     | 1     | 15         | 37         | 16               | 13               | 23               | 23         | 22         | 21         | (1,2m)-CMA-ES [5]                                   |
| (1,2ms)-CMA-ES                                      | 1     | 1     | 6.4        | 23         | 9.5              | 26               | <i>18e-2/1e4</i> | .          | .          | .          | (1,2ms)-CMA-ES [5]                                  |
| (1,2s)-CMA-ES                                       | 1     | 1     | 3.1        | 105        | <i>98e-2/1e4</i> | .                | .                | .          | .          | .          | (1,2s)-CMA-ES [3]                                   |
| (1,4)-CMA-ES                                        | 1     | 1     | 5.7        | 28         | 7.0              | 12               | 11               | 22         | 22         | 21         | (1,4)-CMA-ES [6, 4]                                 |
| (1,4m)-CMA-ES                                       | 1     | 1     | 3.8        | 12         | 4.2              | <i>87e-3/1e4</i> | .                | .          | .          | .          | (1,4m)-CMA-ES [6]                                   |
| (1,4ms)-CMA-ES                                      | 1     | 1     | <b>2.2</b> | 8.9        | 24               | 25               | <i>20e-2/1e4</i> | .          | .          | .          | (1,4ms)-CMA-ES [1, 6]                               |
| (1,4s)-CMA-ES                                       | 1     | 1     | <b>3.0</b> | 23         | 51               | <i>23e-2/1e4</i> | .                | .          | .          | .          | (1,4s)-CMA-ES [4]                                   |
| (1+1)-CMA-ES                                        | 1     | 1     | 5.0        | <b>5.4</b> | 5.5              | 12               | <i>10e-2/1e4</i> | .          | .          | .          | (1+1)-CMA-ES [7]                                    |
| (1+2ms)-CMA-ES                                      | 1     | 1     | 4.7        | <b>1.3</b> | 9.3              | <i>12e-2/1e4</i> | .                | .          | .          | .          | (1+2ms)-CMA-ES [2]                                  |
| Artif Bee Colony                                    | 1     | 1     | <b>2.2</b> | 19         | <i>37e-2/1e5</i> | .                | .                | .          | .          | .          | Artif Bee Colony [8]                                |
| avg NEWUOA                                          | 1     | 1     | 6.0        | <b>2.5</b> | 14               | <i>15e-2/9e3</i> | .                | .          | .          | .          | avg NEWUOA [23]                                     |
| CMA-EGS (IPOP,r1)                                   | 1     | 8.1   | 15         | 33         | <i>55e-2/1e5</i> | .                | .                | .          | .          | .          | CMA-EGS (IPOP,r1) [12]                              |
| Adap DE (F-AUC)                                     | 1     | 1     | <b>2.4</b> | 9.3        | <b>2.3</b>       | <b>2.5</b>       | <b>3.4</b>       | <b>4.4</b> | <b>5.3</b> | <b>6.9</b> | Adap DE (F-AUC) [10]                                |
| DE (Uniform)                                        | 1     | 1     | <b>2.0</b> | 11         | <b>2.5</b>       | <b>2.7</b>       | <b>3.6</b>       | <b>4.6</b> | <b>5.5</b> | <b>7.2</b> | DE (Uniform) [9]                                    |
| IPOP-aCMA-ES                                        | 1     | 1     | <b>1.6</b> | 20         | 76               | 39               | 34               | 33         | 33         | 32         | IPOP-aCMA-ES [16]                                   |
| IPOP-CMA-ES                                         | 1     | 1     | <b>2.2</b> | 26         | 33               | 17               | 15               | 15         | 14         | 14         | IPOP-CMA-ES [22]                                    |
| CMA+DE-MOS                                          | 1     | 1     | <b>2.2</b> | 16         | <b>4.1</b>       | <b>3.5</b>       | <b>3.8</b>       | <b>3.7</b> | <b>4.0</b> | <b>3.9</b> | CMA+DE-MOS [18]                                     |
| NBC-CMA                                             | 1     | 1     | <b>1.4</b> | 42         | 299              | 153              | 135              | 132        | 129        | 124        | NBC-CMA [21]                                        |
| POEMS                                               | 1     | 1     | 12         | 21         | 41               | 63               | 57               | 56         | 55         | 54         | POEMS [17]                                          |
| PM-AdapSS-DE                                        | 1     | 1     | <b>1.8</b> | 8.9        | 12               | 15               | 14               | 15         | 21         | 27         | PM-AdapSS-DE [9, 10]                                |
| pPOEMS                                              | 1     | 1     | 3.4        | 71         | 29               | 43               | 42               | 44         | 47         | 53         | pPOEMS [17, 20]                                     |
| Basic RCGA                                          | 1     | 1     | <b>2.2</b> | 37         | 119              | <i>53e-2/5e4</i> | .                | .          | .          | .          | Basic RCGA [24]                                     |
| SPSA                                                | 1     | 105   | 309        | 1779       | <i>11e-1/1e5</i> | .                | .                | .          | .          | .          | SPSA [13]                                           |





Table 73: Running time excess  $ERT/ERT_{best}$  2009 on  $f_1$  in **10-D**, in *italics* is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | <b>1 Sphere</b> |            |            |            |            |            |            |            |            |            |                                       |
|---------------------------------------|-----------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03           | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>        | 23         | 13         | 21         | 31         | 40         | 48         | 58         | 67         | 85         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>        | 13         | 6.5        | 12         | 17         | 23         | 28         | 34         | 40         | 52         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>        | 8.3        | 5.9        | 11         | 15         | 20         | 25         | 31         | 36         | 45         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>        | 20         | 10         | 19         | 28         | 35         | 45         | 53         | 62         | 81         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>        | 11         | 4.7        | 10         | 14         | 20         | 25         | 30         | 36         | 46         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>        | <b>2.7</b> | 4.1        | 8.2        | 13         | 17         | 21         | 26         | 30         | 39         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>        | 5.5        | <b>3.6</b> | <b>6.7</b> | <b>10</b>  | <b>13</b>  | <b>16</b>  | <b>20</b>  | <b>23</b>  | <b>29</b>  | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>        | 14         | 4.3        | 8.3        | 13         | 16         | 21         | 25         | 29         | 38         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>        | 11         | 4.1        | 8.1        | 12         | 15         | 19         | 23         | 27         | 34         | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>        | 9.3        | <b>3.7</b> | <b>6.8</b> | <b>10</b>  | <b>13</b>  | <b>17</b>  | <b>20</b>  | <b>24</b>  | <b>31</b>  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>        | 4.9        | 24         | 55         | 86         | 114        | 165        | 203        | 238        | 306        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>        | 27         | <b>1.7</b> | <b>1.7</b> | <b>1.7</b> | <b>1.7</b> | <b>1.7</b> | <b>1.7</b> | <b>1.7</b> | <b>1.7</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 7.7             | 85         | 11         | 19         | 26         | 34         | 42         | 49         | 57         | 72         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>        | 4.5        | 37         | 91         | 137        | 189        | 239        | 290        | 343        | 443        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>        | 4.9        | 48         | 121        | 198        | 269        | 344        | 423        | 496        | 649        | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>        | 9.2        | 6.2        | 13         | 19         | 26         | 32         | 39         | 44         | 58         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>        | 7.7        | 5.0        | 11         | 18         | 24         | 30         | 37         | 43         | 56         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>        | 5.9        | 19         | 57         | 71         | 94         | 124        | 140        | 166        | 214        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>        | 5.8        | 16         | 25         | 34         | 45         | 54         | 63         | 73         | 93         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>        | 1684       | 130        | 244        | 608        | 1045       | 1469       | 1958       | 2403       | 3321       | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>        | <b>4.3</b> | 41         | 95         | 158        | 218        | 275        | 338        | 399        | 518        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>        | 527        | 125        | 252        | 1035       | 3154       | 5744       | 8009       | 10514      | 16455      | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>        | <b>4.0</b> | 33         | 105        | 207        | 345        | 1034       | 1984       | 2693       | 3761       | Basic RCGA [24]                       |
| SPSA                                  | 8.4             | 104        | 7.7        | 11         | 13         | 16         | 19         | 22         | 25         | 31         | SPSA [13]                             |



























Table 86: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{14}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>14 Sum of different powers</b> |          |            |            |            |            |            |            |                  |                  |                  |                        |
|-----------------------------------|----------|------------|------------|------------|------------|------------|------------|------------------|------------------|------------------|------------------------|
| $\Delta f_{target}$               | 1e+03    | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05            | 1e-07            | $\Delta f_{target}$    |
| $ERT_{best}/D$                    | 0.10     | 0.10       | 3.7        | 10         | 13         | 20         | 39         | 50               | 69               | 430              | $ERT_{best}/D$         |
| (1,2)-CMA-ES                      | <b>1</b> | 3.8        | 9.1        | 6.7        | 6.9        | 7.6        | 7.9        | 10               | 12               | 4.3              | (1,2)-CMA-ES [5, 3]    |
| (1,2m)-CMA-ES                     | <b>1</b> | 4.0        | 4.2        | 3.7        | 3.9        | 4.2        | 4.4        | 6.3              | 7.7              | <b>2.5</b>       | (1,2m)-CMA-ES [5]      |
| (1,2ms)-CMA-ES                    | <b>1</b> | <b>2.9</b> | 3.4        | <b>2.8</b> | 3.0        | 3.3        | 3.6        | 5.3              | 6.7              | <b>2.1</b>       | (1,2ms)-CMA-ES [5]     |
| (1,2s)-CMA-ES                     | <b>1</b> | 23         | 10         | 6.6        | 7.1        | 7.7        | 7.6        | 11               | 13               | 4.0              | (1,2s)-CMA-ES [3]      |
| (1,4)-CMA-ES                      | <b>1</b> | 7.5        | <b>2.8</b> | <b>2.8</b> | 3.2        | 3.7        | 3.6        | 5.3              | 6.1              | <b>1.8</b>       | (1,4)-CMA-ES [6, 4]    |
| (1,4m)-CMA-ES                     | <b>1</b> | 3.3        | <b>2.3</b> | <b>2.4</b> | <b>2.7</b> | <b>3.0</b> | 3.1        | 4.4              | 5.5              | <b>1.6</b>       | (1,4m)-CMA-ES [6]      |
| (1,4ms)-CMA-ES                    | <b>1</b> | <b>1.9</b> | <b>2.1</b> | <b>1.9</b> | <b>2.2</b> | <b>2.5</b> | <b>2.6</b> | <b>3.6</b>       | <b>4.4</b>       | <b>1.3</b>       | (1,4ms)-CMA-ES [1, 6]  |
| (1,4s)-CMA-ES                     | <b>1</b> | 7.3        | <b>2.8</b> | <b>2.5</b> | <b>2.9</b> | 3.1        | 3.1        | 4.1              | 4.8              | <b>1.4</b>       | (1,4s)-CMA-ES [4]      |
| (1+1)-CMA-ES                      | <b>1</b> | 3.4        | <b>2.0</b> | <b>1.9</b> | <b>2.3</b> | <b>2.4</b> | <b>2.4</b> | 3.8              | 4.9              | <b>1.1</b>       | (1+1)-CMA-ES [7]       |
| (1+2ms)-CMA-ES                    | <b>1</b> | 3.1        | <b>1.8</b> | <b>1.6</b> | <b>2.0</b> | <b>2.1</b> | <b>2.1</b> | <b>3.0</b>       | <b>3.7</b>       | <b>1.0</b>       | (1+2ms)-CMA-ES [2]     |
| Artif Bee Colony                  | <b>1</b> | <b>1.9</b> | 6.4        | 17         | 22         | 35         | 703        | <i>64e-5/1e5</i> | .                | .                | Artif Bee Colony [8]   |
| avg NEWUOA                        | <b>1</b> | 9.2        | <b>1.7</b> | <b>1.3</b> | <b>1.3</b> | <b>1.2</b> | <b>1.1</b> | <b>2.2</b>       | 7.1              | 64               | avg NEWUOA [23]        |
| CMA-EGS (IPOP,r1)                 | 8.9      | 71         | 9.2        | 5.7        | 6.1        | 6.2        | 8.4        | 19               | 26               | 64               | CMA-EGS (IPOP,r1) [12] |
| Adap DE (F-AUC)                   | <b>1</b> | <b>2.1</b> | 10         | 18         | 26         | 24         | 16         | 15               | 13               | <b>2.8</b>       | Adap DE (F-AUC) [10]   |
| DE (Uniform)                      | <b>1</b> | <b>2.0</b> | 9.5        | 25         | 34         | 33         | 22         | 22               | 19               | 4.1              | DE (Uniform) [9]       |
| IPOP-aCMA-ES                      | <b>1</b> | 3.7        | <b>2.1</b> | <b>2.8</b> | 3.7        | 3.8        | 3.1        | 3.6              | <b>3.5</b>       | <b>0.84</b>      | IPOP-aCMA-ES [16]      |
| IPOP-CMA-ES                       | <b>1</b> | 5.4        | <b>2.2</b> | <b>2.9</b> | 3.8        | 4.2        | 3.8        | 4.8              | 5.0              | <b>1.3</b>       | IPOP-CMA-ES [22]       |
| CMA+DE-MOS                        | <b>1</b> | 3.0        | 7.5        | 13         | 14         | 14         | 13         | 15               | 14               | 3.2              | CMA+DE-MOS [18]        |
| NBC-CMA                           | <b>1</b> | <b>2.3</b> | 5.2        | 5.7        | 6.5        | 6.3        | 5.1        | 6.6              | 7.1              | <b>1.9</b>       | NBC-CMA [21]           |
| POEMS                             | <b>1</b> | 847        | 73         | 53         | 105        | 142        | 116        | 186              | 1491             | <i>33e-7/3e5</i> | POEMS [17]             |
| PM-AdapSS-DE                      | <b>1</b> | <b>1.9</b> | 13         | 21         | 29         | 27         | 19         | 18               | 15               | 3.2              | PM-AdapSS-DE [9, 10]   |
| pPOEMS                            | <b>1</b> | 103        | 73         | 61         | 193        | 496        | 570        | 818              | 987              | <i>61e-8/3e5</i> | pPOEMS [17, 20]        |
| Basic RCGA                        | <b>1</b> | <b>2.1</b> | 5.5        | 30         | 44         | 91         | 1052       | 13979            | <i>76e-5/5e4</i> | .                | Basic RCGA [24]        |
| SPSA                              | 21       | 348        | 97         | 74         | 61         | 49         | 53         | 293              | 1046             | <i>43e-7/1e5</i> | SPSA [13]              |





Table 88: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{16}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>16 Weierstrass</b>                 |          |            |            |                  |                  |                  |                  |             |                  |             |                                       |
|---------------------------------------|----------|------------|------------|------------------|------------------|------------------|------------------|-------------|------------------|-------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02      | 1e+01      | 1e+00            | 1e-01            | 1e-02            | 1e-03            | 1e-04       | 1e-05            | 1e-07       | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | <b>1.7</b> | 553        | <i>11e+0/1e4</i> | .                | .                | .                | .           | .                | .           | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | <b>1.4</b> | 26         | 96               | <i>25e-1/1e4</i> | .                | .                | .           | .                | .           | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | <b>1.3</b> | 32         | 96               | <i>32e-1/1e4</i> | .                | .                | .           | .                | .           | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | <b>1.3</b> | 779        | <i>15e+0/1e4</i> | .                | .                | .                | .           | .                | .           | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | <b>1.5</b> | 22         | 45               | <i>20e-1/1e4</i> | .                | .                | .           | .                | .           | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | <b>1.4</b> | 11         | 14               | 91               | <i>64e-2/1e4</i> | .                | .           | .                | .           | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | <b>1.4</b> | 12         | 24               | <i>13e-1/1e4</i> | .                | .                | .           | .                | .           | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | <b>1.5</b> | 27         | 97               | <i>28e-1/1e4</i> | .                | .                | .           | .                | .           | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | <b>1.7</b> | 5.2        | 46               | <i>16e-1/1e4</i> | .                | .                | .           | .                | .           | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>1.2</b> | 4.2        | 97               | <i>13e-1/1e4</i> | .                | .                | .           | .                | .           | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | <b>1.3</b> | 3.3        | 149              | <i>92e-2/1e5</i> | .                | .                | .           | .                | .           | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | <b>1.5</b> | <b>3.3</b> | 41               | <i>13e-1/1e4</i> | .                | .                | .           | .                | .           | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b> | 53         | 14         | 20               | 89               | 308              | <i>10e-2/1e5</i> | .           | .                | .           | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | <b>1.7</b> | 70         | <i>51e-1/1e5</i> | .                | .                | .                | .           | .                | .           | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | <b>1.7</b> | 104        | <i>45e-1/1e5</i> | .                | .                | .                | .           | .                | .           | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>1.3</b> | <b>1.6</b> | <b>0.95</b>      | <b>1.2</b>       | <b>0.84</b>      | <b>1.1</b>       | <b>0.91</b> | <b>0.92</b>      | <b>0.87</b> | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>1.3</b> | 3.5        | <b>1.2</b>       | <b>1.2</b>       | <b>0.87</b>      | <b>0.90</b>      | <b>0.72</b> | <b>0.75</b>      | <b>0.71</b> | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | <b>1.3</b> | <b>2.6</b> | <b>0.55</b>      | <b>0.99</b>      | <b>1.2</b>       | <b>1.4</b>       | <b>1.1</b>  | <b>1.2</b>       | <b>1.2</b>  | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | <b>1.5</b> | 9.4        | <b>0.71</b>      | <b>1.3</b>       | <b>1.8</b>       | <b>2.9</b>       | 3.5         | 11               | 19          | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | <b>1</b>   | 11         | 3.8              | 130              | 428              | 382              | 301         | 298              | 274         | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | <b>1.5</b> | 70         | <i>34e-1/1e5</i> | .                | .                | .                | .           | .                | .           | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | <b>1.3</b> | 16         | 18               | 89               | 189              | 243              | 192         | 192              | 178         | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | <b>1.3</b> | 7.9        | 13               | 38               | 50               | 142              | 112         | <i>87e-3/5e4</i> | .           | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b> | 1551       | 1239       | 2107             | <i>56e-1/1e5</i> | .                | .                | .           | .                | .           | SPSA [13]                             |

Table 89: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{17}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 17 Schaffer F7, condition 10 |            |            |            |                  |                  |                  |             |             |                  |                                       |
|---------------------------------------|------------------------------|------------|------------|------------|------------------|------------------|------------------|-------------|-------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                        | 1e+02      | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03            | 1e-04       | 1e-05       | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>                     | <b>2.5</b> | 119        | 3362       | <i>25e-1/1e4</i> | .                | .                | .           | .           | .                | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                     | <b>2.7</b> | 5.5        | 55         | 196              | 229              | <i>18e-2/1e4</i> | .           | .           | .                | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                     | <b>1.1</b> | 31         | 52         | 327              | <i>34e-2/1e4</i> | .                | .           | .           | .                | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                     | <b>1.2</b> | 204        | 3343       | <i>24e-1/1e4</i> | .                | .                | .           | .           | .                | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                     | <b>1</b>   | 9.3        | 82         | <i>38e-2/1e4</i> | .                | .                | .           | .           | .                | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                     | <b>1</b>   | 3.1        | 22         | 324              | <i>24e-2/1e4</i> | .                | .           | .           | .                | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                     | <b>1.1</b> | <b>2.6</b> | 51         | 214              | <i>15e-2/1e4</i> | .                | .           | .           | .                | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                     | <b>1.7</b> | 3.4        | 121        | <i>69e-2/1e4</i> | .                | .                | .           | .           | .                | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                     | <b>1.3</b> | 17         | 443        | <i>13e-1/1e4</i> | .                | .                | .           | .           | .                | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                     | <b>1</b>   | 6.2        | 717        | <i>13e-1/1e4</i> | .                | .                | .           | .           | .                | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>                     | <b>1.2</b> | 11         | 954        | <i>65e-2/1e5</i> | .                | .                | .           | .           | .                | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                     | <b>1.1</b> | <b>2.2</b> | 987        | <i>10e-1/3e4</i> | .                | .                | .           | .           | .                | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 24                           | 59         | 6.2        | <b>1.4</b> | <b>0.77</b>      | <b>0.74</b>      | <b>2.0</b>       | 4.4         | 70          | 530              | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                     | <b>1.1</b> | 7.4        | 8.0        | 3.2              | <b>1.8</b>       | <b>1.6</b>       | <b>1.4</b>  | <b>1.5</b>  | <b>1.5</b>       | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                     | <b>1.1</b> | 5.4        | 11         | 4.6              | <b>2.7</b>       | <b>2.4</b>       | <b>2.1</b>  | <b>2.0</b>  | <b>2.0</b>       | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                     | <b>1.1</b> | <b>2.4</b> | <b>1.2</b> | <b>1.8</b>       | <b>1.2</b>       | <b>1.3</b>       | <b>1.0</b>  | <b>1.0</b>  | <b>1.0</b>       | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                     | <b>1.6</b> | <b>2.7</b> | <b>2.6</b> | <b>1.5</b>       | <b>0.83</b>      | <b>1.0</b>       | <b>0.90</b> | <b>0.88</b> | <b>1.0</b>       | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                     | <b>1.4</b> | 3.3        | 30         | 10               | 4.1              | 3.3              | 4.8         | 3.8         | 3.3              | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>                     | <b>1.1</b> | <b>2.9</b> | <b>1.8</b> | <b>0.72</b>      | <b>0.87</b>      | <b>1.6</b>       | 7.7         | 31          | <i>16e-6/3e4</i> | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                     | 274        | 86         | 24         | 111              | 42               | 84               | 104         | 178         | 1591             | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                     | <b>1.2</b> | 4.6        | 8.5        | 3.6              | <b>2.0</b>       | <b>1.8</b>       | <b>1.5</b>  | <b>1.5</b>  | <b>1.5</b>       | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                     | <b>1.2</b> | 91         | 32         | 72               | 54               | 52               | 45          | 44          | 146              | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                     | <b>1.1</b> | 5.8        | 16         | 48               | 36               | 40               | 50          | 111         | <i>16e-5/5e4</i> | Basic RCGA [24]                       |
| SPSA                                  | 6.67e5                       | 8.76e5     | 34195      | 32685      | <i>86e-1/1e5</i> | .                | .                | .           | .           | .                | SPSA [13]                             |



Table 91: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{19}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| $\Delta$ ftarget<br>$ERT_{best}/D$ | <b>19 Griewank-Rosenbrock F8F2</b> |               |               |               |                  |                  |                 |                 |                 |                 | $\Delta$ ftarget<br>$ERT_{best}/D$ |
|------------------------------------|------------------------------------|---------------|---------------|---------------|------------------|------------------|-----------------|-----------------|-----------------|-----------------|------------------------------------|
|                                    | 1e+03<br>0.10                      | 1e+02<br>0.10 | 1e+01<br>0.10 | 1e+00<br>0.10 | 1e-01<br>1061    | 1e-02<br>98379   | 1e-03<br>1.37e5 | 1e-04<br>1.37e5 | 1e-05<br>1.38e5 | 1e-07<br>1.39e5 |                                    |
| (1,2)-CMA-ES                       | <b>1</b>                           | <b>1</b>      | 514           | 7.33e5        | <i>24e-1/1e4</i> | .                | .               | .               | .               | .               | (1,2)-CMA-ES [5, 3]                |
| (1,2m)-CMA-ES                      | <b>1</b>                           | <b>1</b>      | 128           | 1.55e5        | <i>90e-2/1e4</i> | .                | .               | .               | .               | .               | (1,2m)-CMA-ES [5]                  |
| (1,2ms)-CMA-ES                     | <b>1</b>                           | <b>1</b>      | 164           | 2.24e5        | <i>11e-1/1e4</i> | .                | .               | .               | .               | .               | (1,2ms)-CMA-ES [5]                 |
| (1,2s)-CMA-ES                      | <b>1</b>                           | <b>1</b>      | 239           | 1.46e6        | <i>32e-1/1e4</i> | .                | .               | .               | .               | .               | (1,2s)-CMA-ES [3]                  |
| (1,4)-CMA-ES                       | <b>1</b>                           | <b>1</b>      | 82            | 1.99e5        | <i>13e-1/1e4</i> | .                | .               | .               | .               | .               | (1,4)-CMA-ES [6, 4]                |
| (1,4m)-CMA-ES                      | <b>1</b>                           | <b>1</b>      | 68            | 45284         | <i>58e-2/1e4</i> | .                | .               | .               | .               | .               | (1,4m)-CMA-ES [6]                  |
| (1,4ms)-CMA-ES                     | <b>1</b>                           | <b>1</b>      | 57            | 43406         | <i>68e-2/1e4</i> | .                | .               | .               | .               | .               | (1,4ms)-CMA-ES [1, 6]              |
| (1,4s)-CMA-ES                      | <b>1</b>                           | <b>1</b>      | 79            | 75584         | <i>77e-2/1e4</i> | .                | .               | .               | .               | .               | (1,4s)-CMA-ES [4]                  |
| (1+1)-CMA-ES                       | <b>1</b>                           | <b>1</b>      | 63            | 65610         | <i>85e-2/1e4</i> | .                | .               | .               | .               | .               | (1+1)-CMA-ES [7]                   |
| (1+2ms)-CMA-ES                     | <b>1</b>                           | <b>1</b>      | <b>54</b>     | 22281         | <i>55e-2/1e4</i> | .                | .               | .               | .               | .               | (1+2ms)-CMA-ES [2]                 |
| Artif Bee Colony                   | <b>1</b>                           | <b>1.1</b>    | 410           | 4.22e6        | <i>12e-1/1e5</i> | .                | .               | .               | .               | .               | Artif Bee Colony [8]               |
| avg NEWUOA                         | <b>1</b>                           | <b>1</b>      | <b>48</b>     | 7.08e5        | <i>83e-2/1e5</i> | .                | .               | .               | .               | .               | avg NEWUOA [23]                    |
| CMA-EGS (IPOP,r1)                  | 23                                 | 64            | 223           | 28056         | 422              | <i>20e-2/1e5</i> | .               | .               | .               | .               | CMA-EGS (IPOP,r1) [12]             |
| Adap DE (F-AUC)                    | <b>1</b>                           | <b>1.2</b>    | 303           | 4.04e5        | <i>59e-2/1e5</i> | .                | .               | .               | .               | .               | Adap DE (F-AUC) [10]               |
| DE (Uniform)                       | <b>1</b>                           | <b>1.2</b>    | 390           | 8.37e5        | <i>52e-2/1e5</i> | .                | .               | .               | .               | .               | DE (Uniform) [9]                   |
| IPOP-aCMA-ES                       | <b>1</b>                           | <b>1</b>      | 68            | <b>9042</b>   | <b>10</b>        | <b>0.61</b>      | <b>0.53</b>     | <b>0.53</b>     | <b>0.53</b>     | <b>0.54</b>     | IPOP-aCMA-ES [16]                  |
| IPOP-CMA-ES                        | <b>1</b>                           | <b>1</b>      | <b>56</b>     | <b>12509</b>  | <b>8.9</b>       | <b>0.55</b>      | <b>0.53</b>     | <b>0.53</b>     | <b>0.53</b>     | <b>0.53</b>     | IPOP-CMA-ES [22]                   |
| CMA+DE-MOS                         | <b>1</b>                           | <b>1.1</b>    | 212           | <b>5852</b>   | <b>6.5</b>       | <b>1.2</b>       | <b>1.1</b>      | <b>1.1</b>      | <b>1.1</b>      | <b>1.1</b>      | CMA+DE-MOS [18]                    |
| NBC-CMA                            | <b>1</b>                           | <b>1.2</b>    | 117           | 2.11e6        | <i>15e-1/3e4</i> | .                | .               | .               | .               | .               | NBC-CMA [21]                       |
| POEMS                              | <b>1</b>                           | 253           | 2538          | 5.19e5        | 4011             | <i>55e-2/3e5</i> | .               | .               | .               | .               | POEMS [17]                         |
| PM-AdapSS-DE                       | <b>1</b>                           | <b>1.7</b>    | 256           | 5.48e5        | <i>81e-2/1e5</i> | .                | .               | .               | .               | .               | PM-AdapSS-DE [9, 10]               |
| pPOEMS                             | <b>1</b>                           | <b>1.2</b>    | 2624          | 3.58e5        | 4022             | <i>23e-2/3e5</i> | .               | .               | .               | .               | pPOEMS [17, 20]                    |
| Basic RCGA                         | <b>1</b>                           | <b>1.2</b>    | 167           | 70727         | 157              | <i>17e-2/5e4</i> | .               | .               | .               | .               | Basic RCGA [24]                    |
| SPSA                               | 44                                 | 126           | 658           | 6.65e6        | <i>18e-1/1e5</i> | .                | .               | .               | .               | .               | SPSA [13]                          |



Table 93: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{21}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>21 Gallagher 101 peaks</b>         |          |          |            |            |            |            |            |            |            |            |                                       |
|---------------------------------------|----------|----------|------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02    | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | <b>1</b> | 18         | 14         | 22         | 21         | 21         | 20         | 19         | 8.4        | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | <b>1</b> | 8.4        | 11         | 14         | 14         | 13         | 13         | 12         | 5.5        | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | 4.3        | <b>5.4</b> | 7.3        | 7.1        | 7.0        | 6.6        | 6.4        | <b>2.9</b> | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | <b>1</b> | 39         | 20         | 18         | 18         | 17         | 17         | 16         | 7.2        | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | <b>1</b> | 6.2        | 6.4        | 11         | 11         | 10         | 10         | 10         | 4.3        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | <b>1</b> | 4.2        | 6.7        | <b>4.7</b> | <b>4.6</b> | <b>4.5</b> | <b>4.3</b> | <b>4.1</b> | <b>1.9</b> | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | <b>1</b> | 4.8        | <b>4.3</b> | <b>3.6</b> | <b>3.5</b> | <b>3.4</b> | <b>3.3</b> | <b>3.1</b> | <b>1.4</b> | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | <b>1</b> | 7.0        | 6.4        | 6.9        | 6.8        | 6.6        | 6.3        | 6.0        | <b>2.7</b> | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | <b>1</b> | 4.2        | 6.3        | <b>4.4</b> | <b>4.3</b> | <b>4.2</b> | <b>4.0</b> | <b>3.8</b> | <b>1.7</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>4.1</b> | 6.5        | 6.0        | 5.8        | 5.7        | 5.4        | 5.2        | <b>2.3</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | <b>1</b> | 8.0        | <b>2.9</b> | 8.5        | 10         | 12         | 24         | 39         | 82         | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | <b>1</b> | <b>3.2</b> | 8.2        | 4.7        | 4.7        | 4.5        | 4.3        | 4.1        | <b>1.9</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b> | 62       | 13         | 101        | 60         | 59         | 58         | 56         | 55         | 25         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | <b>1</b> | 23         | 114        | 84         | 83         | 81         | 77         | 74         | 33         | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | <b>1</b> | 25         | 115        | 116        | 113        | 110        | 105        | 101        | 45         | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>1</b> | <b>2.6</b> | 31         | 58         | 57         | 55         | 53         | 50         | 23         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>1</b> | 5.9        | 14         | 52         | 51         | 50         | 47         | 45         | 21         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | <b>1</b> | 25         | 347        | 512        | 503        | 489        | 466        | 447        | 201        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | <b>1</b> | 12         | 275        | 188        | 184        | 179        | 170        | 163        | 73         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | <b>1</b> | 3498       | 2668       | 1648       | 1615       | 1570       | 1494       | 1431       | 642        | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | <b>1</b> | 18         | 226        | 262        | 256        | 249        | 237        | 227        | 102        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | <b>1</b> | 38         | 746        | 980        | 1122       | 1317       | 1259       | 1211       | 547        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | <b>1</b> | 121        | 120        | 86         | 86         | 86         | 84         | 82         | 38         | Basic RCGA [24]                       |
| SPSA                                  | <b>1</b> | 102      | 94         | 1309       | 1543       | 1515       | 1488       | 2894       | 2780       | 1272       | SPSA [13]                             |

Table 94: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{22}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>22 Gallagher 21 peaks</b>          |          |          |            |            |                  |            |                  |            |            |            |                                       |
|---------------------------------------|----------|----------|------------|------------|------------------|------------|------------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03            | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | <b>1</b> | 19         | 9.2        | 30               | 29         | 28               | 28         | 23         | 19         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | <b>1</b> | 18         | 9.3        | 18               | 17         | 16               | 16         | 14         | 11         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | 20         | 11         | 25               | 24         | 24               | 23         | 19         | 16         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | <b>1</b> | 62         | 12         | 40               | 39         | 38               | 37         | 31         | 25         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | <b>1</b> | 15         | 7.0        | 10               | 9.3        | 9.1              | 9.0        | 7.5        | 6.1        | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | <b>1</b> | 12         | 6.6        | 12               | 11         | 11               | 11         | 8.9        | 7.2        | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>8.2</b> | <b>4.1</b> | 14               | 14         | 14               | 13         | 11         | 8.9        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | <b>1</b> | 16         | 8.4        | 13               | 13         | 12               | 12         | 10         | 8.2        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | <b>1</b> | <b>9.3</b> | 4.5        | <b>4.0</b>       | <b>3.8</b> | <b>3.8</b>       | <b>3.7</b> | <b>3.1</b> | <b>2.5</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>1</b> | 22         | 4.5        | <b>5.0</b>       | <b>4.8</b> | <b>4.7</b>       | <b>4.6</b> | <b>3.9</b> | <b>3.1</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | <b>1</b> | 17         | <b>4.3</b> | 34               | 364        | <i>13e-3/1e5</i> | .          | .          | .          | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | <b>1</b> | <b>3.6</b> | <b>2.6</b> | <b>2.1</b>       | <b>2.1</b> | <b>2.0</b>       | <b>2.0</b> | <b>1.7</b> | <b>1.4</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1</b> | 53       | 22         | 417        | 1024             | 982        | 957              | 939        | 784        | 628        | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | <b>1</b> | 32         | 706        | <i>20e-1/1e5</i> | .          | .                | .          | .          | .          | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | <b>1</b> | 31         | 405        | 2206             | 2117       | 2061             | 2024       | 1689       | 1354       | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>1</b> | 44         | 203        | 663              | 636        | 620              | 608        | 508        | 407        | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>1</b> | 42         | 90         | 666              | 640        | 623              | 612        | 510        | 409        | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | <b>1</b> | 171        | 538        | 1268             | 1218       | 1187             | 1166       | 974        | 781        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | <b>1</b> | 792        | 221        | <i>51e-1/3e4</i> | .          | .                | .          | .          | .          | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | <b>1</b> | 4774       | 4231       | 3072             | 2950       | 2873             | 2822       | 2356       | 1892       | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | <b>1</b> | 28         | 706        | <i>20e-1/1e5</i> | .          | .                | .          | .          | .          | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | <b>1</b> | 2258       | 363        | 424              | 412        | 404              | 401        | 338        | 276        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | <b>1</b> | 711        | 205        | 343              | 520        | <i>69e-2/5e4</i> | .          | .          | .          | Basic RCGA [24]                       |
| SPSA                                  | 3.3      | 69       | 2954       | 831        | <i>51e-1/1e5</i> | .          | .                | .          | .          | .          | SPSA [13]                             |

Table 95: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{23}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                   | <b>23 Katsuuras</b> |          |            |            |                  |                  |                  |                  |            |            |                        |  |
|-------------------|---------------------|----------|------------|------------|------------------|------------------|------------------|------------------|------------|------------|------------------------|--|
| $\Delta$ target   | 1e+03               | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02            | 1e-03            | 1e-04            | 1e-05      | 1e-07      | $\Delta$ target        |  |
| $ERT_{best}/D$    | 0.10                | 0.10     | 0.28       | 92         | 1643             | 18390            | 20350            | 20641            | 20893      | 21351      | $ERT_{best}/D$         |  |
| (1,2)-CMA-ES      | <b>1</b>            | <b>1</b> | 38         | 1557       | <i>14e-1/1e4</i> | .                | .                | .                | .          | .          | (1,2)-CMA-ES [5, 3]    |  |
| (1,2m)-CMA-ES     | <b>1</b>            | <b>1</b> | 4.7        | 68         | <i>35e-2/1e4</i> | .                | .                | .                | .          | .          | (1,2m)-CMA-ES [5]      |  |
| (1,2ms)-CMA-ES    | <b>1</b>            | <b>1</b> | 8.6        | 70         | <i>39e-2/1e4</i> | .                | .                | .                | .          | .          | (1,2ms)-CMA-ES [5]     |  |
| (1,2s)-CMA-ES     | <b>1</b>            | <b>1</b> | 44         | 797        | <i>14e-1/1e4</i> | .                | .                | .                | .          | .          | (1,2s)-CMA-ES [3]      |  |
| (1,4)-CMA-ES      | <b>1</b>            | <b>1</b> | 7.5        | 33         | <i>35e-2/1e4</i> | .                | .                | .                | .          | .          | (1,4)-CMA-ES [6, 4]    |  |
| (1,4m)-CMA-ES     | <b>1</b>            | <b>1</b> | 5.7        | 33         | <i>34e-2/1e4</i> | .                | .                | .                | .          | .          | (1,4m)-CMA-ES [6]      |  |
| (1,4ms)-CMA-ES    | <b>1</b>            | <b>1</b> | 5.0        | 15         | 91               | <i>23e-2/1e4</i> | .                | .                | .          | .          | (1,4ms)-CMA-ES [1, 6]  |  |
| (1,4s)-CMA-ES     | <b>1</b>            | <b>1</b> | 5.7        | 58         | <i>60e-2/1e4</i> | .                | .                | .                | .          | .          | (1,4s)-CMA-ES [4]      |  |
| (1+1)-CMA-ES      | <b>1</b>            | <b>1</b> | 6.5        | <b>4.5</b> | <i>28e-2/1e4</i> | .                | .                | .                | .          | .          | (1+1)-CMA-ES [7]       |  |
| (1+2ms)-CMA-ES    | <b>1</b>            | <b>1</b> | 5.1        | <b>4.5</b> | <i>26e-2/1e4</i> | .                | .                | .                | .          | .          | (1+2ms)-CMA-ES [2]     |  |
| Artif Bee Colony  | <b>1</b>            | <b>1</b> | <b>2.5</b> | 33         | <i>49e-2/1e5</i> | .                | .                | .                | .          | .          | Artif Bee Colony [8]   |  |
| avg NEWUOA        | <b>1</b>            | <b>1</b> | 11         | <b>2.6</b> | <i>21e-2/1e4</i> | .                | .                | .                | .          | .          | avg NEWUOA [23]        |  |
| CMA-EGS (IPOP,r1) | <b>1</b>            | 35       | 34         | 397        | <i>84e-2/1e5</i> | .                | .                | .                | .          | .          | CMA-EGS (IPOP,r1) [12] |  |
| Adap DE (F-AUC)   | <b>1</b>            | <b>1</b> | <b>2.3</b> | 85         | 160              | <i>15e-2/1e5</i> | .                | .                | .          | .          | Adap DE (F-AUC) [10]   |  |
| DE (Uniform)      | <b>1</b>            | <b>1</b> | <b>1.5</b> | 97         | 278              | <b>80</b>        | <b>72</b>        | <b>71</b>        | <b>70</b>  | <b>69</b>  | DE (Uniform) [9]       |  |
| IPOP-aCMA-ES      | <b>1</b>            | <b>1</b> | <b>1.8</b> | 458        | <i>71e-2/2e5</i> | .                | .                | .                | .          | .          | IPOP-aCMA-ES [16]      |  |
| IPOP-CMA-ES       | <b>1</b>            | <b>1</b> | <b>2.4</b> | 376        | 308              | <b>65</b>        | <b>59</b>        | <b>58</b>        | <b>57</b>  | <b>56</b>  | IPOP-CMA-ES [22]       |  |
| CMA+DE-MOS        | <b>1</b>            | <b>1</b> | <b>1.7</b> | 24         | <b>15</b>        | <b>4.0</b>       | <b>3.6</b>       | <b>3.6</b>       | <b>3.6</b> | <b>3.5</b> | CMA+DE-MOS [18]        |  |
| NBC-CMA           | <b>1</b>            | <b>1</b> | <b>1.4</b> | 692        | <i>11e-1/3e4</i> | .                | .                | .                | .          | .          | NBC-CMA [21]           |  |
| POEMS             | <b>1</b>            | <b>1</b> | 9.1        | 26         | <b>50</b>        | 107              | <i>36e-3/3e5</i> | .                | .          | .          | POEMS [17]             |  |
| PM-AdapSS-DE      | <b>1</b>            | <b>1</b> | <b>1.6</b> | 81         | <i>28e-2/1e5</i> | .                | .                | .                | .          | .          | PM-AdapSS-DE [9, 10]   |  |
| pPOEMS            | <b>1</b>            | <b>1</b> | 5.7        | 161        | <b>77</b>        | 111              | 211              | <i>25e-3/3e5</i> | .          | .          | pPOEMS [17, 20]        |  |
| Basic RCGA        | <b>1</b>            | <b>1</b> | <b>2.5</b> | 162        | 436              | <i>44e-2/5e4</i> | .                | .                | .          | .          | Basic RCGA [24]        |  |
| SPSA              | <b>1</b>            | 173      | 1046       | 3799       | <i>11e-1/1e5</i> | .                | .                | .                | .          | .          | SPSA [13]              |  |



Table 96: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{24}$  in **10-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>24 Lunacek bi-Rastrigin</b> |          |                  |                  |                  |                  |             |             |             |             |                  |                     |          |
|--------------------------------|----------|------------------|------------------|------------------|------------------|-------------|-------------|-------------|-------------|------------------|---------------------|----------|
| $\Delta f_{target}$            | 1e+03    | 1e+02            | 1e+01            | 1e+00            | 1e-01            | 1e-02       | 1e-03       | 1e-04       | 1e-05       | 1e-07            | $\Delta f_{target}$ |          |
| $ERT_{best}/D$                 |          |                  |                  |                  |                  |             |             |             |             |                  | $ERT_{best}/D$      |          |
| (1,2)-CMA-ES                   | <b>1</b> | 54               | <i>50e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1,2)-CMA-ES        | [5, 3]   |
| (1,2m)-CMA-ES                  | <b>1</b> | 4.7              | <i>23e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1,2m)-CMA-ES       | [5]      |
| (1,2ms)-CMA-ES                 | <b>1</b> | 5.9              | <i>22e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1,2ms)-CMA-ES      | [5]      |
| (1,2s)-CMA-ES                  | <b>1</b> | 71               | <i>53e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1,2s)-CMA-ES       | [3]      |
| (1,4)-CMA-ES                   | <b>1</b> | 4.9              | 15               | <i>25e+0/1e4</i> | .                | .           | .           | .           | .           | .                | (1,4)-CMA-ES        | [6, 4]   |
| (1,4m)-CMA-ES                  | <b>1</b> | 3.6              | <b>4.8</b>       | <i>12e+0/1e4</i> | .                | .           | .           | .           | .           | .                | (1,4m)-CMA-ES       | [6]      |
| (1,4ms)-CMA-ES                 | <b>1</b> | <b>2.7</b>       | <i>17e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1,4ms)-CMA-ES      | [1, 6]   |
| (1,4s)-CMA-ES                  | <b>1</b> | 4.8              | <i>23e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1,4s)-CMA-ES       | [4]      |
| (1+1)-CMA-ES                   | <b>1</b> | 8.9              | <i>24e+0/1e4</i> | .                | .                | .           | .           | .           | .           | .                | (1+1)-CMA-ES        | [7]      |
| (1+2ms)-CMA-ES                 | <b>1</b> | 4.2              | <b>4.8</b>       | <i>18e+0/1e4</i> | .                | .           | .           | .           | .           | .                | (1+2ms)-CMA-ES      | [2]      |
| Artif Bee Colony               | <b>1</b> | 24               | <i>24e+0/1e5</i> | .                | .                | .           | .           | .           | .           | .                | Artif Bee Colony    | [8]      |
| avg NEWUOA                     | <b>1</b> | <b>1.4</b>       | <i>21e+0/8e3</i> | .                | .                | .           | .           | .           | .           | .                | avg NEWUOA          | [23]     |
| CMA-EGS (IPOP,r1)              | 78       | 4.8              | <b>3.6</b>       | <i>41e-1/1e5</i> | .                | .           | .           | .           | .           | .                | CMA-EGS (IPOP,r1)   | [12]     |
| Adap DE (F-AUC)                | <b>1</b> | 16               | 47               | <i>14e+0/1e5</i> | .                | .           | .           | .           | .           | .                | Adap DE (F-AUC)     | [10]     |
| DE (Uniform)                   | <b>1</b> | 20               | 47               | <i>16e+0/1e5</i> | .                | .           | .           | .           | .           | .                | DE (Uniform)        | [9]      |
| IPOP-aCMA-ES                   | <b>1</b> | <b>2.1</b>       | 50               | <b>33</b>        | <i>10e+0/2e5</i> | .           | .           | .           | .           | .                | IPOP-aCMA-ES        | [16]     |
| IPOP-CMA-ES                    | <b>1</b> | <b>2.0</b>       | 24               | <b>6.9</b>       | <b>0.48</b>      | <b>0.48</b> | <b>0.48</b> | <b>0.48</b> | <b>0.48</b> | <i>81e-1/2e5</i> | IPOP-CMA-ES         | [22]     |
| CMA+DE-MOS                     | <b>1</b> | 11               | 5.8              | <b>2.9</b>       | <b>0.26</b>      | <b>0.26</b> | <b>0.26</b> | <b>0.26</b> | <b>0.26</b> | <b>0.26</b>      | CMA+DE-MOS          | [18]     |
| NBC-CMA                        | <b>1</b> | 4.9              | <i>32e+0/3e4</i> | .                | .                | .           | .           | .           | .           | .                | NBC-CMA             | [21]     |
| POEMS                          | <b>1</b> | 49               | 122              | <i>16e+0/3e5</i> | .                | .           | .           | .           | .           | .                | POEMS               | [17]     |
| PM-AdapSS-DE                   | <b>1</b> | 16               | 69               | <i>12e+0/1e5</i> | .                | .           | .           | .           | .           | .                | PM-AdapSS-DE        | [9, 10]  |
| pPOEMS                         | <b>1</b> | 47               | 24               | <i>89e-1/3e5</i> | .                | .           | .           | .           | .           | .                | pPOEMS              | [17, 20] |
| Basic RCGA                     | <b>1</b> | 7.3              | 37               | <i>12e+0/5e4</i> | .                | .           | .           | .           | .           | .                | Basic RCGA          | [24]     |
| SPSA                           | 118      | <i>32e+1/1e5</i> | .                | .                | .                | .           | .           | .           | .           | .                | SPSA                | [13]     |

Table 97: Running time excess  $ERT/ERT_{best}$  2009 on  $f_1$  in **20-D**, in *italics* is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 1 Sphere |            |            |            |            |            |            |            |            |            |                                       |
|---------------------------------------|----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b> | 63         | 15         | 25         | 34         | 44         | 53         | 63         | 72         | 93         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b> | 26         | 8.9        | 15         | 20         | 25         | 30         | 35         | 41         | 52         | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b> | 25         | 8.1        | 13         | 18         | 22         | 27         | 32         | 36         | 47         | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b> | 63         | 17         | 26         | 35         | 44         | 53         | 62         | 72         | 89         | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b> | 18         | 7.7        | 13         | 18         | 23         | 27         | 33         | 38         | 49         | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b> | 15         | 6.2        | 11         | 15         | 19         | 24         | 28         | 32         | 42         | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b> | 14         | <b>4.7</b> | <b>8.1</b> | <b>11</b>  | <b>14</b>  | <b>18</b>  | <b>21</b>  | <b>24</b>  | <b>31</b>  | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b> | 17         | 6.3        | 11         | 15         | 19         | 23         | 26         | 31         | 40         | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b> | 11         | 5.5        | 10         | 14         | 18         | 21         | 25         | 29         | 37         | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b> | <b>10</b>  | <b>4.9</b> | <b>8.5</b> | <b>12</b>  | <b>15</b>  | <b>19</b>  | <b>23</b>  | <b>26</b>  | <b>33</b>  | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b> | 50         | 36         | 66         | 94         | 136        | 177        | 244        | 292        | 374        | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b> | 18         | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | <b>2.3</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 47       | 41         | 13         | 19         | 26         | 33         | 40         | 47         | 54         | 68         | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b> | 79         | 93         | 180        | 265        | 350        | 431        | 515        | 597        | 763        | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b> | 89         | 146        | 298        | 442        | 588        | 734        | 882        | 1027       | 1319       | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b> | <b>9.4</b> | 7.9        | 14         | 20         | 27         | 33         | 39         | 45         | 58         | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b> | <b>10</b>  | 8.0        | 14         | 20         | 26         | 33         | 39         | 46         | 58         | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b> | 34         | 34         | 58         | 68         | 91         | 123        | 134        | 148        | 200        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b> | 17         | 13         | 21         | 30         | 38         | 46         | 54         | 62         | 79         | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b> | 804        | 183        | 411        | 853        | 1372       | 1783       | 2331       | 2828       | 3744       | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b> | 69         | 101        | 196        | 291        | 377        | 465        | 555        | 646        | 827        | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b> | 847        | 196        | 468        | 1052       | 1852       | 2567       | 3510       | 4501       | 7123       | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b> | 36         | 55         | 133        | 868        | 2715       | 3825       | 4686       | 5435       | 6380       | Basic RCGA [24]                       |
| SPSA                                  | 158      | 59         | 12         | 16         | 20         | 25         | 29         | 34         | 38         | 46         | SPSA [13]                             |

























Table 109: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{13}$  in **20-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 13 Sharp ridge |            |                  |            |                  |            |                  |                  |                  |                  |                                       |  |
|---------------------------------------|----------------|------------|------------------|------------|------------------|------------|------------------|------------------|------------------|------------------|---------------------------------------|--|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03          | 1e+02      | 1e+01            | 1e+00      | 1e-01            | 1e-02      | 1e-03            | 1e-04            | 1e-05            | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |  |
| (1,2)-CMA-ES                          | 11             | 10         | 20               | 25         | 41               | 87         | 47               | 63               | <i>13e-3/1e4</i> | .                | (1,2)-CMA-ES [5, 3]                   |  |
| (1,2m)-CMA-ES                         | 4.8            | 5.2        | 13               | 12         | 24               | 36         | 33               | 62               | 55               | 93               | (1,2m)-CMA-ES [5]                     |  |
| (1,2ms)-CMA-ES                        | 4.5            | 4.7        | 4.6              | 6.9        | 23               | 37         | 49               | 130              | 116              | 94               | (1,2ms)-CMA-ES [5]                    |  |
| (1,2s)-CMA-ES                         | 10             | 9.5        | 13               | 29         | 41               | 115        | 36               | <i>27e-3/1e4</i> | .                | .                | (1,2s)-CMA-ES [3]                     |  |
| (1,4)-CMA-ES                          | 4.2            | 5.0        | 8.3              | 15         | 25               | 42         | 21               | 65               | 121              | <i>46e-4/1e4</i> | (1,4)-CMA-ES [6, 4]                   |  |
| (1,4m)-CMA-ES                         | 3.4            | 4.0        | 6.4              | 10         | 16               | 28         | 8.0              | 18               | 36               | <i>32e-5/1e4</i> | (1,4m)-CMA-ES [6]                     |  |
| (1,4ms)-CMA-ES                        | <b>2.6</b>     | <b>3.2</b> | <b>4.5</b>       | 6.6        | 11               | 26         | 21               | 30               | 56               | <i>18e-4/1e4</i> | (1,4ms)-CMA-ES [1, 6]                 |  |
| (1,4s)-CMA-ES                         | 3.5            | 4.0        | 7.6              | 4.9        | 14               | 23         | 17               | 30               | 57               | <i>10e-4/1e4</i> | (1,4s)-CMA-ES [4]                     |  |
| (1+1)-CMA-ES                          | <b>2.5</b>     | 3.3        | 6.5              | <b>4.8</b> | 10               | 16         | 4.1              | 5.4              | 7.6              | 13               | (1+1)-CMA-ES [7]                      |  |
| (1+2ms)-CMA-ES                        | <b>2.3</b>     | <b>3.0</b> | 4.9              | 6.0        | <b>7.7</b>       | 13         | 3.3              | 3.6              | 5.2              | 18               | (1+2ms)-CMA-ES [2]                    |  |
| Artif Bee Colony                      | 25             | 41         | 25               | 73         | 627              | 3931       | 1555             | <i>60e-3/1e5</i> | .                | .                | Artif Bee Colony [8]                  |  |
| avg NEWUOA                            | <b>2.1</b>     | <b>1.8</b> | <b>1.5</b>       | 5.3        | 14               | 30         | 14               | 57               | 172              | <i>67e-5/2e4</i> | avg NEWUOA [23]                       |  |
| CMA-EGS (IPOP,r1)                     | 6.4            | 6.5        | 6.8              | 7.6        | 37               | 125        | 108              | 256              | 556              | <i>90e-5/1e5</i> | CMA-EGS (IPOP,r1) [12]                |  |
| Adap DE (F-AUC)                       | 35             | 55         | 25               | 12         | 11               | <b>11</b>  | <b>2.4</b>       | <b>2.4</b>       | <b>2.5</b>       | <b>2.5</b>       | Adap DE (F-AUC) [10]                  |  |
| DE (Uniform)                          | 57             | 90         | 43               | 20         | 19               | 19         | 4.1              | 4.1              | 4.2              | 4.2              | DE (Uniform) [9]                      |  |
| IPOP-aCMA-ES                          | 3.9            | 5.3        | <b>3.6</b>       | <b>3.4</b> | <b>3.7</b>       | <b>3.4</b> | <b>0.80</b>      | <b>0.98</b>      | <b>1.3</b>       | <b>1.3</b>       | IPOP-aCMA-ES [16]                     |  |
| IPOP-CMA-ES                           | 3.5            | 5.3        | 6.5              | <b>4.8</b> | <b>6.2</b>       | <b>5.1</b> | <b>1.4</b>       | <b>1.6</b>       | <b>1.7</b>       | <b>2.3</b>       | IPOP-CMA-ES [22]                      |  |
| CMA+DE-MOS                            | 16             | 18         | 10               | 9.1        | 12               | 12         | <b>2.8</b>       | <b>2.9</b>       | 3.2              | 3.0              | CMA+DE-MOS [18]                       |  |
| NBC-CMA                               | 6.0            | 7.6        | 4.7              | 15         | 29               | 24         | 5.7              | 7.4              | 9.3              | 45               | NBC-CMA [21]                          |  |
| POEMS                                 | 98             | 201        | 6277             | 41616      | <i>90e-1/3e5</i> | .          | .                | .                | .                | .                | POEMS [17]                            |  |
| PM-AdapSS-DE                          | 41             | 63         | 28               | 13         | 12               | 12         | <b>2.6</b>       | <b>2.6</b>       | <b>2.6</b>       | <b>2.6</b>       | PM-AdapSS-DE [9, 10]                  |  |
| pPOEMS                                | 104            | 223        | 938              | 2244       | 6207             | 24363      | 4562             | <i>57e-2/3e5</i> | .                | .                | pPOEMS [17, 20]                       |  |
| Basic RCGA                            | 19             | 112        | 232              | 296        | 825              | 1228       | <i>28e-2/5e4</i> | .                | .                | .                | Basic RCGA [24]                       |  |
| SPSA                                  | 76             | 2892       | <i>29e+0/1e5</i> | .          | .                | .          | .                | .                | .                | .                | SPSA [13]                             |  |

Table 110: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{14}$  in **20-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| $\Delta f_{target}$<br>$ERT_{best}/D$ | 14 Sum of different powers |            |            |            |            |            |            |                  |                  |                  | $\Delta f_{target}$<br>$ERT_{best}/D$ |
|---------------------------------------|----------------------------|------------|------------|------------|------------|------------|------------|------------------|------------------|------------------|---------------------------------------|
|                                       | 1e+03                      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05            | 1e-07            |                                       |
| (1,2)-CMA-ES                          | <b>1</b>                   | 156        | 16         | 8.2        | 8.2        | 8.2        | 7.8        | 10               | 14               | 4.8              | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>                   | 62         | 7.7        | 3.8        | 4.1        | 4.2        | 4.2        | 5.6              | 8.1              | <b>2.0</b>       | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>                   | 41         | 6.0        | 3.1        | 3.3        | 3.5        | 3.6        | 4.9              | 6.6              | <b>1.6</b>       | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>                   | 143        | 14         | 6.9        | 7.4        | 7.4        | 6.9        | 9.3              | 13               | 5.7              | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>                   | 16         | 5.7        | 3.1        | 3.6        | 4.0        | 3.9        | 5.2              | 7.3              | <b>1.6</b>       | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>                   | 19         | 5.0        | <b>2.8</b> | 3.1        | 3.3        | 3.2        | 4.5              | 6.4              | <b>1.4</b>       | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>                   | 16         | 3.8        | <b>2.1</b> | <b>2.3</b> | <b>2.6</b> | <b>2.6</b> | 3.5              | <b>5.0</b>       | <b>1.1</b>       | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>                   | 17         | 4.7        | <b>2.6</b> | <b>2.9</b> | 3.4        | 3.2        | 4.2              | 5.4              | <b>1.3</b>       | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>                   | 12         | <b>2.9</b> | <b>1.9</b> | <b>2.3</b> | <b>2.5</b> | <b>2.2</b> | <b>3.3</b>       | 5.4              | <b>1.2</b>       | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>                   | 13         | <b>2.3</b> | <b>1.6</b> | <b>1.9</b> | <b>2.1</b> | <b>1.9</b> | <b>2.7</b>       | <b>4.5</b>       | <b>0.97</b>      | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1.1</b>                 | <b>4.0</b> | 18         | 18         | 28         | 53         | 3378       | <i>10e-4/1e5</i> | .                | .                | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>                   | 38         | <b>2.7</b> | <b>1.5</b> | <b>1.6</b> | <b>1.3</b> | <b>1.3</b> | <b>2.7</b>       | 9.3              | 26               | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | 26                         | 159        | 10         | 4.6        | 5.2        | 5.7        | 6.2        | 11               | 22               | 4.8              | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>                   | <b>4.5</b> | 33         | 30         | 38         | 36         | 23         | 20               | 19               | <b>2.8</b>       | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>                   | 5.5        | 53         | 50         | 64         | 60         | 38         | 32               | 31               | 4.2              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>                   | 10         | 3.6        | <b>2.7</b> | 3.5        | 4.0        | 3.2        | 3.4              | <b>3.9</b>       | <b>0.67</b>      | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>                   | 13         | 3.7        | <b>2.8</b> | 3.6        | 4.2        | 3.9        | 4.7              | 6.0              | <b>1.2</b>       | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>                   | 5.1        | 20         | 10         | 11         | 13         | 12         | 13               | 14               | <b>2.3</b>       | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1.1</b>                 | <b>3.5</b> | 5.5        | 3.7        | 4.6        | 5.3        | 5.1        | 6.9              | 9.0              | <b>1.7</b>       | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>                   | 3152       | 98         | 65         | 123        | 165        | 131        | 1158             | <i>27e-6/3e5</i> | .                | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>                   | 5.1        | 43         | 34         | 43         | 40         | 25         | 21               | 20               | <b>2.8</b>       | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>                   | 743        | 102        | 72         | 143        | 423        | 353        | 443              | 4529             | <i>78e-7/3e5</i> | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>                   | 4.9        | 16         | 26         | 57         | 298        | 1502       | <i>11e-4/5e4</i> | .                | .                | Basic RCGA [24]                       |
| SPSA                                  | 59                         | 853        | 98         | 51         | 45         | 39         | 56         | 234              | 1207             | <i>85e-7/1e5</i> | SPSA [13]                             |















Table 117: Running time excess  $ERT/ERT_{\text{best}}$  2009 on  $f_{21}$  in **20-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>21 Gallagher 101 peaks</b>                       |            |          |            |            |                  |            |            |            |            |            |                                                     |
|-----------------------------------------------------|------------|----------|------------|------------|------------------|------------|------------|------------|------------|------------|-----------------------------------------------------|
| $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ | 1e+03      | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{\text{target}}$<br>$ERT_{\text{best}}/D$ |
| (1,2)-CMA-ES                                        | <b>1</b>   | <b>1</b> | 13         | 8.3        | 10               | 10         | 11         | 11         | 10         | 9.1        | (1,2)-CMA-ES [5, 3]                                 |
| (1,2m)-CMA-ES                                       | <b>1</b>   | <b>1</b> | 5.9        | <b>3.3</b> | 3.6              | 3.5        | 3.4        | 3.4        | 3.3        | <b>2.9</b> | (1,2m)-CMA-ES [5]                                   |
| (1,2ms)-CMA-ES                                      | <b>1</b>   | <b>1</b> | 7.2        | 4.9        | 4.0              | 4.0        | 3.9        | 3.8        | 3.7        | 3.3        | (1,2ms)-CMA-ES [5]                                  |
| (1,2s)-CMA-ES                                       | <b>1</b>   | <b>1</b> | 6.8        | 9.3        | 9.1              | 9.0        | 8.9        | 8.6        | 8.4        | 7.4        | (1,2s)-CMA-ES [3]                                   |
| (1,4)-CMA-ES                                        | <b>1</b>   | <b>1</b> | <b>2.1</b> | 3.6        | 4.7              | 4.6        | 4.5        | 4.4        | 4.3        | 3.8        | (1,4)-CMA-ES [6, 4]                                 |
| (1,4m)-CMA-ES                                       | <b>1</b>   | <b>1</b> | 3.9        | 4.7        | 4.8              | 4.7        | 4.7        | 4.5        | 4.4        | 3.9        | (1,4m)-CMA-ES [6]                                   |
| (1,4ms)-CMA-ES                                      | <b>1</b>   | <b>1</b> | <b>2.4</b> | <b>1.7</b> | <b>1.8</b>       | <b>1.8</b> | <b>1.7</b> | <b>1.7</b> | <b>1.6</b> | <b>1.5</b> | (1,4ms)-CMA-ES [1, 6]                               |
| (1,4s)-CMA-ES                                       | <b>1</b>   | <b>1</b> | 3.8        | <b>2.3</b> | <b>2.6</b>       | <b>2.6</b> | <b>2.5</b> | <b>2.4</b> | <b>2.4</b> | <b>2.1</b> | (1,4s)-CMA-ES [4]                                   |
| (1+1)-CMA-ES                                        | <b>1</b>   | <b>1</b> | 3.5        | 5.5        | 5.4              | 5.3        | 5.2        | 5.1        | 4.9        | 4.4        | (1+1)-CMA-ES [7]                                    |
| (1+2ms)-CMA-ES                                      | <b>1</b>   | <b>1</b> | 3.3        | 4.6        | 3.9              | 3.8        | 3.8        | 3.7        | 3.6        | 3.2        | (1+2ms)-CMA-ES [2]                                  |
| Artif Bee Colony                                    | <b>1</b>   | <b>1</b> | 5.0        | 22         | 25               | 26         | 27         | 30         | 35         | 85         | Artif Bee Colony [8]                                |
| avg NEWUOA                                          | <b>1</b>   | <b>1</b> | 3.2        | 5.7        | <b>3.5</b>       | <b>3.5</b> | <b>3.4</b> | <b>3.3</b> | <b>3.3</b> | <b>2.9</b> | avg NEWUOA [23]                                     |
| CMA-EGS (IPOP,r1)                                   | <b>2.7</b> | 106      | <b>1.9</b> | 211        | 217              | 214        | 210        | 204        | 197        | 175        | CMA-EGS (IPOP,r1) [12]                              |
| Adap DE (F-AUC)                                     | <b>1</b>   | <b>1</b> | 12         | 613        | 568              | 560        | 547        | 531        | 515        | 456        | Adap DE (F-AUC) [10]                                |
| DE (Uniform)                                        | <b>1</b>   | <b>1</b> | 21         | 461        | 568              | 560        | 548        | 532        | 516        | 457        | DE (Uniform) [9]                                    |
| IPOP-aCMA-ES                                        | <b>1</b>   | <b>1</b> | <b>1.9</b> | 81         | 66               | 65         | 64         | 62         | 60         | 54         | IPOP-aCMA-ES [16]                                   |
| IPOP-CMA-ES                                         | <b>1</b>   | <b>1</b> | 3.7        | 139        | 110              | 108        | 106        | 103        | 100        | 88         | IPOP-CMA-ES [22]                                    |
| CMA+DE-MOS                                          | <b>1</b>   | <b>1</b> | 11         | 262        | 285              | 281        | 275        | 268        | 260        | 231        | CMA+DE-MOS [18]                                     |
| NBC-CMA                                             | <b>1</b>   | <b>1</b> | 84         | 69         | 59               | 58         | 56         | 55         | 53         | 47         | NBC-CMA [21]                                        |
| POEMS                                               | <b>1</b>   | <b>1</b> | 11053      | 5970       | <i>47e-1/3e5</i> | .          | .          | .          | .          | .          | POEMS [17]                                          |
| PM-AdapSS-DE                                        | <b>1</b>   | <b>1</b> | 12         | 351        | 568              | 560        | 547        | 531        | 515        | 456        | PM-AdapSS-DE [9, 10]                                |
| pPOEMS                                              | <b>1</b>   | <b>1</b> | 137        | 1172       | 956              | 1186       | 1160       | 1127       | 1093       | 974        | pPOEMS [17, 20]                                     |
| Basic RCGA                                          | <b>1</b>   | <b>1</b> | 119        | 103        | 85               | 85         | 86         | 97         | 96         | 87         | Basic RCGA [24]                                     |
| SPSA                                                | 3.5        | 251      | 597        | 1240       | <i>18e-1/1e5</i> | .          | .          | .          | .          | .          | SPSA [13]                                           |

Table 118: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{22}$  in **20-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                       | 22 Gallagher 21 peaks |          |            |            |                  |           |                  |            |            |            |                                       |
|---------------------------------------|-----------------------|----------|------------|------------|------------------|-----------|------------------|------------|------------|------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03                 | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02     | 1e-03            | 1e-04      | 1e-05      | 1e-07      | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1,2)-CMA-ES                          | <b>1</b>              | <b>1</b> | 10         | 27         | 124              | 120       | 116              | 111        | 108        | 22         | (1,2)-CMA-ES [5, 3]                   |
| (1,2m)-CMA-ES                         | <b>1</b>              | <b>1</b> | 8.8        | 13         | 21               | 20        | 20               | 19         | 18         | 3.7        | (1,2m)-CMA-ES [5]                     |
| (1,2ms)-CMA-ES                        | <b>1</b>              | <b>1</b> | 8.2        | 13         | 17               | 16        | 16               | 15         | 15         | <b>3.0</b> | (1,2ms)-CMA-ES [5]                    |
| (1,2s)-CMA-ES                         | <b>1</b>              | <b>1</b> | 35         | 22         | 37               | 36        | 35               | 34         | 33         | 6.6        | (1,2s)-CMA-ES [3]                     |
| (1,4)-CMA-ES                          | <b>1</b>              | <b>1</b> | 18         | 6.6        | <b>11</b>        | <b>11</b> | <b>11</b>        | <b>10</b>  | <b>10</b>  | <b>2.0</b> | (1,4)-CMA-ES [6, 4]                   |
| (1,4m)-CMA-ES                         | <b>1</b>              | <b>1</b> | <b>5.6</b> | 7.7        | 16               | 16        | 15               | 15         | 14         | <b>2.9</b> | (1,4m)-CMA-ES [6]                     |
| (1,4ms)-CMA-ES                        | <b>1</b>              | <b>1</b> | 9.0        | <b>5.0</b> | 28               | 27        | 26               | 25         | 24         | 4.9        | (1,4ms)-CMA-ES [1, 6]                 |
| (1,4s)-CMA-ES                         | <b>1</b>              | <b>1</b> | <b>4.7</b> | 13         | 27               | 26        | 25               | 24         | 24         | 4.7        | (1,4s)-CMA-ES [4]                     |
| (1+1)-CMA-ES                          | <b>1</b>              | <b>1</b> | 17         | 9.4        | 15               | 14        | 14               | 13         | 13         | <b>2.6</b> | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>1</b>              | <b>1</b> | 10         | <b>4.4</b> | <b>10</b>        | <b>10</b> | <b>9.2</b>       | <b>8.8</b> | <b>8.6</b> | <b>1.7</b> | (1+2ms)-CMA-ES [2]                    |
| Artif Bee Colony                      | <b>1</b>              | <b>1</b> | 10         | 47         | 77               | 578       | <i>44e-3/1e5</i> | .          | .          | .          | Artif Bee Colony [8]                  |
| avg NEWUOA                            | <b>1</b>              | <b>1</b> | <b>2.0</b> | <b>5.6</b> | <b>14</b>        | <b>13</b> | <b>13</b>        | <b>12</b>  | <b>12</b>  | <b>2.4</b> | avg NEWUOA [23]                       |
| CMA-EGS (IPOP,r1)                     | <b>1.9</b>            | 104      | 676        | 546        | <i>20e-1/1e5</i> | .         | .                | .          | .          | .          | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | <b>1</b>              | <b>1</b> | 675        | 1436       | <i>26e-1/1e5</i> | .         | .                | .          | .          | .          | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | <b>1</b>              | <b>1</b> | 1580       | 989        | <i>20e-1/1e5</i> | .         | .                | .          | .          | .          | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>1</b>              | <b>1</b> | 462        | 264        | <i>20e-1/6e4</i> | .         | .                | .          | .          | .          | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | <b>1</b>              | <b>1</b> | 445        | 287        | <i>20e-1/6e4</i> | .         | .                | .          | .          | .          | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | <b>1</b>              | <b>1</b> | 536        | 797        | 677              | 659       | 638              | 610        | 594        | 118        | CMA+DE-MOS [18]                       |
| NBC-CMA                               | <b>1</b>              | <b>1</b> | 323        | 350        | <i>73e-1/1e4</i> | .         | .                | .          | .          | .          | NBC-CMA [21]                          |
| POEMS                                 | <b>1</b>              | <b>1</b> | 6453       | 6994       | <i>73e-1/3e5</i> | .         | .                | .          | .          | .          | POEMS [17]                            |
| PM-AdapSS-DE                          | <b>1</b>              | <b>1</b> | 1572       | 2332       | <i>51e-1/1e5</i> | .         | .                | .          | .          | .          | PM-AdapSS-DE [9, 10]                  |
| pPOEMS                                | <b>1</b>              | <b>1</b> | 2022       | 1439       | 1680             | 1634      | 1584             | 1513       | 1474       | 294        | pPOEMS [17, 20]                       |
| Basic RCGA                            | <b>1</b>              | <b>1</b> | 1186       | 1200       | <i>73e-1/5e4</i> | .         | .                | .          | .          | .          | Basic RCGA [24]                       |
| SPSA                                  | 7.6                   | 240      | 1073       | 1439       | <i>26e-1/1e5</i> | .         | .                | .          | .          | .          | SPSA [13]                             |







Table 121: Running time excess  $ERT/ERT_{best}$  2009 on  $f_1$  in **40-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

|                                          | <b>1 Sphere</b> |            |            |            |            |            |            |            |            |            |                                          |
|------------------------------------------|-----------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------------------------------------|
| $\frac{\Delta f_{target}}{ERT_{best}/D}$ | 1e+03           | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\frac{\Delta f_{target}}{ERT_{best}/D}$ |
|                                          | 0.03            | 2.1        | 2.1        | 2.1        | 2.1        | 2.1        | 2.1        | 2.1        | 2.1        | 2.1        |                                          |
| (1+1)-CMA-ES                             | <b>1</b>        | <b>3.2</b> | <b>7.1</b> | <b>11</b>  | <b>15</b>  | <b>19</b>  | <b>23</b>  | <b>27</b>  | <b>31</b>  | <b>39</b>  | (1+1)-CMA-ES [7]                         |
| (1+2ms)-CMA-ES                           | <b>1</b>        | <b>2.7</b> | <b>6.1</b> | <b>10</b>  | <b>13</b>  | <b>17</b>  | <b>20</b>  | <b>24</b>  | <b>27</b>  | <b>35</b>  | (1+2ms)-CMA-ES [2]                       |
| avg NEWUOA                               | <b>1</b>        | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | <b>3.2</b> | avg NEWUOA [23]                          |
| CMA-EGS (IPOP,r1)                        | 139             | 7.7        | 15         | 22         | 30         | 37         | 44         | 52         | 59         | 74         | CMA-EGS (IPOP,r1) [12]                   |
| Adap DE (F-AUC)                          | <b>1</b>        | 65         | 205        | 383        | 594        | 823        | 1086       | 1353       | 1573       | 2016       | Adap DE (F-AUC) [10]                     |
| DE (Uniform)                             | <b>1</b>        | 113        | 376        | 642        | 898        | 1164       | 1442       | 1709       | 1982       | 2502       | DE (Uniform) [9]                         |
| IPOP-aCMA-ES                             | <b>1</b>        | 3.3        | 10         | 16         | 21         | 28         | 34         | 40         | 46         | 58         | IPOP-aCMA-ES [16]                        |
| IPOP-CMA-ES                              | <b>1</b>        | 3.3        | 9.4        | 16         | 21         | 27         | 33         | 39         | 45         | 57         | IPOP-CMA-ES [22]                         |
| CMA+DE-MOS                               | <b>1</b>        | 18         | 50         | 58         | 65         | 76         | 106        | 126        | 134        | 162        | CMA+DE-MOS [18]                          |
| NBC-CMA                                  | <b>1</b>        | 4.7        | 12         | 19         | 26         | 32         | 38         | 45         | 52         | 66         | NBC-CMA [21]                             |
| PM-AdapSS-DE                             | <b>1</b>        | 75         | 212        | 364        | 524        | 694        | 871        | 1063       | 1252       | 1643       | PM-AdapSS-DE [9, 10]                     |
| Basic RCGA                               | <b>1</b>        | 12         | 72         | 1089       | 4155       | 5781       | 7051       | 8001       | 8768       | 9840       | Basic RCGA [24]                          |
| SPSA                                     | 478             | 11         | 15         | 20         | 24         | 29         | 33         | 37         | 41         | 50         | SPSA [13]                                |

























Table 133: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{13}$  in **40-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>13 Sharp ridge</b>                 |            |            |            |            |            |                  |            |                  |                  |                  |                                       |
|---------------------------------------|------------|------------|------------|------------|------------|------------------|------------|------------------|------------------|------------------|---------------------------------------|
| $\Delta f_{target}$<br>$ERT_{best}/D$ | 1e+03      | 1e+02      | 1e+01      | 1e+00      | 1e-01      | 1e-02            | 1e-03      | 1e-04            | 1e-05            | 1e-07            | $\Delta f_{target}$<br>$ERT_{best}/D$ |
| (1+1)-CMA-ES                          | <b>3.2</b> | <b>3.4</b> | 3.1        | 5.4        | 10         | 25               | 10         | 8.6              | 14               | 23               | (1+1)-CMA-ES [7]                      |
| (1+2ms)-CMA-ES                        | <b>2.9</b> | <b>2.9</b> | <b>2.8</b> | <b>3.2</b> | <b>7.2</b> | <b>14</b>        | 7.0        | 16               | 29               | <i>82e-5/1e4</i> | (1+2ms)-CMA-ES [2]                    |
| CMA-EGS (IPOP,r1)                     | 7.6        | 6.4        | <b>2.7</b> | 4.2        | 37         | 215              | 780        | 669              | 570              | <i>67e-4/1e5</i> | CMA-EGS (IPOP,r1) [12]                |
| Adap DE (F-AUC)                       | 78         | 105        | 37         | 17         | 18         | 17               | 3.3        | 3.3              | 3.2              | 3.3              | Adap DE (F-AUC) [10]                  |
| DE (Uniform)                          | 145        | 168        | 54         | 22         | 23         | 20               | 4.0        | 3.9              | 3.8              | 3.9              | DE (Uniform) [9]                      |
| IPOP-aCMA-ES                          | <b>4.4</b> | <b>4.7</b> | <b>1.6</b> | <b>2.1</b> | <b>4.7</b> | <b>5.9</b>       | <b>1.3</b> | <b>1.4</b>       | <b>1.6</b>       | <b>1.9</b>       | IPOP-aCMA-ES [16]                     |
| IPOP-CMA-ES                           | 4.8        | 5.1        | <b>2.8</b> | <b>3.5</b> | <b>6.6</b> | <b>10</b>        | <b>2.3</b> | <b>2.9</b>       | <b>2.7</b>       | <b>2.9</b>       | IPOP-CMA-ES [22]                      |
| CMA+DE-MOS                            | 26         | 14         | 6.4        | 7.0        | 11         | 15               | <b>3.1</b> | 3.4              | <b>3.2</b>       | 3.6              | CMA+DE-MOS [18]                       |
| NBC-CMA                               | 5.6        | 5.7        | <b>2.5</b> | 5.0        | 16         | 26               | 10         | 25               | <i>63e-4/7e3</i> | .                | NBC-CMA [21]                          |
| PM-AdapSS-DE                          | 85         | 102        | 34         | 15         | 16         | 15               | 3.1        | <b>3.2</b>       | 3.2              | <b>3.3</b>       | PM-AdapSS-DE [9, 10]                  |
| Basic RCGA                            | 29         | 733        | 319        | 177        | 724        | 1169             | 402        | <i>20e-2/5e4</i> | .                | .                | Basic RCGA [24]                       |
| SPSA                                  | 75         | 4772       | 14665      | 8631       | 6843       | <i>52e+0/1e5</i> | .          | .                | .                | .                | SPSA [13]                             |

Table 134: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{14}$  in **40-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>14 Sum of different powers</b>        |            |           |            |            |            |            |            |                  |            |                  |                                          |
|------------------------------------------|------------|-----------|------------|------------|------------|------------|------------|------------------|------------|------------------|------------------------------------------|
| $\frac{\Delta f_{target}}{ERT_{best}/D}$ | 1e+03      | 1e+02     | 1e+01      | 1e+00      | 1e-01      | 1e-02      | 1e-03      | 1e-04            | 1e-05      | 1e-07            | $\frac{\Delta f_{target}}{ERT_{best}/D}$ |
| (1+1)-CMA-ES                             | <b>1</b>   | <b>36</b> | <b>1.7</b> | <b>1.6</b> | <b>1.8</b> | <b>2.1</b> | <b>2.0</b> | <b>3.0</b>       | <b>5.1</b> | <b>1.0</b>       | (1+1)-CMA-ES [7]                         |
| (1+2ms)-CMA-ES                           | <b>1</b>   | 57        | <b>1.7</b> | <b>1.5</b> | <b>1.7</b> | <b>1.9</b> | <b>1.9</b> | <b>2.7</b>       | <b>4.2</b> | <b>0.85</b>      | (1+2ms)-CMA-ES [2]                       |
| CMA-EGS (IPOP,r1)                        | 85         | 316       | 5.4        | 3.8        | 4.3        | 5.1        | 6.3        | 10               | 19         | 4.3              | CMA-EGS (IPOP,r1) [12]                   |
| Adap DE (F-AUC)                          | <b>1</b>   | 128       | 38         | 46         | 63         | 68         | 47         | 37               | 34         | 4.0              | Adap DE (F-AUC) [10]                     |
| DE (Uniform)                             | <b>1</b>   | 74        | 72         | 80         | 99         | 95         | 61         | 45               | 40         | 4.5              | DE (Uniform) [9]                         |
| IPOP-aCMA-ES                             | <b>1</b>   | <b>31</b> | <b>2.5</b> | <b>2.4</b> | <b>3.0</b> | <b>3.7</b> | <b>3.4</b> | <b>3.5</b>       | <b>3.9</b> | <b>0.57</b>      | IPOP-aCMA-ES [16]                        |
| IPOP-CMA-ES                              | <b>1</b>   | <b>32</b> | <b>2.7</b> | <b>2.5</b> | 3.0        | 3.9        | 4.3        | 5.2              | 6.7        | <b>1.1</b>       | IPOP-CMA-ES [22]                         |
| CMA+DE-MOS                               | <b>1.1</b> | 118       | 12         | 7.8        | 7.7        | 10         | 12         | 16               | 19         | <b>2.7</b>       | CMA+DE-MOS [18]                          |
| NBC-CMA                                  | <b>1.1</b> | 44        | <b>2.9</b> | <b>2.6</b> | 3.2        | 4.4        | 5.3        | 8.1              | 11         | <b>1.8</b>       | NBC-CMA [21]                             |
| PM-AdapSS-DE                             | <b>1.1</b> | 90        | 44         | 47         | 59         | 60         | 41         | 32               | 30         | 3.7              | PM-AdapSS-DE [9, 10]                     |
| Basic RCGA                               | <b>1</b>   | 51        | 12         | 28         | 366        | 484        | 1403       | <i>10e-4/5e4</i> | .          | .                | Basic RCGA [24]                          |
| SPSA                                     | 195        | 1670      | 58         | 41         | 36         | 33         | 41         | 130              | 6065       | <i>22e-6/1e5</i> | SPSA [13]                                |















Table 141: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{21}$  in **40-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>21 Gallagher 101 peaks</b>            |          |          |            |            |                  |             |             |             |             |             |                                          |
|------------------------------------------|----------|----------|------------|------------|------------------|-------------|-------------|-------------|-------------|-------------|------------------------------------------|
| $\frac{\Delta f_{target}}{ERT_{best}/D}$ | 1e+03    | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02       | 1e-03       | 1e-04       | 1e-05       | 1e-07       | $\frac{\Delta f_{target}}{ERT_{best}/D}$ |
| (1+1)-CMA-ES                             | <b>1</b> | <b>1</b> | <b>5.0</b> | <b>1.9</b> | <b>0.97</b>      | <b>0.97</b> | <b>0.97</b> | <b>0.97</b> | <b>0.97</b> | <b>0.97</b> | (1+1)-CMA-ES [7]                         |
| (1+2ms)-CMA-ES                           | <b>1</b> | <b>1</b> | <b>2.4</b> | <b>2.3</b> | <b>1.1</b>       | <b>1.1</b>  | <b>1.1</b>  | <b>1.1</b>  | <b>1.1</b>  | <b>1.1</b>  | (1+2ms)-CMA-ES [2]                       |
| CMA-EGS (IPOP,r1)                        | 20       | 224      | 14         | 107        | 62               | 62          | 62          | 62          | 62          | 62          | CMA-EGS (IPOP,r1) [12]                   |
| Adap DE (F-AUC)                          | <b>1</b> | <b>1</b> | 293        | 758        | 258              | 258         | 257         | 256         | 256         | 255         | Adap DE (F-AUC) [10]                     |
| DE (Uniform)                             | <b>1</b> | <b>1</b> | 36         | 287        | 557              | 555         | 553         | 552         | 550         | 548         | DE (Uniform) [9]                         |
| IPOP-aCMA-ES                             | <b>1</b> | <b>1</b> | 9.2        | 161        | 118              | 118         | 118         | 117         | 117         | 116         | IPOP-aCMA-ES [16]                        |
| IPOP-CMA-ES                              | <b>1</b> | <b>1</b> | 10         | 166        | 83               | 83          | 83          | 83          | 82          | 82          | IPOP-CMA-ES [22]                         |
| CMA+DE-MOS                               | <b>1</b> | <b>1</b> | 15         | 224        | 101              | 101         | 101         | 100         | 100         | 100         | CMA+DE-MOS [18]                          |
| NBC-CMA                                  | <b>1</b> | <b>1</b> | 73         | 199        | 42               | 42          | 41          | 41          | 41          | 41          | NBC-CMA [21]                             |
| PM-AdapSS-DE                             | <b>1</b> | <b>1</b> | 295        | 1231       | <i>21e-1/1e5</i> | .           | .           | .           | .           | .           | PM-AdapSS-DE [9, 10]                     |
| Basic RCGA                               | <b>1</b> | <b>1</b> | <b>7.7</b> | <b>89</b>  | <b>31</b>        | <b>33</b>   | <b>33</b>   | <b>34</b>   | <b>34</b>   | <b>35</b>   | Basic RCGA [24]                          |
| SPSA                                     | 188      | 541      | 880        | 2650       | <i>25e-1/1e5</i> | .           | .           | .           | .           | .           | SPSA [13]                                |

Table 142: Running time excess  $ERT/ERT_{best}$  2009 on  $f_{22}$  in **40-D**, in italics is given the median final function value and the median number of function evaluations to reach this value divided by dimension

| <b>22 Gallagher 21 peaks</b>        |          |          |            |            |                  |            |            |            |            |            |                                     |
|-------------------------------------|----------|----------|------------|------------|------------------|------------|------------|------------|------------|------------|-------------------------------------|
| $\Delta_{target}$<br>$ERT_{best}/D$ | 1e+03    | 1e+02    | 1e+01      | 1e+00      | 1e-01            | 1e-02      | 1e-03      | 1e-04      | 1e-05      | 1e-07      | $\Delta_{target}$<br>$ERT_{best}/D$ |
| (1+1)-CMA-ES                        | <b>1</b> | <b>1</b> | <b>9.1</b> | <b>6.2</b> | <b>2.0</b>       | <b>2.0</b> | <b>2.0</b> | <b>2.0</b> | <b>2.0</b> | <b>2.0</b> | (1+1)-CMA-ES [7]                    |
| (1+2ms)-CMA-ES                      | <b>1</b> | <b>1</b> | <b>1.9</b> | <b>4.9</b> | <b>9.0</b>       | <b>8.9</b> | <b>8.9</b> | <b>8.9</b> | <b>8.9</b> | <b>8.9</b> | (1+2ms)-CMA-ES [2]                  |
| CMA-EGS (IPOP,r1)                   | 21       | 205      | 326        | 226        | <i>20e-1/1e5</i> | .          | .          | .          | .          | .          | CMA-EGS (IPOP,r1) [12]              |
| Adap DE (F-AUC)                     | <b>1</b> | <b>1</b> | 478        | 312        | <i>26e-1/1e5</i> | .          | .          | .          | .          | .          | Adap DE (F-AUC) [10]                |
| DE (Uniform)                        | <b>1</b> | <b>1</b> | 661        | 453        | <i>73e-1/1e5</i> | .          | .          | .          | .          | .          | DE (Uniform) [9]                    |
| IPOP-aCMA-ES                        | <b>1</b> | <b>1</b> | 295        | 174        | <i>20e-1/7e4</i> | .          | .          | .          | .          | .          | IPOP-aCMA-ES [16]                   |
| IPOP-CMA-ES                         | <b>1</b> | <b>1</b> | 367        | 133        | <i>20e-1/8e4</i> | .          | .          | .          | .          | .          | IPOP-CMA-ES [22]                    |
| CMA+DE-MOS                          | <b>1</b> | <b>1</b> | 490        | 205        | <i>20e-1/1e5</i> | .          | .          | .          | .          | .          | CMA+DE-MOS [18]                     |
| NBC-CMA                             | <b>1</b> | <b>1</b> | <b>49</b>  | <b>23</b>  | <i>51e-1/7e3</i> | .          | .          | .          | .          | .          | NBC-CMA [21]                        |
| PM-AdapSS-DE                        | <b>1</b> | <b>1</b> | 654        | 1581       | <i>56e-1/1e5</i> | .          | .          | .          | .          | .          | PM-AdapSS-DE [9, 10]                |
| Basic RCGA                          | <b>1</b> | <b>1</b> | 335        | 101        | <i>20e-1/5e4</i> | .          | .          | .          | .          | .          | Basic RCGA [24]                     |
| SPSA                                | 183      | 630      | 769        | 737        | <i>51e-1/1e5</i> | .          | .          | .          | .          | .          | SPSA [13]                           |







## References

- [1] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Benchmarking the (1, 4)-CMA-ES with mirrored sampling and sequential selection on the noiseless BBOB-2010 testbed. In Pelikan and Branke [19], pages 1617–1624.
- [2] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Comparing the (1+1)-CMA-ES with a mirrored (1+2)-CMA-ES with sequential selection on the noiseless BBOB-2010 testbed. In Pelikan and Branke [19], pages 1543–1550.
- [3] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Investigating the impact of sequential selection in the (1, 2)-CMA-ES on the noiseless BBOB-2010 testbed. In Pelikan and Branke [19], pages 1591–1596.
- [4] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Investigating the impact of sequential selection in the (1, 4)-CMA-ES on the noiseless BBOB-2010 testbed. In Pelikan and Branke [19], pages 1597–1604.
- [5] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Mirrored variants of the (1, 2)-CMA-ES compared on the noiseless BBOB-2010 testbed. In Pelikan and Branke [19], pages 1551–1558.
- [6] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Mirrored variants of the (1, 4)-CMA-ES compared on the noiseless BBOB-2010 testbed. In Pelikan and Branke [19], pages 1559–1566.
- [7] Anne Auger and Nikolaus Hansen. Benchmarking the (1+1)-CMA-ES on the BBOB-2009 function testbed. In Franz Rothlauf, editor, *GECCO (Companion)*, pages 2459–2466. ACM, 2009.
- [8] Mohammed El-Abd. Black-box optimization benchmarking for noiseless function testbed using artificial bee colony algorithm. In Pelikan and Branke [19], pages 1719–1724.
- [9] Álvaro Fialho, Wenyin Gong, and Zhihua Cai. Probability matching-based adaptive strategy selection vs. uniform strategy selection within differential evolution: an empirical comparison on the BBOB-2010 noiseless testbed. In Pelikan and Branke [19], pages 1527–1534.
- [10] Álvaro Fialho, Marc Schoenauer, and Michèle Sebag. Fitness-AUC bandit adaptive strategy selection vs. the probability matching one within differential evolution: an empirical comparison on the BBOB-2010 noiseless testbed. In Pelikan and Branke [19], pages 1535–1542.
- [11] S. Finck, N. Hansen, R. Ros, and A. Auger. Real-parameter black-box optimization benchmarking 2009: Presentation of the noiseless functions. Technical Report 2009/20, Research Center PPE, 2009. Updated February 2010.
- [12] Steffen Finck and Hans-Georg Beyer. Benchmarking CMA-EGS on the BBOB 2010 noiseless function testbed. In Pelikan and Branke [19], pages 1633–1640.

- [13] Steffen Finck and Hans-Georg Beyer. Benchmarking SPSA on BBOB-2010 noiseless function testbed. In Pelikan and Branke [19], pages 1657–1664.
- [14] N. Hansen, A. Auger, S. Finck, and R. Ros. Real-parameter black-box optimization benchmarking 2010: Experimental setup. Technical Report RR-7215, INRIA, 2010.
- [15] N. Hansen, S. Finck, R. Ros, and A. Auger. Real-parameter black-box optimization benchmarking 2009: Noiseless functions definitions. Technical Report RR-6829, INRIA, 2009. Updated February 2010.
- [16] Nikolaus Hansen and Raymond Ros. Benchmarking a weighted negative covariance matrix update on the BBOB-2010 noiseless testbed. In Pelikan and Branke [19], pages 1673–1680.
- [17] Jirí Kubařík. Black-box optimization benchmarking of two variants of the POEMS algorithm on the noiseless testbed. In Pelikan and Branke [19], pages 1567–1574.
- [18] Antonio LaTorre, Santiago Muelas, and José María Peña. Benchmarking a MOS-based algorithm on the BBOB-2010 noiseless function testbed. In Pelikan and Branke [19], pages 1649–1656.
- [19] Martin Pelikan and Jürgen Branke, editors. *Genetic and Evolutionary Computation Conference, GECCO 2010, Proceedings, Portland, Oregon, USA, July 7-11, 2010, Companion Material*. ACM, 2010.
- [20] Petr Posík and Jirí Kubařík. Comparison of Cauchy EDA and pPOEMS algorithms on the BBOB noiseless testbed. In Pelikan and Branke [19], pages 1703–1710.
- [21] Mike Preuss. Niching the CMA-ES via nearest-better clustering. In Pelikan and Branke [19], pages 1711–1718.
- [22] Raymond Ros. Black-box optimization benchmarking the IPOP-CMA-ES on the noiseless testbed: comparison to the BIPOP-CMA-ES. In Pelikan and Branke [19], pages 1503–1510.
- [23] Raymond Ros. Comparison of NEWUOA with different numbers of interpolation points on the BBOB noiseless testbed. In Pelikan and Branke [19], pages 1487–1494.
- [24] Thanh-Do Tran and Gang-Gyoo Jin. Real-coded genetic algorithm benchmarked on noiseless black-box optimization testbed. In Pelikan and Branke [19], pages 1731–1738.



---

Centre de recherche INRIA Saclay – Île-de-France  
Parc Orsay Université - ZAC des Vignes  
4, rue Jacques Monod - 91893 Orsay Cedex (France)

Centre de recherche INRIA Bordeaux – Sud Ouest : Domaine Universitaire - 351, cours de la Libération - 33405 Talence Cedex  
Centre de recherche INRIA Grenoble – Rhône-Alpes : 655, avenue de l'Europe - 38334 Montbonnot Saint-Ismier  
Centre de recherche INRIA Lille – Nord Europe : Parc Scientifique de la Haute Borne - 40, avenue Halley - 59650 Villeneuve d'Ascq  
Centre de recherche INRIA Nancy – Grand Est : LORIA, Technopôle de Nancy-Brabois - Campus scientifique  
615, rue du Jardin Botanique - BP 101 - 54602 Villers-lès-Nancy Cedex  
Centre de recherche INRIA Paris – Rocquencourt : Domaine de Voluceau - Rocquencourt - BP 105 - 78153 Le Chesnay Cedex  
Centre de recherche INRIA Rennes – Bretagne Atlantique : IRISA, Campus universitaire de Beaulieu - 35042 Rennes Cedex  
Centre de recherche INRIA Sophia Antipolis – Méditerranée : 2004, route des Lucioles - BP 93 - 06902 Sophia Antipolis Cedex

---

Éditeur  
INRIA - Domaine de Voluceau - Rocquencourt, BP 105 - 78153 Le Chesnay Cedex (France)  
<http://www.inria.fr>  
ISSN 0249-0803