# Comparison Tables: BBOB 2013 Testbed in 3-D (Expensive Setting)

The BBOBies

May 15, 2014

**Abstract**

This document provides tabular results of the workshop for Black-Box Optimization Benchmarking at GECCO 2013 with a focus on benchmarking black-box algorithms for small function evaluation budgets ("expensive setting"), see `http://coco.gforge.inria.fr/doku.php?id=bbob-2013`. About 30 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 [6, 4]. The experimental set-up is described in [5].

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 in BBOB-2009 (see [2]) if an algorithm from BBOB-2009 reached the given target function value. The ERT value is given otherwise ($\text{ERT}_{\text{best}}$ is noted as infinite). See [5] for details on how ERT is obtained. Bold entries in the table correspond to values below 3 or the top-three best values. Table 1 gives an overview on all algorithms submitted to the noise-free testbed in 2013.

Table 1: Names and references of all algorithms submitted for the noise-free testbed

| algorithm short name | paper | reference |
|---|---|---|
| BIPOP-aCMA-STEP los | BI-Population CMA-ES Algorithms with Surrogate Models and Line Searches (Page 1177) | [11] |
| BIPOP-saACM-k los | BI-Population CMA-ES Algorithms with Surrogate Models and Line Searches (Page 1177) | [11] |
| CMAES hut | An Evaluation of Sequential Model-Based Optimization for Expensive Blackbox Functions (Page 1209) | [8] |
| DE pal | Benchmarking a Hybrid Multi Level Single Linkage Algorithm on the BBOB Noiseless Testbed | [12] |
| HCMA los | BI-Population CMA-ES Algorithms with Surrogate Models and Line Searches (Page 1177) | [11] |
| HMLSL pal | Benchmarking a Hybrid Multi Level Single Linkage Algorithm on the BBOB Noiseless Testbed | [12] |
| IPOP-10DDr lia | Bounding the Population Size of IPOP-CMA-ES on the Noiseless BBOB Testbed (Page 1161) | [9] |
| IPOP-500 lia | Bounding the Population Size of IPOP-CMA-ES on the Noiseless BBOB Testbed (Page 1161) | [9] |
| IPOP-tany lia | Testing the Impact of Parameter Tuning on a Variant of IPOP-CMA-ES with a Bounded Maximum Population Size on the Noiseless BBOB Testbed (Page 1169) | [10] |
| IPOP-texp lia | Testing the Impact of Parameter Tuning on a Variant of IPOP-CMA-ES with a Bounded Maximum Population Size on the Noiseless BBOB Testbed (Page 1169) | [10] |
| IPOP lia | Bounding the Population Size of IPOP-CMA-ES on the Noiseless BBOB Testbed (Page 1161) | [9] |
|  | Testing the Impact of Parameter Tuning on a Variant of IPOP-CMA-ES with a Bounded Maximum Population Size on the Noiseless BBOB Testbed (Page 1169) | [10] |
| MLSL pal | Benchmarking a Hybrid Multi Level Single Linkage Algorithm on the BBOB Noiseless Testbed | [12] |
| OQNLP pal | Comparison of Multistart Global Optimization Algorithms on the BBOB Noiseless Testbed (Page 1153) | [13] |
| P-DCN tra | Multiobjectivization with NSGA-II on the Noiseless BBOB Testbed (Page 1217) | [15] |
| P-zero tra | Multiobjectivization with NSGA-II on the Noiseless BBOB Testbed (Page 1217) | [15] |
| SMAC hut | An Evaluation of Sequential Model-Based Optimization for Expensive Blackbox Functions (Page 1209) | [8] |
| U-DCN tra | Multiobjectivization with NSGA-II on the Noiseless BBOB Testbed (Page 1217) | [15] |
| U-zero tra | Multiobjectivization with NSGA-II on the Noiseless BBOB Testbed (Page 1217) | [15] |
| fmincon pal | Comparison of Multistart Global Optimization Algorithms on the BBOB Noiseless Testbed (Page 1153) | [13] |
| fminunc pal | Comparison of Multistart Global Optimization Algorithms on the BBOB Noiseless Testbed (Page 1153) | [13] |
| ga100 hol | Benchmarking Cellular Genetic Algorithms on the BBOB Noiseless Testbed (Page 1201) | [7] |
| grid100 hol | Benchmarking Cellular Genetic Algorithms on the BBOB Noiseless Testbed (Page 1201) | [7] |
| grid16 hol | Benchmarking Cellular Genetic Algorithms on the BBOB Noiseless Testbed (Page 1201) | [7] |
| hill hol | Benchmarking Cellular Genetic Algorithms on the BBOB Noiseless Testbed (Page 1201) | [7] |
| lmmCMA aug | Benchmarking the Local Metamodel CMA-ES on the Noiseless BBOB'2013 Test Bed (Page 1225) | [1] |
| memPSODE vog | Adapt-MEMPSODE: A Memetic Algorithm with Adaptive Selection of Local Searches (Page 1137) | [16] |
| prcga saw | Benchmarking Projection-Based Real Coded Genetic Algorithm on BBOB-2013 Noiseless Function Testbed (Page 1193) | [14] |
| ring100 hol | Benchmarking Cellular Genetic Algorithms on the BBOB Noiseless Testbed (Page 1201) | [7] |
| ring16 hol | Benchmarking Cellular Genetic Algorithms on the BBOB Noiseless Testbed (Page 1201) | [7] |
| simplex pal | Comparison of Multistart Global Optimization Algorithms on the BBOB Noiseless Testbed (Page 1153) | [13] |

Table 2: 03-D, running time excess $\mathrm{ERT}/\mathrm{ERT}_{\text{best 2009}}$ on $f_1$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f1** | *1.6e+1*:3.0 | *1.0e+1*:3.6 | *1.0e-8*:8.0 | *1.0e-8*:8.0 | *1.0e-8*:8.0 | 15/15 |
| BIPOP-aCMA | **2.6**(3) | **2.7**(2) | 13(0.2) | 13(0.2) | 13(0.2) | 15/15 |
| BIPOP-saAC | 3.0(3) | 3.4(3) | 21(1) | 21(1) | 21(1) | 15/15 |
| CMAES hut | 3.8(5) | 4.0(5) | $\infty$ | $\infty$ | $\infty$ *303* | 0/15 |
| DE pal | **1.5**(1) | **2.6**(2) | 115(11) | 115(11) | 115(11) | 15/15 |
| HCMA los | **1.8**(1) | **1.8**(1.0) | **1**(0)$^{\star 4}$ | **1**(0)$^{\star 4}$ | **1**(0)$^{\star 4}$ | 15/15 |
| HMLSL pal | **0.87**(0.7) | **1.1**(0.6) | **3.7**(1) | **3.7**(1) | **3.7**(1) | 15/15 |
| IPOP-10DDr | **1.9**(2) | **2.0**(2) | 52(2) | 52(2) | 52(2) | 15/15 |
| IPOP-500 l | **1.9**(2) | **2.0**(2) | 52(2) | 52(2) | 52(2) | 15/15 |
| IPOP-tany | **2.0**(2) | **2.7**(3) | 60(6) | 60(6) | 60(6) | 15/15 |
| IPOP-texp | **2.7**(3) | **2.9**(3) | 54(10) | 54(10) | 54(10) | 15/15 |
| IPOP lia | **1.9**(2) | **2.0**(2) | 52(2) | 52(2) | 52(2) | 15/15 |
| MLSL pal | **0.87**(0.7) | **1.1**(0.6) | **3.7**(1) | **3.7**(1) | **3.7**(1) | 15/15 |
| OQNLP pal | **2.1**(2) | **3.0**(2) | **2.9**(0.6) | **2.9**(0.6) | **2.9**(0.6) | 15/15 |
| P-DCN tra | **1.6**(2) | 3.2(3) | 482(252) | 482(252) | 482(252) | 15/15 |
| P-zero tra | **1.4**(2) | **2.4**(2) | 1959(1123) | 1959(1123) | 1959(1123) | 15/15 |
| SMAC hut | **0.69**(0.5) | **1.0**(0.7) | $\infty$ | $\infty$ | $\infty$ *300* | 0/15 |
| U-DCN tra | **1.4**(2) | **2.9**(3) | 2968(3565) | 2968(3565) | 2968(3565) | 15/15 |
| U-zero tra | **1.4**(2) | **2.5**(3) | 9.2e4(6e4) | 9.2e4(6e4) | 9.2e4(6e4) | 15/15 |
| fmincon pa | **0.87**(0.7) | **1.1**(0.6) | **3.7**(1) | **3.7**(1) | **3.7**(1) | 15/15 |
| fminunc pa | **1.0**(1) | **1.5**(1) | **1.1**(0) | **1.1**(0) | **1.1**(0) | 15/15 |
| ga100 hol | **2.9**(3) | **2.9**(3) | $\infty$ | $\infty$ | $\infty$ *2e5* | 0/15 |
| grid100 ho | **2.4**(4) | 3.2(3) | $\infty$ | $\infty$ | $\infty$ *2e5* | 0/15 |
| grid16 hol | **1.8**(2) | 4.1(5) | $\infty$ | $\infty$ | $\infty$ *2e5* | 0/15 |
| hill hol | 6.0(7) | 6.1(6) | 8.7e4(9e4) | 8.7e4(9e4) | 8.7e4(9e4) | 3/15 |
| lmmCMA aug | **1.0**(1) | **1.7**(2) | 9.0(0.9) | 9.0(0.9) | 9.0(0.9) | 15/15 |
| memPSODE v | **2.8**(2) | **2.8**(3) | 22(1) | 22(1) | 22(1) | 15/15 |
| prcga saw | **1.3**(1) | **1.5**(2) | 617(714) | 617(714) | 617(714) | 15/15 |
| ring100 ho | **1.5**(2) | **2.9**(5) | 8.9e4(9e4) | 8.9e4(9e4) | 8.9e4(9e4) | 3/15 |
| ring16 hol | **1.4**(1) | 4.0(7) | 1.3e5(2e5) | 1.3e5(1e5) | 1.3e5(1e5) | 2/15 |
| simplex pa | 6.1(8) | 11(13) | 35(6) | 35(6) | 35(6) | 15/15 |

3

Table 3: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_2$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f2** | *6.3e+6*:1.5 | *6.3e+5*:4.3 | *4.0e+4*:10 | *1.0e+2*:32 | *1.0e-8*:49 | 15/15 |
| BIPOP-aCMA | **1.7**(2) | **2.7**(3) | **2.3**(2) | **1.9**(0.2) | **3.3**(0.2) | 15/15 |
| BIPOP-saAC | **2.9**(4) | **2.1**(2) | **2.9**(4) | 3.9(1) | 6.1(0.7) | 15/15 |
| CMAES hut | **1.1**(1.0) | **1.1**(2) | 3.3(3) | 10(6) | ∞ *303* | 0/15 |
| DE pal | **1.2**(0.7) | **0.95**(0.9) | 3.5(4) | 6.9(2) | 27(1) | 15/15 |
| HCMA los | **1.3**(2) | **1.4**(0.8) | **0.96**(0.3) | **1.1**(0.8) | **4.6**(3) | 15/15 |
| HMLSL pal | **1.7**(1) | 3.3(2) | **2.4**(1) | **1.4**(0.6) | 6.2(6) | 15/15 |
| IPOP-10DDr | **1.3**(0.7) | **1.9**(1) | **2.2**(2) | 8.6(5) | 26(3) | 15/15 |
| IPOP-500 l | **1.3**(0.7) | **1.9**(1) | **2.2**(2) | 8.6(5) | 26(3) | 15/15 |
| IPOP-tany | **1.9**(0.7) | **2.2**(2) | **2.1**(2) | 7.7(4) | 25(2) | 15/15 |
| IPOP-texp | 5.2(11) | 3.2(5) | **2.8**(3) | 9.0(4) | 26(2) | 15/15 |
| IPOP lia | **1.3**(0.7) | **1.9**(1) | **2.2**(2) | 8.6(5) | 26(3) | 15/15 |
| MLSL pal | **1.7**(1) | 3.3(2) | **2.4**(1) | **1.4**(0.6) | **5.2**(4) | 15/15 |
| OQNLP pal | 4.1(5) | 3.3(0.2) | **2.7**(2) | **1.4**(0.4) | 152(181) | 5/15 |
| P-DCN tra | **1.1**(0.3) | **2.4**(4) | 5.1(5) | 10(11) | 852(958) | 15/15 |
| P-zero tra | **1.1**(0.3) | **2.1**(4) | 4.1(6) | 11(10) | 6.8e4(7e4) | 9/15 |
| SMAC hut | **1.1**(1.0) | **0.77**(0.5) | **1.0**(0.7) | 4.5(3) | ∞ *300* | 0/15 |
| U-DCN tra | **1.1**(0.3) | **1.4**(2) | 6.0(7) | 45(38) | 1.5e4(3e4) | 13/15 |
| U-zero tra | **1.1**(0.3) | **1.3**(2) | 4.3(4) | 65(74) | ∞ *3e6* | 0/15 |
| fmincon pa | **1.7**(1) | 3.3(2) | **2.4**(1) | **1.4**(0.6) | 5.6(5) | 15/15 |
| fminunc pa | **2.0**(3) | **2.2**(1) | **1.3**(0.6) | **1.9**(0.8) | **4.7**(1) | 15/15 |
| ga100 hol | **1.5**(1) | **1.8**(1) | 5.6(5) | 44(29) | ∞ *2e5* | 0/15 |
| grid100 ho | **1.3**(0.7) | **1.8**(2) | 3.3(4) | 70(54) | ∞ *2e5* | 0/15 |
| grid16 hol | **1.5**(1) | **1.2**(0.9) | 5.0(7) | 31(38) | ∞ *2e5* | 0/15 |
| hill hol | 5.2(4) | 4.1(4) | 6.5(6) | 20(14) | ∞ *2e5* | 0/15 |
| lmmCMA aug | **2.0**(2) | **1.8**(2) | **1.5**(1) | **2.3**(0.6) | **5.0**(0.8) | 15/15 |
| memPSODE v | **2.7**(2) | **1.8**(2) | 3.0(2) | 3.5(0.5) | 6.1(1.0) | 15/15 |
| prcga saw | **1.2**(1.0) | **1.3**(1) | 3.5(4) | 10(5) | 698(946) | 15/15 |
| ring100 ho | **1.3**(0.7) | **0.95**(0.8) | **1.9**(3) | 51(29) | ∞ *2e5* | 0/15 |
| ring16 hol | **1.6**(1.0) | **1.4**(1) | 8.7(9) | 28(25) | ∞ *2e5* | 0/15 |
| simplex pa | 11(14) | 10(1) | 4.8(1.0) | 6.4(2) | 12(3) | 15/15 |

Table 4: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_3$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f3** | *1.0e+2*:2.2 | *6.3e+1*:6.1 | *4.0e+1*:10 | *1.6e+1*:32 | *4.0e+0*:319 | 15/15 |
| BIPOP-aCMA | **2.5**(3) | **1.8**(1) | **2.0**(0.3) | **1.6**(0.6) | **0.47**(0.1) | 15/15 |
| BIPOP-saAC | 3.7(3) | **2.7**(2) | **2.2**(1) | **2.5**(2) | **1.8**(2) | 15/15 |
| CMAES hut | 5.6(8) | **2.9**(3) | 3.1(4) | **2.7**(1) | **1.6**(2) | 7/15 |
| DE pal | **2.2**(2) | **1.9**(1) | **2.0**(1) | 2.9(2) | **1.1**(0.5) | 15/15 |
| HCMA los | 3.1(3) | **2.0**(2) | 1.9(2) | **1.5**(0.9) | **0.66**(0.3) | 15/15 |
| HMLSL pal | 5.0(4) | 4.8(9) | 5.5(6) | 7.5(5) | **1.6**(0.5) | 15/15 |
| IPOP-10DDr | **1.8**(2) | **1.7**(2) | **2.5**(2) | **2.0**(1) | **2.7**(3) | 15/15 |
| IPOP-500 l | **1.8**(2) | **1.7**(2) | **2.5**(2) | **2.0**(1) | **2.7**(3) | 15/15 |
| IPOP-tany | **1.8**(2) | **1.7**(2) | **2.2**(2) | 4.7(2) | **2.9**(3) | 15/15 |
| IPOP-texp | **2.1**(3) | **1.3**(1) | **1.7**(2) | 3.7(2) | 3.6(2) | 15/15 |
| IPOP lia | **1.8**(2) | **1.7**(2) | **2.5**(2) | **2.0**(1) | **2.7**(3) | 15/15 |
| MLSL pal | 4.8(4) | 4.7(7) | 6.3(8) | 7.2(7) | **2.8**(2) | 15/15 |
| OQNLP pal | 21(36) | 15(14) | 15(14) | 10(5) | **2.7**(2) | 15/15 |
| P-DCN tra | **2.0**(3) | **2.4**(2) | 4.5(4) | 80(230) | 95(118) | 15/15 |
| P-zero tra | **2.5**(3) | 3.6(2) | 7.9(3) | 81(92) | 50(32) | 15/15 |
| SMAC hut | **0.97**(1) | **0.98**(1.0) | **1.0**(1) | 4.4(3) | 3.2(3) | 4/15 |
| U-DCN tra | **1.9**(3) | **2.4**(3) | **2.4**(2) | 4.0(3) | **1.2**(0.8) | 15/15 |
| U-zero tra | **2.5**(3) | **2.1**(2) | **2.1**(2) | **2.1**(2) | **0.83**(0.7) | 15/15 |
| fmincon pa | 5.2(4) | 4.8(8) | 5.6(6) | 7.1(7) | 3.2(4) | 15/15 |
| fminunc pa | 4.3(9) | 5.4(6) | 10(10) | 8.7(6) | **2.2**(2) | 15/15 |
| ga100 hol | **2.5**(2) | **2.5**(3) | 4.7(5) | 10(8) | 3.4(1) | 15/15 |
| grid100 ho | **1.1**(0.9) | **1.1**(0.9) | **2.9**(3) | 17(13) | 7.3(4) | 15/15 |
| grid16 hol | **1.5**(1) | **1.9**(3) | 4.5(5) | 6.1(4) | **2.3**(2) | 15/15 |
| hill hol | 6.2(7) | 3.1(3) | **2.1**(2) | **2.1**(1) | **0.60**(0.3) | 15/15 |
| lmmCMA aug | **1.4**(3) | **1.2**(1) | **1.5**(1) | **1.5**(0.8) | **1.3**(2) | 15/15 |
| memPSODE v | 4.2(3) | **2.8**(3) | 4.1(3) | 8.2(11) | 6.3(7) | 15/15 |
| prcga saw | **1.6**(2) | **1.0**(0.9) | **1.7**(2) | 3.8(1) | **2.1**(0.9) | 15/15 |
| ring100 ho | **1.5**(2) | **1.5**(2) | 3.8(5) | 14(12) | 5.6(2) | 15/15 |
| ring16 hol | **2.2**(3) | **2.5**(4) | 4.0(4) | 5.9(4) | **1.8**(1) | 15/15 |
| simplex pa | 45(73) | 29(30) | 24(17) | 15(7) | 5.4(4) | 15/15 |

Table 5: 03-D, running time excess $\mathrm{ERT}/\mathrm{ERT}_{\text{best 2009}}$ on $f_4$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f4** | *1.0e+2*:5.4 | *6.3e+1*:10 | *6.3e+1*:10 | *2.5e+1*:36 | *4.0e+0*:617 | 15/15 |
| BIPOP-aCMA | **2.9**(2) | **2.9**(2) | **2.9**(2) | **2.0**(1) | **2.9**(6) | 15/15 |
| BIPOP-saAC | **0.98**(1) | **1.0**(1) | **1.0**(1) | **1.7**(1) | **2.6**(3) | 15/15 |
| CMAES hut | **1.8**(2) | **2.0**(2) | **2.0**(2) | **2.8**(2) | 3.5(4) | 2/15 |
| DE pal | **1.8**(2) | **2.1**(2) | **2.1**(2) | **2.7**(2) | **0.78**(0.3) | 15/15 |
| HCMA los | **2.8**(3) | **2.6**(2) | **2.6**(2) | **1.7**(1) | **1.0**(2) | 15/15 |
| HMLSL pal | **2.0**(1) | **2.3**(2) | **2.3**(2) | 3.7(4) | **1.1**(0.7) | 15/15 |
| IPOP-10DDr | **1.6**(2) | **2.7**(2) | **2.7**(2) | **1.9**(1) | 4.5(5) | 15/15 |
| IPOP-500 l | **1.6**(2) | **2.7**(2) | **2.7**(2) | **1.9**(1) | 4.6(5) | 15/15 |
| IPOP-tany | **1.5**(2) | **1.7**(2) | **1.7**(2) | **1.8**(0.9) | 4.7(5) | 15/15 |
| IPOP-texp | **0.91**(1) | **1.2**(2) | **1.2**(2) | 3.0(2) | 4.6(6) | 15/15 |
| IPOP lia | **1.6**(2) | **2.7**(2) | **2.7**(2) | **1.9**(1) | 4.6(5) | 15/15 |
| MLSL pal | **1.9**(1) | **2.3**(2) | **2.3**(2) | 3.8(4) | 3.5(4) | 15/15 |
| OQNLP pal | 5.0(15) | 9.1(10) | 9.1(10) | 6.6(5) | 5.7(6) | 11/15 |
| P-DCN tra | **2.5**(2) | 4.9(5) | 4.9(5) | 11(8) | 28(33) | 15/15 |
| P-zero tra | **2.7**(3) | 6.1(3) | 6.1(3) | 196(235) | 76(112) | 15/15 |
| SMAC hut | **0.38**(0.5) | **1.4**(1) | **1.4**(1) | **2.8**(3) | $\infty$ *300* | 0/15 |
| U-DCN tra | **1.8**(1) | **2.6**(2) | **2.6**(2) | **2.7**(2) | **1.1**(0.8) | 15/15 |
| U-zero tra | **2.0**(1) | **2.3**(2) | **2.3**(2) | **1.7**(0.9) | **1.6**(2) | 15/15 |
| fmincon pa | **2.0**(1) | **2.1**(2) | **2.1**(2) | 3.7(3) | 4.2(4) | 15/15 |
| fminunc pa | **2.6**(6) | 4.0(5) | 4.0(5) | 6.3(8) | 4.0(3) | 15/15 |
| ga100 hol | **1.8**(1) | **1.7**(2) | **1.7**(2) | 7.9(6) | **2.8**(1) | 15/15 |
| grid100 ho | **1.3**(1) | 3.6(3) | 3.6(3) | 17(12) | 7.5(5) | 15/15 |
| grid16 hol | **2.2**(2) | 4.1(4) | 4.1(4) | 4.8(2) | **1.5**(0.7) | 15/15 |
| hill hol | **2.9**(3) | **1.8**(2) | **1.8**(2) | **1.3**(0.9) | **0.59**(0.5) | 15/15 |
| lmmCMA aug | **0.40**(0.2) | **0.95**(0.9) | **0.95**(0.9) | **1.5**(0.7) | **1.8**(2) | 13/15 |
| memPSODE v | 3.6(3) | 3.9(3) | 3.9(3) | 5.7(6) | 4.3(3) | 15/15 |
| prcga saw | **1.0**(0.8) | **1.9**(2) | **1.9**(2) | 3.2(2) | 3.8(3) | 15/15 |
| ring100 ho | **1.6**(3) | **2.1**(2) | **2.1**(2) | 10(11) | 4.7(1) | 15/15 |
| ring16 hol | **1.5**(3) | 3.4(4) | 3.4(4) | 5.5(3) | **1.3**(0.6) | 15/15 |
| simplex pa | 11(22) | 17(20) | 17(20) | 8.7(7) | 4.8(6) | 15/15 |

Table 6: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_5$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f5** | *4.0e+1*:2.2 | *2.5e+1*:4.8 | *1.0e-8*:6.6 | *1.0e-8*:6.6 | *1.0e-8*:6.6 | 15/15 |
| BIPOP-aCMA | **2.3**(1) | **1.3**(0.2) | **1.2**(0) | **1.2**(0) | **1.2**(0) | 15/15 |
| BIPOP-saAC | 3.7(3) | **2.5**(2) | 5.7(2) | 5.7(2) | 5.7(2) | 15/15 |
| CMAES hut | 5.2(4) | 3.6(2) | 6.0(4) | 6.0(4) | 6.0(4) | 15/15 |
| DE pal | **2.5**(3) | 3.8(6) | 486(27) | 486(27) | 486(27) | 15/15 |
| HCMA los | **2.0**(1) | **1.1**(0.5) | **1.6**(0.5) | **1.6**(0.5) | **1.6**(0.5) | 15/15 |
| HMLSL pal | **2.3**(0) | **1.0**(0) | 21(27) | 21(27) | 21(27) | 15/15 |
| IPOP-10DDr | **1.6**(2) | **2.3**(1) | 16(33) | 16(33) | 16(33) | 15/15 |
| IPOP-500 l | **1.6**(2) | **2.3**(1) | 16(33) | 16(33) | 16(33) | 15/15 |
| IPOP-tany | 4.9(5) | 3.2(2) | 8.2(6) | 8.2(6) | 8.2(6) | 15/15 |
| IPOP-texp | 13(13) | 7.3(7) | 40(32) | 40(32) | 40(32) | 15/15 |
| IPOP lia | **1.6**(2) | **2.3**(1) | 16(33) | 16(33) | 16(33) | 15/15 |
| MLSL pal | **2.3**(0) | **1.0**(0) | 37(54) | 37(54) | 37(54) | 15/15 |
| OQNLP pal | 7.3(0) | 3.5(0) | **3.0**(0) | **3.0**(0) | **3.0**(0) | 15/15 |
| P-DCN tra | **1.9**(1) | **2.0**(1) | 218(47) | 218(47) | 218(47) | 15/15 |
| P-zero tra | **1.9**(1) | 4.0(7) | 146(59) | 146(59) | 146(59) | 15/15 |
| SMAC hut | **1.8**(0.9) | **1.2**(0.4) | **1.1**(0.2) | **1.1**(0.2) | **1.1**(0.2) | 15/15 |
| U-DCN tra | **1.9**(1) | **2.8**(2) | ∞ | ∞ | ∞ *3e6* | 0/15 |
| U-zero tra | **1.9**(1) | **2.2**(2) | ∞ | ∞ | ∞ *3e6* | 0/15 |
| fmincon pa | **2.3**(0) | **1.0**(0) | 34(97) | 34(97) | 34(97) | 15/15 |
| fminunc pa | 4.1(0) | **1.9**(0) | **3.2**(0) | **3.2**(0) | **3.2**(0) | 15/15 |
| ga100 hol | **1.6**(1) | **2.5**(3) | 104(20) | 104(20) | 104(20) | 15/15 |
| grid100 ho | **2.8**(2) | 4.3(4) | 154(89) | 154(89) | 154(89) | 15/15 |
| grid16 hol | **2.8**(2) | 4.0(7) | 45(27) | 45(27) | 45(27) | 15/15 |
| hill hol | 6.6(7) | 4.4(4) | 8.1(6) | 8.1(6) | 8.1(6) | 15/15 |
| lmmCMA aug | 3.6(2) | **2.6**(1) | 4.4(2) | 4.4(2) | 4.4(2) | 15/15 |
| memPSODE v | **1**(0.7) | **1.1**(1) | 14(5) | 14(5) | 14(5) | 15/15 |
| prcga saw | 4.5(3) | 12(11) | ∞ | ∞ | ∞ *2e5* | 0/15 |
| ring100 ho | **2.3**(2) | 3.1(4) | 134(38) | 134(38) | 134(38) | 15/15 |
| ring16 hol | **2.4**(2) | 5.3(6) | 34(9) | 34(9) | 34(9) | 15/15 |
| simplex pa | 22(0.7) | 11(0.6) | 44(52) | 44(52) | 44(52) | 15/15 |

Table 7: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_6$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f6** | *6.3e+4*:1.8 | *6.3e+3*:3.7 | *4.0e+1*:13 | *1.0e+1*:34 | *6.3e-4*:159 | 15/15 |
| BIPOP-aCMA | **2.3**(2) | **2.8**(4) | **3.0**(2) | **2.7**(2) | 3.0(0.3) | 15/15 |
| BIPOP-saAC | 3.8(4) | 4.5(3) | **2.9**(3) | 3.3(2) | 3.2(2) | 15/15 |
| CMAES hut | 4.5(4) | 3.5(3) | **2.6**(2) | **2.0**(1) | ∞ *303* | 0/15 |
| DE pal | **1.8**(2) | **2.6**(4) | 3.3(3) | 3.3(3) | 10(2) | 15/15 |
| HCMA los | **2.0**(2) | **1.6**(2) | **2.3**(2) | **2.9**(2) | 4.5(2) | 15/15 |
| HMLSL pal | **2.3**(2) | 3.1(3) | **2.4**(3) | **1.5**(1) | **1.2**(0.5) | 15/15 |
| IPOP-10DDr | **1.5**(1) | **2.0**(2) | **1.2**(1) | **2.2**(1) | 3.1(0.5) | 15/15 |
| IPOP-500 l | **1.5**(1) | **2.0**(2) | **1.2**(1) | **2.2**(1) | 3.1(0.5) | 15/15 |
| IPOP-tany | **1.5**(1) | **2.1**(2) | **1.5**(2) | **1.8**(0.9) | 3.4(0.7) | 15/15 |
| IPOP-texp | **2.8**(4) | 4.0(5) | **1.8**(2) | **1.8**(0.9) | 3.6(0.7) | 15/15 |
| IPOP lia | **1.5**(1) | **2.0**(2) | **1.2**(1) | **2.2**(1) | 3.1(0.5) | 15/15 |
| MLSL pal | **2.3**(2) | 3.1(3) | **2.4**(3) | **1.5**(1) | **1.2**(0.5) | 15/15 |
| OQNLP pal | 4.5(4) | 4.1(4) | **1.8**(1) | **1.4**(0.7) | **2.8**(2) | 15/15 |
| P-DCN tra | **1.3**(2) | 4.8(9) | 8.3(9) | 8.9(8) | 29(24) | 15/15 |
| P-zero tra | **1.3**(2) | **2.1**(2) | 13(26) | 11(18) | 47(91) | 15/15 |
| SMAC hut | **1.3**(0.8) | **1.4**(1) | **0.91**(1.0) | **1.1**(1) | ∞ *300* | 0/15 |
| U-DCN tra | **1.3**(2) | 3.1(5) | 3.8(5) | 3.6(3) | 489(741) | 15/15 |
| U-zero tra | **1.3**(2) | **2.1**(3) | **2.3**(3) | 3.4(3) | 3459(3552) | 14/15 |
| fmincon pa | **2.3**(2) | 3.1(3) | **2.4**(3) | **1.5**(1) | **1.2**(0.5) | 15/15 |
| fminunc pa | **2.8**(3) | 3.0(3) | **1.3**(0.9) | **2.4**(2) | **2.0**(0.8) | 15/15 |
| ga100 hol | **2.0**(3) | 3.0(6) | 3.7(5) | 10(7) | 2358(2624) | 5/15 |
| grid100 ho | **1.9**(2) | 5.3(10) | 4.2(3) | 10(13) | 4314(4995) | 3/15 |
| grid16 hol | **2.0**(3) | 4.4(5) | 4.9(6) | 5.1(5) | 1861(2272) | 6/15 |
| hill hol | 6.8(9) | 10(6) | 5.2(4) | 3.4(4) | 913(1010) | 9/15 |
| lmmCMA aug | **2.3**(2) | **2.5**(3) | **2.0**(2) | **2.6**(3) | **3.0**(1) | 15/15 |
| memPSODE v | **2.2**(2) | **2.5**(4) | **2.3**(2) | **2.0**(1.0) | **1.5**(0.5) | 15/15 |
| prcga saw | **2.4**(3) | 4.4(6) | 5.5(6) | 7.4(14) | 154(113) | 15/15 |
| ring100 ho | **2.1**(2) | 4.4(6) | 4.7(6) | 8.8(13) | 778(804) | 11/15 |
| ring16 hol | **1.7**(0.8) | 3.6(6) | 3.5(3) | 4.9(6) | 678(943) | 10/15 |
| simplex pa | 13(13) | 16(17) | 5.4(4) | 5.9(5) | 3.5(2) | 15/15 |

∞

Table 8: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_7$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f7** | *2.5e+2*:1.5 | *6.3e+1*:4.2 | *1.0e+1*:11 | *2.5e+0*:38 | *4.0e-1*:174 | 15/15 |
| BIPOP-aCMA | **2.6**(2) | **2.3**(2) | **3.0**(3) | **2.1**(2) | **1.0**(0.8) | 15/15 |
| BIPOP-saAC | **2.2**(2) | **2.0**(2) | **2.5**(2) | **1.7**(2) | **1.0**(0.7) | 15/15 |
| CMAES hut | **1.8**(2) | **1.7**(1) | **2.7**(2) | **2.1**(1) | **1.2**(1) | 12/15 |
| DE pal | **1.3**(1) | **2.8**(4) | 4.0(3) | 3.5(2) | **1.8**(0.7) | 15/15 |
| HCMA los | **2.8**(3) | **2.3**(1) | **1.9**(2) | **2.7**(4) | **1.2**(1) | 15/15 |
| HMLSL pal | **1.8**(2) | **1.9**(2) | 3.8(3) | 4.4(3) | **2.5**(1) | 15/15 |
| IPOP-10DDr | **1.6**(1.0) | **1.6**(2) | 4.2(2) | 3.7(3) | **2.0**(2) | 15/15 |
| IPOP-500 l | **1.6**(1.0) | **1.6**(2) | 4.2(2) | 3.7(3) | **2.0**(2) | 15/15 |
| IPOP-tany | **1.4**(1.0) | **1.7**(2) | 3.2(3) | **2.0**(1.0) | **1.0**(0.7) | 15/15 |
| IPOP-texp | **1.5**(1) | **1.9**(2) | **2.2**(1) | 4.7(10) | **2.8**(3) | 15/15 |
| IPOP lia | **1.6**(1.0) | **1.6**(2) | 4.2(2) | 3.7(3) | **2.0**(2) | 15/15 |
| MLSL pal | **2.0**(2) | **2.3**(2) | 4.7(6) | 15(13) | 63(57) | 14/15 |
| OQNLP pal | 4.1(6) | 4.8(3) | 4.9(6) | 4.8(2) | **2.4**(1) | 15/15 |
| P-DCN tra | **1.3**(0.7) | 8.1(2) | 40(70) | 978(53) | 282(194) | 15/15 |
| P-zero tra | **1.3**(0.7) | **1.9**(2) | 14(22) | 37(50) | 90(135) | 15/15 |
| SMAC hut | **1.1**(1) | **1.3**(2) | **1.2**(1) | **0.85**(0.7) | **0.82**(0.7) | 14/15 |
| U-DCN tra | **1.3**(0.7) | **2.0**(2) | 6.8(9) | 11(13) | 211(553) | 15/15 |
| U-zero tra | **1.3**(0.7) | **1.9**(2) | 4.4(4) | 5.8(4) | 295(746) | 15/15 |
| fmincon pa | **2.2**(3) | **2.2**(2) | 5.0(4) | 15(24) | 25(30) | 15/15 |
| fminunc pa | **2.0**(2) | **1.9**(2) | 4.0(4) | 10(10) | 42(53) | 15/15 |
| ga100 hol | **2.1**(2) | **1.5**(1) | 4.7(5) | 7.7(6) | 5.8(2) | 15/15 |
| grid100 ho | **1.6**(2) | **1.8**(2) | 5.6(4) | 14(16) | 34(70) | 15/15 |
| grid16 hol | **1.3**(1.0) | 3.7(2) | 6.1(6) | 7.1(4) | 11(14) | 15/15 |
| hill hol | **2.7**(3) | 3.4(3) | 6.0(7) | 10(22) | 79(108) | 15/15 |
| lmmCMA aug | **1.2**(1.0) | **1.4**(2) | **1.5**(1) | **2.6**(4) | **1.4**(2) | 15/15 |
| memPSODE v | **2.6**(2) | **2.6**(2) | 6.3(3) | 23(29) | 16(16) | 15/15 |
| prcga saw | **1.7**(1) | **1.5**(1) | **2.6**(4) | 3.1(3) | 5.2(5) | 15/15 |
| ring100 ho | **1.4**(1.0) | **2.0**(3) | 3.4(3) | 8.6(8) | 10(5) | 15/15 |
| ring16 hol | **1.9**(1) | **1.3**(1) | 5.0(6) | 3.9(6) | 8.4(13) | 15/15 |
| simplex pa | **2.3**(3) | **2.2**(2) | **2.9**(3) | 6.3(5) | 15(17) | 15/15 |

Table 9: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_8$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f8** | *1.0e+4*:1.8 | *1.6e+3*:4.0 | *1.0e+2*:15 | *6.3e+0*:31 | *1.0e-1*:152 | 15/15 |
| BIPOP-aCMA | **1.7**(1) | **2.5**(3) | 5.2(3) | 4.4(1) | 4.0(1) | 15/15 |
| BIPOP-saAC | **2.2**(2) | **2.1**(2) | **2.1**(2) | **2.9**(1) | **2.0**(0.9) | 15/15 |
| CMAES hut | 3.5(4) | **2.9**(3) | 3.5(2) | 4.4(3) | 30(30) | 1/15 |
| DE pal | **1.1**(0.8) | **2.4**(3) | 4.8(4) | 6.7(4) | 9.4(5) | 15/15 |
| HCMA los | **2.1**(2) | **2.1**(1) | **2.0**(2) | 4.3(4) | **2.7**(1) | 15/15 |
| HMLSL pal | **1.1**(1) | **1.4**(1) | **1.0**(1) | **1.0**(0.4) | **0.63**(0.5) | 15/15 |
| IPOP-10DDr | **1.1**(0.6) | 3.3(3) | **2.8**(1) | 3.1(1) | 5.0(3) | 15/15 |
| IPOP-500 l | **1.1**(0.6) | 3.3(3) | **2.8**(1) | 3.1(1) | 5.0(3) | 15/15 |
| IPOP-tany | **2.0**(3) | **2.5**(2) | **2.0**(1) | **2.4**(1) | 4.7(2) | 15/15 |
| IPOP-texp | **3.0**(6) | 4.0(4) | **2.7**(2) | **2.6**(1) | 4.7(4) | 15/15 |
| IPOP lia | **1.1**(0.6) | 3.3(3) | **2.8**(1) | 3.1(1) | 5.0(3) | 15/15 |
| MLSL pal | **1.1**(1) | **1.4**(1) | **1.0**(1) | **1.0**(0.4) | **0.63**(0.5) | 15/15 |
| OQNLP pal | **2.0**(4) | **2.4**(2) | **1.3**(1) | **1.1**(0.6) | **0.69**(0.3) | 15/15 |
| P-DCN tra | **1.9**(4) | 3.5(4) | 13(16) | 16(12) | 198(183) | 15/15 |
| P-zero tra | **1.9**(4) | 3.1(4) | 10(13) | 180(393) | 521(459) | 15/15 |
| SMAC hut | **0.89**(0.6) | **0.75**(0.6) | **1.4**(2) | 4.7(4) | 9.3(11) | 3/15 |
| U-DCN tra | **1.8**(2) | **2.8**(2) | 5.1(4) | 9.0(5) | 2671(3435) | 15/15 |
| U-zero tra | **1.9**(3) | **2.8**(3) | 3.8(2) | 8.5(8) | 6.0e4(7e4) | 4/15 |
| fmincon pa | **1.1**(1) | **1.4**(1) | **1.0**(1) | **1.0**(0.4) | **0.63**(0.6) | 15/15 |
| fminunc pa | **1**(1) | **1.2**(2) | **1.1**(1.0) | **0.90**(0.6) | **0.73**(0.3) | 15/15 |
| ga100 hol | **2.2**(1) | **2.0**(2) | 3.2(3) | 19(16) | 238(304) | 15/15 |
| grid100 ho | **1.6**(2) | **2.5**(3) | 9.4(11) | 34(29) | 1721(2020) | 6/15 |
| grid16 hol | **1.9**(2) | 3.4(4) | 7.0(5) | 12(8) | 4090(4947) | 3/15 |
| hill hol | 5.4(4) | 5.0(4) | **2.9**(2) | 5.1(3) | 1666(1980) | 6/15 |
| lmmCMA aug | **1.1**(0.8) | **1.3**(2) | **1.6**(1) | **1.6**(0.5) | **1.1**(0.3) | 15/15 |
| memPSODE v | **2.2**(2) | **2.5**(2) | 3.5(2) | **2.7**(0.3) | **1.1**(0.7) | 15/15 |
| prcga saw | **1.6**(1) | **1.8**(2) | **2.0**(2) | 4.5(3) | 258(259) | 14/15 |
| ring100 ho | **1.4**(1) | **2.2**(3) | 5.2(11) | 29(23) | 106(75) | 15/15 |
| ring16 hol | **2.0**(1) | 3.5(6) | 6.0(4) | 11(7) | 787(999) | 9/15 |
| simplex pa | 4.7(11) | 8.1(6) | 5.3(5) | 4.2(4) | **1.8**(0.9) | 15/15 |

Table 10: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_9$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f9** | *1.0e+1*:21 | *6.3e+0*:25 | *4.0e+0*:32 | *2.5e+0*:48 | *6.3e-3*:152 | 15/15 |
| BIPOP-aCMA | 4.5(2) | 5.8(5) | 6.3(10) | 5.9(10) | 5.9(4) | 15/15 |
| BIPOP-saAC | **2.9**(2) | **2.7**(0.8) | **2.4**(0.9) | **2.2**(2) | **2.4**(0.8) | 15/15 |
| CMAES hut | 3.4(1) | 3.6(3) | 3.9(2) | 4.3(4) | $\infty$ *303* | 0/15 |
| DE pal | 8.6(4) | 8.4(3) | 8.0(5) | 6.8(3) | 12(4) | 15/15 |
| HCMA los | **2.7**(3) | 3.0(3) | 3.3(2) | 3.6(2) | 3.0(1) | 15/15 |
| HMLSL pal | **0.53**(0)$_{\downarrow 4}$ | **0.44**(0)$_{\downarrow 4}$ | **0.34**(0)$_{\downarrow 4}$ | **0.23**(0)$_{\downarrow 4}$ | **0.48**(0.0) | 15/15 |
| IPOP-10DDr | 4.3(3) | 4.3(2) | 4.7(1) | 4.6(4) | 6.6(3) | 15/15 |
| IPOP-500 l | 4.3(3) | 4.3(2) | 4.7(1) | 4.6(4) | 6.6(3) | 15/15 |
| IPOP-tany | 3.0(1) | 3.1(1) | 3.1(1) | 4.2(5) | 6.1(2) | 15/15 |
| IPOP-texp | **1.9**(1) | **1.9**(1) | **1.8**(1) | 3.1(3) | 6.4(3) | 15/15 |
| IPOP lia | 4.3(3) | 4.3(2) | 4.7(1) | 4.6(4) | 6.6(3) | 15/15 |
| MLSL pal | **0.53**(0)$_{\downarrow 4}$ | **0.44**(0)$_{\downarrow 4}$ | **0.34**(0)$_{\downarrow 4}$ | **0.23**(0)$_{\downarrow 4}$ | **0.48**(0.0) | 15/15 |
| OQNLP pal | **0.48**(0)$_{\downarrow 4}$ | **0.45**(0.0)$_{\downarrow 4}$ | **0.37**(0)$_{\downarrow 4}$ | **0.25**(0)$_{\downarrow 4}$ | **0.49**(0.0) | 15/15 |
| P-DCN tra | 13(15) | 493(1602) | 755(2628) | 557(1843) | 668(681) | 15/15 |
| P-zero tra | 13(13) | 1684(4202) | 2231(5617) | 1639(4261) | 1468(1665) | 15/15 |
| SMAC hut | 7.0(6) | 7.9(5) | 12(12) | 14(13) | $\infty$ *300* | 0/15 |
| U-DCN tra | 14(13) | 18(14) | 80(95) | 58(65) | 2.9e4(3e4) | 7/15 |
| U-zero tra | 10(7) | 21(16) | 45(48) | 33(36) | $\infty$ *3e6* | 0/15 |
| fmincon pa | **0.53**(0)$_{\downarrow 4}$ | **0.44**(0)$_{\downarrow 4}$ | **0.34**(0)$_{\downarrow 4}$ | **0.23**(0)$_{\downarrow 4}$ | **0.48**(0.0) | 15/15 |
| fminunc pa | **0.43**(0)$^{\star}_{\downarrow 4}$ | **0.36**(0)$^{\star 2}_{\downarrow 4}$ | **0.28**(0)$^{\star 2}_{\downarrow 4}$ | **0.19**(0)$^{\star 2}_{\downarrow 4}$ | **0.45**(0.0) | 15/15 |
| ga100 hol | 16(11) | 18(10) | 20(12) | 21(11) | 2302(2489) | 5/15 |
| grid100 ho | 31(19) | 41(39) | 50(50) | 52(42) | 1.4e4(2e4) | 1/15 |
| grid16 hol | 17(13) | 130(38) | 104(33) | 75(22) | 1.5e4(2e4) | 1/15 |
| hill hol | 7.2(8) | 64(19) | 68(91) | 292(220) | 1.4e4(2e4) | 1/15 |
| lmmCMA aug | **1.6**(0.6) | **1.6**(0.5) | **1.4**(0.3) | **1.1**(0.5) | **1.5**(0.4) | 15/15 |
| memPSODE v | 3.8(0.6) | 3.7(0.7) | 3.2(1) | **2.7**(2) | **1.6**(0.7) | 15/15 |
| prcga saw | 4.8(4) | 5.3(4) | 4.7(3) | 3.5(2) | 1393(1626) | 9/15 |
| ring100 ho | 30(28) | 46(24) | 44(25) | 32(18) | 1010(1097) | 9/15 |
| ring16 hol | 13(7) | 13(8) | 14(11) | 17(10) | $\infty$ *2e5* | 0/15 |
| simplex pa | **1.3**(0.0) | **1.4**(0.1) | **1.6**(0.7) | **1.2**(0.6) | **1.5**(0.2) | 15/15 |

Table 11: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_{10}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f10** | *6.3e+6*:1.7 | *1.6e+5*:4.4 | *4.0e+4*:12 | *4.0e+2*:37 | *1.0e+0*:152 | 15/15 |
| BIPOP-aCMA | **1.2**(0.6) | 3.5(4) | **2.2**(2) | 5.7(2) | 3.8(0.7) | 15/15 |
| BIPOP-saAC | **2.0**(3) | **2.8**(3) | 2.4(3) | **2.8**(0.7) | **1.3**(0.3) | 15/15 |
| CMAES hut | **2.0**(2) | 4.0(3) | **2.2**(2) | 4.8(2) | ∞ *303* | 0/15 |
| DE pal | **1.4**(2) | 3.9(4) | **2.2**(2) | 8.7(4) | 10(5) | 15/15 |
| HCMA los | **1.8**(1) | **2.3**(0.9) | **1.7**(1) | 3.3(2) | **1.7**(0.2) | 15/15 |
| HMLSL pal | **1.5**(2) | 3.6(5) | **1.7**(2) | **1.1**(0.9) | **0.38**(0.2) | 15/15 |
| IPOP-10DDr | **0.88**(0.3) | **1.9**(2) | 3.6(6) | 7.2(4) | 5.8(1) | 15/15 |
| IPOP-500 l | **0.88**(0.3) | **1.9**(2) | 3.6(6) | 7.2(4) | 5.8(1) | 15/15 |
| IPOP-tany | **0.88**(0.3) | **2.1**(3) | 2.1(2) | 7.6(3) | 5.5(2) | 15/15 |
| IPOP-texp | **0.92**(0.3) | **2.3**(2) | **1.4**(1) | 5.8(4) | 4.4(2) | 15/15 |
| IPOP lia | **0.88**(0.3) | **1.9**(2) | 3.6(6) | 7.2(4) | 5.8(1) | 15/15 |
| MLSL pal | **1.5**(2) | 3.6(5) | **1.7**(2) | **1.1**(0.9) | **0.38**(0.2) | 15/15 |
| OQNLP pal | 3.2(4) | 3.5(2) | **1.4**(0.3) | **1.1**(0.4) | **0.45**(0.2) | 15/15 |
| P-DCN tra | **1.4**(0.9) | 3.7(5) | 3.5(3) | 45(61) | 2188(3783) | 15/15 |
| P-zero tra | **1.4**(0.9) | **2.6**(3) | 2.5(2) | 46(54) | 1.0e4(1e4) | 12/15 |
| SMAC hut | **1.0**(0.9) | **1.2**(1) | **0.87**(0.5) | **2.3**(1) | ∞ *300* | 0/15 |
| U-DCN tra | **1.4**(0.9) | **2.7**(3) | 2.1(2) | 35(53) | 1.3e4(2e4) | 10/15 |
| U-zero tra | **1.4**(0.9) | **2.5**(2) | 3.2(4) | 79(129) | 2.8e4(3e4) | 7/15 |
| fmincon pa | **1.5**(2) | 3.6(5) | **1.7**(2) | **1.1**(0.9) | **0.38**(0.2) | 15/15 |
| fminunc pa | **1.6**(1) | **2.3**(2) | **1.1**(0.7) | **1.6**(1.0) | **0.95**(0.3) | 15/15 |
| ga100 hol | **1.1**(0.9) | 4.3(6) | 4.0(4) | 26(27) | 4164(4834) | 3/15 |
| grid100 ho | **1.4**(2) | 3.4(4) | **2.7**(3) | 66(80) | 1.4e4(2e4) | 1/15 |
| grid16 hol | **1**(0.6) | 3.7(3) | 3.4(4) | 55(90) | ∞ *2e5* | 0/15 |
| hill hol | 3.8(3) | 3.2(4) | **2.3**(2) | 36(24) | 6686(7813) | 2/15 |
| lmmCMA aug | **1.4**(2) | **2.5**(2) | **1.5**(1) | **1.5**(0.8) | **1.1**(0.3) | 15/15 |
| memPSODE v | **1.8**(1) | 4.3(3) | **3.0**(3) | **3.0**(0.6) | **1.6**(0.6) | 15/15 |
| prcga saw | **1.2**(1) | **2.9**(2) | **2.0**(2) | 254(418) | 1987(2588) | 7/15 |
| ring100 ho | **1.3**(1) | **2.0**(3) | 3.2(4) | 36(35) | 3262(3630) | 4/15 |
| ring16 hol | **1.4**(0.9) | **2.7**(2) | 4.1(4) | 36(31) | 3088(3714) | 4/15 |
| simplex pa | 8.9(13) | 8.7(5) | 3.8(1) | 5.5(2) | **2.7**(1) | 15/15 |

Table 12: 03-D, running time excess $\mathrm{ERT}/\mathrm{ERT}_{\text{best 2009}}$ on $f_{11}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f11** | *2.5e+6*:1.9 | *4.0e+5*:4.5 | *6.3e+4*:9.4 | *2.5e+1*:36 | *2.5e-1*:174 | 15/15 |
| BIPOP-aCMA | **1.5**(1) | 3.1(3) | **2.3**(2) | 11(5) | 3.4(0.9) | 15/15 |
| BIPOP-saAC | 4.0(4) | **2.3**(2) | **2.0**(2) | 4.4(2) | **1.2**(0.2) | 15/15 |
| CMAES hut | **2.2**(2) | **1.8**(2) | **2.1**(2) | 22(22) | $\infty$ *303* | 0/15 |
| DE pal | **1.6**(1) | **1.9**(2) | **2.8**(3) | 12(6) | 8.9(2) | 15/15 |
| HCMA los | **2.6**(2) | **1.8**(1) | **1.2**(0.3) | 3.4(3) | **1.4**(0.2) | 15/15 |
| HMLSL pal | **2.6**(2) | **1.8**(0.6) | **1.2**(0.5) | **0.61**(0.2) | **0.18**(0.0) | 15/15 |
| IPOP-10DDr | **1.8**(2) | **1.9**(2) | **2.0**(2) | 15(10) | 5.6(1) | 15/15 |
| IPOP-500 l | **1.8**(2) | **1.9**(2) | **2.0**(2) | 15(10) | 5.6(1) | 15/15 |
| IPOP-tany | **2.1**(1) | **2.4**(2) | **2.3**(2) | 12(10) | 5.3(0.9) | 15/15 |
| IPOP-texp | 5.3(7) | 3.3(4) | **2.5**(2) | 11(9) | 5.1(0.9) | 15/15 |
| IPOP lia | **1.8**(2) | **1.9**(2) | **2.0**(2) | 15(10) | 5.6(1) | 15/15 |
| MLSL pal | **2.6**(2) | **1.8**(0.6) | **1.2**(0.5) | **0.61**(0.2) | **0.18**(0.0) | 15/15 |
| OQNLP pal | 5.1(4) | 3.2(0.6) | **1.8**(0.2) | **1.3**(0.3) | **0.46**(0.1) | 15/15 |
| P-DCN tra | **1.9**(2) | **2.1**(2) | **1.8**(1) | 61(134) | 394(233) | 15/15 |
| P-zero tra | **1.9**(2) | **2.3**(2) | **2.5**(3) | 395(617) | 843(369) | 15/15 |
| SMAC hut | **1.5**(1) | **1.1**(1) | **0.82**(0.4) | 3.1(3) | $\infty$ *300* | 0/15 |
| U-DCN tra | **1.7**(2) | **1.7**(1) | **2.0**(2) | 21(30) | 5109(4419) | 15/15 |
| U-zero tra | **1.9**(2) | **1.8**(2) | **2.2**(2) | 74(131) | 4146(5594) | 15/15 |
| fmincon pa | **2.6**(2) | **1.8**(0.6) | **1.2**(0.5) | **0.61**(0.2) | **0.18**(0.0) | 15/15 |
| fminunc pa | **2.7**(2) | **1.8**(1) | **1.2**(0.6) | **0.77**(0.3) | **0.98**(1.0) | 15/15 |
| ga100 hol | **1.3**(2) | **1.1**(0.9) | **2.2**(2) | 690(2107) | 5933(6311) | 2/15 |
| grid100 ho | **1.8**(2) | **1.4**(2) | **2.1**(2) | 806(2111) | 1.3e4(1e4) | 1/15 |
| grid16 hol | **1.6**(2) | **1.4**(1) | **3.0**(3) | 155(306) | 1861(1729) | 6/15 |
| hill hol | 6.2(10) | 3.5(5) | **2.0**(3) | 195(236) | 2782(3025) | 4/15 |
| lmmCMA aug | 3.2(3) | **2.2**(2) | **1.6**(0.8) | **2.0**(1) | **1.1**(0.3) | 15/15 |
| memPSODE v | **2.2**(2) | **1.4**(0.6) | **1.6**(2) | 4.6(2) | **1.7**(0.4) | 15/15 |
| prcga saw | **1.2**(1) | **1.1**(1) | **1.3**(1) | 38(9) | 2154(2461) | 5/15 |
| ring100 ho | **1.2**(1) | **1.2**(1) | **1.8**(2) | 36(39) | 1077(1297) | 8/15 |
| ring16 hol | **1.9**(2) | **2.0**(2) | **1.4**(1) | 54(72) | 1339(1451) | 7/15 |
| simplex pa | 15(12) | 9.2(1) | 4.9(0.7) | 3.2(2) | 3.5(0.9) | 15/15 |

13

Table 13: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_{12}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f12** | *1.0e+8*:1.5 | *1.0e+7*:3.6 | *6.3e+5*:13 | *6.3e+2*:31 | *1.0e+0*:168 | 15/15 |
| BIPOP-aCMA | **1.0**(0.7) | 3.2(3) | 3.6(2) | 6.1(2) | 8.4(9) | 15/15 |
| BIPOP-saAC | **2.6**(3) | 3.4(4) | **2.9**(2) | 3.2(0.4) | 3.6(6) | 15/15 |
| CMAES hut | **0.96**(0.7) | **1.6**(2) | **2.5**(2) | 5.0(2) | 27(28) | 1/15 |
| DE pal | **1.8**(1) | **1.9**(2) | **2.6**(3) | 15(6) | 27(27) | 15/15 |
| HCMA los | **0.91**(0.7) | **1.9**(2) | **1.3**(0.5) | **2.8**(2) | 4.6(5) | 15/15 |
| HMLSL pal | **1**(1) | **1.6**(2) | **1.2**(0.6) | **1.2**(0.5) | **0.77**(0.8) | 15/15 |
| IPOP-10DDr | **1.3**(1) | **1.5**(1) | **2.4**(2) | 4.6(1) | 6.8(6) | 15/15 |
| IPOP-500 l | **1.3**(1) | **1.5**(1) | **2.4**(2) | 4.6(1) | 6.8(6) | 15/15 |
| IPOP-tany | **1.7**(2) | **1.9**(2) | **1.8**(2) | 4.7(2) | 7.4(7) | 15/15 |
| IPOP-texp | **2.1**(3) | **2.9**(3) | **2.1**(1) | 4.0(1) | 10(10) | 15/15 |
| IPOP lia | **1.3**(1) | **1.5**(1) | **2.4**(2) | 4.6(1) | 6.8(6) | 15/15 |
| MLSL pal | **1**(1) | **1.6**(2) | **1.2**(0.6) | **1.2**(0.5) | **0.77**(0.8) | 15/15 |
| OQNLP pal | **1.8**(4) | **2.9**(2) | **1.5**(0.5) | **1.6**(0.6) | **1.4**(1) | 15/15 |
| P-DCN tra | **1.0**(0.3) | **1.5**(0.8) | 5.0(4) | 7.3(4) | 1.6e4(2e4) | 9/15 |
| P-zero tra | **1.0**(0.3) | **1.4**(0.8) | 6.1(4) | 6.1(4) | 4.9e4(6e4) | 4/15 |
| SMAC hut | **0.87**(0.7) | **0.96**(1.0) | **1.2**(2) | 9.0(10) | ∞ *300* | 0/15 |
| U-DCN tra | **1.0**(0.3) | **1.5**(0.8) | 4.0(3) | 43(42) | 2.7e4(4e4) | 6/15 |
| U-zero tra | **1.0**(0.3) | **1.4**(0.8) | 3.2(4) | 49(55) | 3.6e4(4e4) | 5/15 |
| fmincon pa | **1**(1) | **1.6**(2) | **1.2**(0.6) | **1.2**(0.5) | **0.77**(0.8) | 15/15 |
| fminunc pa | **1.3**(1) | **2.0**(2) | **1.3**(1) | **0.98**(0.9) | **0.80**(0.8) | 15/15 |
| ga100 hol | **1.2**(1) | **1.5**(2) | 7.5(8) | 72(37) | 3758(4446) | 3/15 |
| grid100 ho | **0.83**(0.3) | **1.3**(2) | **2.9**(4) | 138(61) | 2852(3164) | 4/15 |
| grid16 hol | **0.91**(0.7) | **0.96**(1) | 3.7(5) | 64(43) | 5967(7036) | 2/15 |
| hill hol | 4.3(6) | 3.4(5) | **2.4**(2) | 30(31) | 2503(3132) | 4/15 |
| lmmCMA aug | **0.87**(0.7) | **1.6**(2) | **1.4**(1) | **1.7**(0.4) | **1.6**(1) | 15/15 |
| memPSODE v | **1.7**(3) | **2.4**(3) | 3.2(3) | 3.3(0.4) | **2.6**(2) | 15/15 |
| prcga saw | **0.91**(0.3) | **1.4**(1) | 3.7(5) | 10(3) | 213(315) | 12/15 |
| ring100 ho | **1.1**(0.7) | **1.6**(2) | 7.4(13) | 103(61) | 712(680) | 11/15 |
| ring16 hol | **1.0**(1.0) | **1.3**(1) | 5.0(6) | 41(24) | 1983(2640) | 5/15 |
| simplex pa | 7.2(14) | 12(7) | 7.7(4) | 4.8(1) | **2.9**(2) | 15/15 |

14

Table 14: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_{13}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f13** | *1.0e+3*:1.6 | *4.0e+2*:6.8 | *2.5e+2*:11 | *4.0e+1*:30 | *2.5e-3*:182 | 15/15 |
| BIPOP-aCMA | **1.2**(2) | **2.1**(2) | **2.1**(1) | 4.0(1) | 3.4(0.6) | 15/15 |
| BIPOP-saAC | **0.96**(0.3) | **1.1**(1) | **1.4**(1) | **2.2**(0.9) | **1.5**(0.4) | 15/15 |
| CMAES hut | 3.6(4) | **2.6**(2) | **2.2**(2) | 3.2(2) | $\infty$ *303* | 0/15 |
| DE pal | **0.87**(0.3) | **1.4**(1) | **1.7**(2) | 4.7(2) | 17(3) | 15/15 |
| HCMA los | **1.3**(2) | **1.0**(0.7) | **0.96**(0.3) | **1.8**(2) | **1.8**(0.4) | 15/15 |
| HMLSL pal | **0.79**(0) | **1.2**(1.0) | **1.3**(0.7) | **0.96**(0.2) | **0.63**(0.1) | 15/15 |
| IPOP-10DDr | **1.1**(0.6) | **1.8**(2) | **2.2**(2) | 3.3(0.8) | 5.6(1) | 15/15 |
| IPOP-500 l | **1.1**(0.6) | **1.8**(2) | **2.2**(2) | 3.3(0.8) | 5.6(1) | 15/15 |
| IPOP-tany | **1.1**(0.6) | **1.7**(1) | **1.6**(1) | **2.8**(0.9) | 5.5(1) | 15/15 |
| IPOP-texp | **1.9**(1) | **2.2**(2) | **2.3**(2) | **2.9**(1) | 5.2(1) | 15/15 |
| IPOP lia | **1.1**(0.6) | **1.8**(2) | **2.2**(2) | 3.3(0.8) | 5.6(1) | 15/15 |
| MLSL pal | **0.79**(0) | **1.2**(1.0) | **1.3**(0.7) | **0.96**(0.2) | **0.63**(0.1) | 15/15 |
| OQNLP pal | **1.2**(0) | **2.1**(2) | **1.8**(0.5) | **1.4**(0.4) | 3.6(3) | 15/15 |
| P-DCN tra | **1.3**(2) | 3.6(4) | 5.7(5) | 15(20) | 3.0e4(3e4) | 6/15 |
| P-zero tra | **1.3**(2) | **1.9**(2) | 4.1(4) | 55(96) | 2.3e5(2e5) | 1/15 |
| SMAC hut | **0.87**(0.6) | **0.84**(0.8) | **0.79**(0.4) | **0.98**(0.5) | $\infty$ *300* | 0/15 |
| U-DCN tra | **1.3**(2) | **1.5**(1) | **2.9**(3) | 13(10) | $\infty$ *3e6* | 0/15 |
| U-zero tra | **1.3**(2) | **1.5**(1) | **2.3**(1) | 13(7) | $\infty$ *3e6* | 0/15 |
| fmincon pa | **0.79**(0) | **1.2**(1.0) | **1.3**(0.7) | **0.96**(0.2) | **0.63**(0.1) | 15/15 |
| fminunc pa | **1.1**(0) | **1.4**(0.9) | **1.2**(0.5) | **0.97**(0.4) | **0.87**(0.2) | 15/15 |
| ga100 hol | **1.1**(0.6) | **1.3**(1) | 3.9(4) | 15(14) | $\infty$ *2e5* | 0/15 |
| grid100 ho | **1.7**(2) | **1.4**(1) | 3.7(4) | 32(19) | $\infty$ *2e5* | 0/15 |
| grid16 hol | **0.92**(0.6) | **1.3**(1) | **2.8**(4) | 21(12) | $\infty$ *2e5* | 0/15 |
| hill hol | 4.2(7) | **2.4**(2) | **2.2**(2) | 57(92) | $\infty$ *2e5* | 0/15 |
| lmmCMA aug | **1.3**(2) | **1.2**(1) | **1.2**(0.9) | **1.6**(0.4) | **1.5**(0.3) | 15/15 |
| memPSODE v | **2.0**(2) | **1.8**(2) | **2.5**(2) | **2.9**(1) | **1.7**(0.6) | 15/15 |
| prcga saw | **1.5**(0.6) | **2.5**(1) | **2.8**(6) | 5.7(5) | 1507(1864) | 6/15 |
| ring100 ho | **1.2**(0.9) | **1.5**(1) | **2.4**(2) | 27(20) | $\infty$ *2e5* | 0/15 |
| ring16 hol | **1.1**(0.6) | **2.7**(4) | 3.9(3) | 10(9) | $\infty$ *2e5* | 0/15 |
| simplex pa | **2.5**(0) | 6.7(5) | 7.7(4) | 7.4(5) | 4.5(2) | 15/15 |

Table 15: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_{14}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f14** | *1.0e+1*:2.2 | *6.3e+0*:4.2 | *2.5e+0*:10 | *6.3e-2*:31 | *2.5e-6*:160 | 15/15 |
| BIPOP-aCMA | 3.7(5) | 3.8(4) | 3.7(3) | 4.2(2) | 3.9(0.7) | 15/15 |
| BIPOP-saAC | **2.9**(3) | **2.4**(3) | **2.4**(3) | 3.3(1) | **2.0**(0.2) | 15/15 |
| CMAES hut | 3.2(4) | **2.3**(3) | 3.1(3) | 3.8(1) | $\infty$ *303* | 0/15 |
| DE pal | **1.4**(2) | **2.1**(2) | **2.4**(2) | 7.9(2) | 15(4) | 15/15 |
| HCMA los | 4.3(4) | **2.8**(3) | **1.9**(2) | 3.9(2) | **2.3**(0.3) | 15/15 |
| HMLSL pal | **1.3**(1) | **1**(1.0) | **0.83**(0.5) | **0.82**(0.2) | 10(14) | 15/15 |
| IPOP-10DDr | **2.3**(3) | **2.0**(2) | 3.1(3) | 3.7(2) | 6.6(0.9) | 15/15 |
| IPOP-500 l | **2.3**(3) | **2.0**(2) | 3.1(3) | 3.7(2) | 6.6(0.9) | 15/15 |
| IPOP-tany | **2.7**(4) | **1.7**(2) | **2.0**(2) | 3.5(0.9) | 6.0(0.8) | 15/15 |
| IPOP-texp | **2.8**(6) | **1.9**(3) | **2.0**(2) | **3.0**(2) | 5.4(1) | 15/15 |
| IPOP lia | **2.3**(3) | **2.0**(2) | 3.1(3) | 3.7(2) | 6.6(0.9) | 15/15 |
| MLSL pal | **1.3**(1) | **1**(1.0) | **0.83**(0.5) | **0.82**(0.2) | 140(201) | 9/15 |
| OQNLP pal | **2.7**(3) | **2.2**(2) | **1.7**(0.6) | **1.2**(0.6) | 10(9) | 15/15 |
| P-DCN tra | **1.7**(2) | **1.4**(2) | 4.7(6) | 11(7) | 1.9e4(2e4) | 9/15 |
| P-zero tra | **1.5**(2) | **1.2**(1) | 4.0(4) | 8.8(6) | 4.6e4(5e4) | 5/15 |
| SMAC hut | **1**(0.9) | **0.90**(0.8) | **1.6**(1) | 4.4(1) | $\infty$ *300* | 0/15 |
| U-DCN tra | **1.9**(2) | **1.4**(2) | **2.3**(2) | 21(13) | $\infty$ *3e6* | 0/15 |
| U-zero tra | **1.5**(2) | **1.5**(1) | **2.5**(2) | 17(14) | $\infty$ *3e6* | 0/15 |
| fmincon pa | **1.3**(1) | **1**(1.0) | **0.83**(0.5) | **0.82**(0.2) | 137(200) | 9/15 |
| fminunc pa | **1.5**(2) | **1.1**(1.0) | **0.98**(0.4) | **1.0**(0.5) | **1.2**(1) | 15/15 |
| ga100 hol | **2.0**(1) | **2.0**(2) | 4.0(6) | 29(17) | $\infty$ *2e5* | 0/15 |
| grid100 ho | **2.4**(2) | **1.7**(2) | 3.3(4) | 70(38) | $\infty$ *2e5* | 0/15 |
| grid16 hol | **2.4**(3) | **2.2**(3) | 3.9(4) | 18(10) | $\infty$ *2e5* | 0/15 |
| hill hol | 4.6(4) | **2.8**(2) | 3.0(2) | 10(10) | $\infty$ *2e5* | 0/15 |
| lmmCMA aug | **1.7**(2) | **1.4**(2) | **1.6**(1) | **1.7**(0.5) | **1.6**(0.2) | 15/15 |
| memPSODE v | 3.5(3) | 3.5(2) | 4.0(4) | 3.2(0.6) | **1.4**(0.2) | 15/15 |
| prcga saw | **2.0**(1) | **1.4**(1) | 3.1(4) | 10(7) | 1395(1556) | 8/15 |
| ring100 ho | 3.2(2) | **2.2**(3) | **3.0**(5) | 54(37) | $\infty$ *2e5* | 0/15 |
| ring16 hol | **1.8**(2) | **2.0**(1) | 4.4(5) | 17(8) | $\infty$ *2e5* | 0/15 |
| simplex pa | 8.5(10) | 6.8(5) | 7.2(4) | 6.5(2) | **2.0**(0.3) | 15/15 |

16

Table 16: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_{15}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f15** | *1.6e+2*:1.6 | *6.3e+1*:5.6 | *4.0e+1*:12 | *1.6e+1*:68 | *6.3e+0*:221 | 15/15 |
| BIPOP-aCMA | 3.2(6) | **2.6**(2) | **2.8**(3) | **1.5**(0.7) | **1.3**(0.7) | 15/15 |
| BIPOP-saAC | **2.2**(3) | **1.8**(2) | **2.2**(2) | **1.1**(1) | **1.2**(0.6) | 15/15 |
| CMAES hut | 5.7(7) | 4.0(3) | **2.9**(2) | **1.5**(0.8) | **1.1**(0.8) | 12/15 |
| DE pal | **1.7**(0.9) | **1.8**(2) | **2.5**(2) | **1.7**(1) | **1.8**(2) | 15/15 |
| HCMA los | **2.5**(2) | **1.9**(1) | **2.1**(1.0) | **1.8**(1) | **1.3**(0.6) | 15/15 |
| HMLSL pal | 10(28) | 7.7(9) | 7.2(6) | 3.7(2) | **1.8**(0.7) | 15/15 |
| IPOP-10DDr | **1.5**(0.9) | **2.5**(2) | **2.6**(2) | **1.1**(0.5) | **1.7**(2) | 15/15 |
| IPOP-500 l | **1.5**(0.9) | **2.5**(2) | **2.6**(2) | **1.1**(0.5) | **1.7**(2) | 15/15 |
| IPOP-tany | **1.8**(0.9) | **2.3**(2) | **2.0**(2) | **1.2**(0.7) | **1.6**(1) | 15/15 |
| IPOP-texp | 8.1(10) | 4.2(4) | 3.2(3) | **1.4**(0.6) | **2.3**(3) | 15/15 |
| IPOP lia | **1.5**(0.9) | **2.5**(2) | **2.6**(2) | **1.1**(0.5) | **1.7**(2) | 15/15 |
| MLSL pal | 10(28) | 7.7(10) | 6.8(5) | 3.3(2) | **1.9**(2) | 15/15 |
| OQNLP pal | 29(55) | 17(16) | 13(12) | 4.4(2) | **1.9**(0.4) | 15/15 |
| P-DCN tra | **1.7**(2) | **1.5**(2) | **2.2**(2) | 4672(9712) | 1516(3118) | 14/15 |
| P-zero tra | **1.7**(2) | 14(3) | 16(3) | 6942(2e4) | 4407(6811) | 12/15 |
| SMAC hut | **1.7**(2) | **1.0**(1.0) | **1.3**(1) | **1.3**(0.8) | 4.6(5) | 4/15 |
| U-DCN tra | **1.7**(2) | **1.4**(2) | **1.6**(1) | 3.1(3) | 5.5(4) | 15/15 |
| U-zero tra | **1.7**(2) | **1.2**(1) | **1.9**(2) | 3.4(5) | 25(26) | 15/15 |
| fmincon pa | 11(31) | 7.9(10) | 7.5(6) | 3.4(2) | **2.6**(2) | 15/15 |
| fminunc pa | 16(37) | 9.4(12) | 6.1(6) | **2.9**(2) | **2.3**(2) | 15/15 |
| ga100 hol | **1.3**(0.9) | **2.4**(4) | **2.7**(2) | 3.6(3) | 4.1(4) | 15/15 |
| grid100 ho | **1.7**(2) | **2.0**(2) | 3.0(4) | 7.3(7) | 11(10) | 15/15 |
| grid16 hol | **1.2**(0.9) | **1.9**(2) | 3.5(4) | 4.1(4) | 4.9(2) | 15/15 |
| hill hol | 7.2(10) | 3.2(3) | **2.5**(3) | **2.6**(1) | 4.1(5) | 15/15 |
| lmmCMA aug | **1.8**(1) | **1.6**(2) | **1.3**(0.8) | **1.1**(0.5) | **0.91**(0.8) | 15/15 |
| memPSODE v | **1.9**(2) | **2.7**(3) | 3.9(2) | 7.1(13) | 8.5(10) | 15/15 |
| prcga saw | **1.9**(2) | **1.8**(2) | **2.6**(2) | **2.1**(0.8) | 6.3(16) | 15/15 |
| ring100 ho | **1.5**(2) | **1.2**(1) | **2.1**(1) | 6.9(5) | 8.7(6) | 15/15 |
| ring16 hol | **2.2**(2) | **2.3**(2) | 4.0(5) | **2.5**(2) | 4.6(3) | 15/15 |
| simplex pa | 49(91) | 27(27) | 18(14) | 6.7(2) | 4.4(4) | 15/15 |

Table 17: 03-D, running time excess $\mathrm{ERT}/\mathrm{ERT}_{\text{best 2009}}$ on $f_{16}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f16** | *6.3e+1*:1.5 | *2.5e+1*:8.2 | *1.6e+1*:10 | *1.0e+1*:41 | *2.5e+0*:208 | 15/15 |
| BIPOP-aCMA | **2.2**(2) | **1.9**(2) | 3.3(3) | **1.9**(2) | **1.9**(3) | 15/15 |
| BIPOP-saAC | **1.7**(1.0) | **2.1**(3) | 4.2(4) | **2.4**(2) | **2.4**(3) | 15/15 |
| CMAES hut | **1.4**(2) | **1.7**(2) | **2.4**(3) | **1.2**(1) | **1.3**(1) | 11/15 |
| DE pal | **1.7**(1.0) | **1.5**(1) | **2.3**(2) | **1.2**(2) | **2.4**(4) | 15/15 |
| HCMA los | 3.6(4) | **2.4**(3) | 3.2(4) | **1.3**(1) | **2.5**(4) | 15/15 |
| HMLSL pal | 7.7(3) | 6.6(10) | 7.7(8) | 3.0(3) | 4.6(5) | 15/15 |
| IPOP-10DDr | **1.9**(2) | **1.2**(1) | **2.1**(3) | **1.1**(1) | **1.0**(0.9) | 15/15 |
| IPOP-500 l | **1.9**(2) | **1.2**(1) | **2.1**(3) | **1.1**(1) | **1.0**(0.9) | 15/15 |
| IPOP-tany | **2.0**(2) | **1.3**(1) | **2.1**(2) | **1.5**(3) | 3.3(4) | 15/15 |
| IPOP-texp | **1.7**(1) | **1.7**(2) | 3.4(4) | **2.2**(3) | **1.4**(1) | 15/15 |
| IPOP lia | **1.9**(2) | **1.2**(1) | **2.1**(3) | **1.1**(1) | **1.0**(0.9) | 15/15 |
| MLSL pal | 7.7(3) | 6.8(10) | 8.7(8) | 3.3(4) | **2.9**(4) | 15/15 |
| OQNLP pal | 35(57) | 14(13) | 18(14) | 5.1(3) | 5.9(8) | 15/15 |
| P-DCN tra | **2.1**(0.7) | **1.2**(1) | **2.4**(4) | **0.93**(1) | **1.5**(1) | 15/15 |
| P-zero tra | **1.5**(0.7) | **0.99**(1) | 11(1.0) | 3.1(0.8) | 1092(161) | 14/15 |
| SMAC hut | **2.2**(2) | **1.3**(1) | **1.7**(1) | **0.64**(0.8) | **0.59**(0.7) | 14/15 |
| U-DCN tra | **1.5**(0.7) | **1.1**(1) | **1.6**(2) | **1.0**(1) | **2.0**(2) | 15/15 |
| U-zero tra | **1.5**(0.7) | **0.97**(0.9) | **1.9**(2) | **1.2**(1) | **2.6**(3) | 15/15 |
| fmincon pa | 7.7(3) | 6.3(9) | 8.2(9) | 3.4(3) | 4.1(3) | 15/15 |
| fminunc pa | 30(76) | 15(16) | 13(14) | 4.7(4) | 13(13) | 15/15 |
| ga100 hol | **2.4**(3) | **1.6**(2) | 4.1(6) | **1.9**(2) | 3.2(2) | 15/15 |
| grid100 ho | **1.5**(2) | **2.3**(3) | **2.6**(3) | **1.5**(1) | 4.6(5) | 15/15 |
| grid16 hol | **1.2**(0.7) | **1.1**(1.0) | **2.8**(3) | **1.2**(2) | 9.4(6) | 15/15 |
| hill hol | **2.5**(3) | **2.0**(2) | **2.0**(2) | **1.4**(2) | 4.9(9) | 15/15 |
| lmmCMA aug | **2.9**(3) | **1.5**(1) | 4.2(6) | **1.5**(1) | **1.7**(2) | 15/15 |
| memPSODE v | **2.3**(4) | **1.4**(2) | **2.9**(4) | **2.0**(1) | 10(13) | 15/15 |
| prcga saw | **1.6**(2) | **1.2**(1) | **2.3**(3) | **1.7**(2) | **1.8**(2) | 15/15 |
| ring100 ho | **2.3**(2) | **1.2**(1) | **1.8**(2) | **1.3**(2) | **2.9**(3) | 15/15 |
| ring16 hol | **1.3**(0.7) | **1.4**(1) | **2.7**(3) | **1.2**(1) | **2.0**(3) | 15/15 |
| simplex pa | 119(104) | 27(19) | 25(6) | 7.4(2) | **2.4**(0.7) | 15/15 |

18

Table 18: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_{17}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f17** | *1.6e+1*:1.8 | *1.0e+1*:3.6 | *6.3e+0*:14 | *2.5e+0*:34 | *2.5e-1*:189 | 5/5 |
| BIPOP-aCMA | **1.6**(0.6) | **2.6**(3) | **1.4**(2) | **2.0**(1) | **2.1**(3) | 15/15 |
| BIPOP-saAC | 5.4(7) | 5.4(6) | **2.4**(2) | 5.1(2) | **2.3**(3) | 15/15 |
| CMAES hut | **2.0**(3) | **2.6**(3) | **1.6**(1) | **1.7**(2) | **0.99**(0.5) | 14/15 |
| DE pal | **2.1**(1) | **2.7**(3) | **2.1**(2) | **3.0**(2) | **2.6**(1) | 15/15 |
| HCMA los | 4.9(3) | 4.2(5) | 3.1(3) | **2.9**(2) | **2.6**(3) | 15/15 |
| HMLSL pal | 21(47) | 23(49) | 14(17) | 21(14) | 14(19) | 15/15 |
| IPOP-10DDr | **2.7**(4) | **2.5**(2) | **1.5**(1) | **1.9**(1) | **1.7**(0.5) | 15/15 |
| IPOP-500 l | **2.7**(4) | **2.5**(2) | **1.5**(1) | **1.9**(1) | **1.7**(0.5) | 15/15 |
| IPOP-tany | **2.7**(3) | **3.0**(2) | **1.4**(0.9) | **1.7**(0.9) | **2.1**(0.4) | 15/15 |
| IPOP-texp | 4.9(7) | 20(16) | 10(24) | 6.9(13) | **2.5**(3) | 15/15 |
| IPOP lia | **2.7**(4) | **2.5**(2) | **1.5**(1) | **1.9**(1) | **1.7**(0.5) | 15/15 |
| MLSL pal | 21(46) | 23(51) | 15(18) | 21(16) | 139(173) | 12/15 |
| OQNLP pal | 16(36) | 15(18) | 7.6(5) | 6.4(3) | 22(30) | 12/15 |
| P-DCN tra | **2.3**(3) | **2.4**(3) | **1.2**(1) | 24(44) | 1.5e4(2e4) | 8/15 |
| P-zero tra | **2.1**(3) | **2.3**(2) | **1.3**(1) | 92(142) | 3.2e4(4e4) | 5/15 |
| SMAC hut | **1.2**(1) | **1.9**(2) | **0.93**(1.0) | **1.7**(2) | 12(13) | 2/15 |
| U-DCN tra | **1.9**(2) | **2.3**(2) | **1.2**(1) | **3.0**(3) | 2560(6257) | 15/15 |
| U-zero tra | **2.0**(3) | **2.3**(3) | **1.5**(1) | 3.3(3) | 592(462) | 15/15 |
| fmincon pa | 18(47) | 21(37) | 13(16) | 34(89) | 164(184) | 13/15 |
| fminunc pa | 13(36) | 10(18) | 5.2(4) | 6.7(3) | 35(48) | 15/15 |
| ga100 hol | **1.9**(1) | 3.3(3) | **1.7**(2) | 4.2(6) | 11(6) | 15/15 |
| grid100 ho | **2.8**(3) | 3.1(4) | **2.3**(2) | 7.6(10) | 74(46) | 15/15 |
| grid16 hol | **2.4**(2) | 3.2(5) | **1.8**(1) | 6.7(6) | 134(335) | 14/15 |
| hill hol | 5.0(6) | 5.5(5) | **2.5**(3) | 5.0(4) | 75(80) | 14/15 |
| lmmCMA aug | **0.93**(0.6) | **0.94**(1) | **0.77**(0.8) | **1.3**(0.8) | **0.85**(0.9) | 15/15 |
| memPSODE v | 3.0(2) | 3.2(2) | 6.3(16) | 19(25) | 22(10) | 15/15 |
| prcga saw | **1.1**(0.8) | **1.5**(2) | **0.91**(1) | **2.1**(2) | 12(18) | 15/15 |
| ring100 ho | **2.2**(2) | 3.6(5) | **2.8**(3) | 6.0(6) | 22(10) | 15/15 |
| ring16 hol | **2.7**(3) | **2.4**(2) | **1.4**(1) | 3.1(3) | 20(17) | 15/15 |
| simplex pa | 29(64) | 24(32) | 12(9) | 12(5) | 55(78) | 14/15 |

Table 19: 03-D, running time excess $\mathrm{ERT/ERT_{best\ 2009}}$ on $f_{18}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT_{best\ 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f18** | *6.3e+1*:1.8 | *4.0e+1*:4.8 | *2.5e+1*:13 | *1.0e+1*:40 | *6.3e-1*:184 | 15/15 |
| BIPOP-aCMA | 5.0(5) | 3.2(4) | **2.7**(2) | **2.1**(2) | **2.6**(5) | 15/15 |
| BIPOP-saAC | 5.0(6) | 3.4(4) | **1.9**(2) | **1.3**(0.9) | **2.9**(3) | 15/15 |
| CMAES hut | 3.6(4) | **2.7**(3) | **1.3**(1) | **1.3**(0.9) | **3.4**(3) | 6/15 |
| DE pal | **2.5**(3) | 4.7(6) | **2.4**(2) | **1.8**(1) | **3.7**(2) | 15/15 |
| HCMA los | 7.2(8) | 3.4(3) | **1.8**(2) | **1.5**(1) | 4.6(5) | 15/15 |
| HMLSL pal | 25(29) | 19(24) | 8.4(12) | 8.4(6) | 16(7) | 15/15 |
| IPOP-10DDr | 3.7(4) | 18(2) | 7.5(2) | 3.1(1) | 5.5(8) | 15/15 |
| IPOP-500 l | 3.7(4) | 18(2) | 7.5(2) | 3.1(1) | 5.5(8) | 15/15 |
| IPOP-tany | 3.1(4) | **2.9**(3) | **1.8**(2) | **1.6**(0.9) | 4.2(6) | 15/15 |
| IPOP-texp | 9.1(14) | 6.1(7) | 3.2(3) | **1.5**(1) | 5.7(8) | 15/15 |
| IPOP lia | 3.7(4) | 18(2) | 7.5(2) | 3.1(1) | 5.5(8) | 15/15 |
| MLSL pal | 26(29) | 20(27) | 9.3(10) | 10(6) | 151(126) | 13/15 |
| OQNLP pal | 28(49) | 19(22) | 11(8) | 7.7(3) | 19(16) | 14/15 |
| P-DCN tra | 3.5(4) | **2.2**(3) | **1.7**(2) | 36(22) | 1.4e4(2e4) | 8/15 |
| P-zero tra | 3.1(3) | **2.6**(3) | **1.8**(2) | 37(5) | 1.9e4(2e4) | 7/15 |
| SMAC hut | **2.2**(2) | **1.4**(2) | **0.95**(1) | **1.0**(0.9) | ∞ *300* | 0/15 |
| U-DCN tra | 4.4(4) | **2.2**(2) | **1.4**(1) | **2.8**(4) | 1711(2367) | 14/15 |
| U-zero tra | 3.2(3) | **1.6**(1) | **1.3**(1) | **2.3**(3) | 1640(1808) | 15/15 |
| fmincon pa | 26(29) | 20(22) | 9.1(9) | 8.1(4) | 213(216) | 12/15 |
| fminunc pa | 16(27) | 11(11) | 5.4(4) | 4.9(3) | 133(143) | 11/15 |
| ga100 hol | 3.4(3) | **2.8**(1) | **1.6**(1) | **2.9**(3) | 25(11) | 15/15 |
| grid100 ho | **2.4**(3) | **1.8**(2) | **2.1**(3) | 4.7(5) | 270(419) | 13/15 |
| grid16 hol | **2.9**(4) | 3.1(4) | **1.7**(2) | 5.2(3) | 474(817) | 10/15 |
| hill hol | 14(21) | 7.2(8) | 4.4(4) | **2.9**(3) | 209(412) | 13/15 |
| lmmCMA aug | **1.6**(2) | **1.3**(1) | **1.1**(1) | **0.74**(0.4) | **1.5**(2) | 15/15 |
| memPSODE v | 4.8(5) | 4.2(3) | **2.3**(2) | 14(21) | 49(40) | 15/15 |
| prcga saw | **2.4**(2) | **1.7**(1) | **1.3**(2) | **2.0**(2) | 41(74) | 15/15 |
| ring100 ho | 5.7(5) | 4.3(4) | **2.8**(3) | 6.3(8) | 36(22) | 15/15 |
| ring16 hol | **2.4**(2) | 3.1(4) | **2.1**(3) | 3.5(3) | 30(29) | 15/15 |
| simplex pa | 46(63) | 27(26) | 16(10) | 9.1(1) | 39(30) | 15/15 |

Table 20: 03-D, running time excess $\mathrm{ERT/ERT_{best\ 2009}}$ on $f_{19}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT_{best\ 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f19** | *1.6e-1*:81 | *1.0e-1*:109 | *6.3e-2*:109 | *4.0e-2*:119 | *1.6e-2*:1230 | 15/15 |
| BIPOP-aCMA | 33(33) | 57(90) | 118(91) | 117(82) | 19(22) | 15/15 |
| BIPOP-saAC | 37(48) | 40(39) | 62(51) | 76(82) | 13(13) | 15/15 |
| CMAES hut | 56(56) | 41(43) | $\infty$ | $\infty$ | $\infty$ *303* | 0/15 |
| DE pal | 15(12) | 22(17) | 35(30) | 47(59) | 16(19) | 14/15 |
| HCMA los | 25(40) | 38(40) | 56(58) | 100(101) | 13(13) | 15/15 |
| HMLSL pal | **0.21**(0)↓ | **0.16**(0)↓ | **0.16**(0)↓ | **0.14**(0)↓ | **0.03**(0)↓4 | 15/15 |
| IPOP-10DDr | 163(367) | 152(270) | 165(274) | 311(331) | 41(52) | 15/15 |
| IPOP-500 l | 163(367) | 152(270) | 165(274) | 295(331) | 31(37) | 15/15 |
| IPOP-tany | 128(269) | 177(265) | 282(249) | 374(532) | 57(73) | 15/15 |
| IPOP-texp | 142(305) | 135(296) | 199(374) | 312(377) | 35(38) | 15/15 |
| IPOP lia | 163(367) | 152(270) | 165(274) | 295(331) | 31(37) | 15/15 |
| MLSL pal | **0.21**(0)↓ | **0.16**(0)↓ | **0.16**(0)↓ | **0.14**(0)↓ | **0.03**(0)↓4 | 15/15 |
| OQNLP pal | **0.15**(0)↓ | **0.11**(0)↓*4 | **0.11**(0)↓*4 | **0.10**(4e-3)↓*4 | **0.03**(4e-4)↓4 | 15/15 |
| P-DCN tra | 136(135) | 171(362) | 207(385) | 311(352) | 346(729) | 14/15 |
| P-zero tra | 2504(3741) | 2382(4313) | 2867(5331) | 3042(4972) | 497(584) | 15/15 |
| SMAC hut | $\infty$ | $\infty$ | $\infty$ | $\infty$ | $\infty$ *300* | 0/15 |
| U-DCN tra | 41(47) | 353(919) | 924(1290) | 2851(4708) | 934(1257) | 13/15 |
| U-zero tra | 59(67) | 304(723) | 468(725) | 1671(3158) | 1359(1717) | 11/15 |
| fmincon pa | **0.21**(0)↓ | **0.16**(0)↓ | **0.16**(0)↓ | **0.14**(0)↓ | **0.03**(0)↓4 | 15/15 |
| fminunc pa | **0.21**(0.0)↓ | **0.16**(0.0)↓ | **0.16**(0.0)↓ | **0.15**(0.0)↓ | **0.02**(2e-3)↓*4 | 15/15 |
| ga100 hol | 38(23) | 58(42) | 78(70) | 181(226) | 44(39) | 15/15 |
| grid100 ho | 104(66) | 122(152) | 426(654) | 738(809) | 216(246) | 6/15 |
| grid16 hol | 66(80) | 216(487) | 447(558) | 623(806) | 147(178) | 8/15 |
| hill hol | 68(93) | 81(107) | 188(206) | 441(492) | 276(335) | 5/15 |
| lmmCMA aug | 29(30) | 27(24) | 47(46) | 58(59) | 5.6(6) | 4/15 |
| memPSODE v | 76(70) | 78(49) | 124(96) | 135(76) | 26(23) | 15/15 |
| prcga saw | 6.3(4) | 12(5) | 44(44) | 89(170) | 22(31) | 15/15 |
| ring100 ho | 67(58) | 77(77) | 151(143) | 337(320) | 113(127) | 10/15 |
| ring16 hol | 32(33) | 48(18) | 106(133) | 355(560) | 87(96) | 11/15 |
| simplex pa | **0.14**(0.0)↓ | **0.14**(0.0)↓ | **0.16**(0.0)↓ | **0.16**(0.0)↓ | **0.03**(6e-3)↓4 | 15/15 |

Table 21: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_{20}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f20** | *4.0e+3*:3.5 | *2.5e+3*:4.3 | *4.0e+0*:13 | *1.6e+0*:41 | *1.0e+0*:385 | 5/5 |
| BIPOP-aCMA | 3.5(3) | 3.4(3) | 3.0(1) | 7.2(12) | 3.2(4) | 15/15 |
| BIPOP-saAC | **1.8**(2) | **1.5**(1) | **2.0**(2) | 11(13) | **2.1**(2) | 15/15 |
| CMAES hut | **1.6**(2) | **1.5**(2) | **2.6**(1) | **3.9**(4) | **2.6**(3) | 4/15 |
| DE pal | **1.1**(1) | **1.2**(0.9) | 4.4(4) | 7.5(3) | **2.0**(1) | 15/15 |
| HCMA los | **1.9**(1) | **1.7**(1) | **1.0**(0.5) | 8.7(12) | 4.2(5) | 15/15 |
| HMLSL pal | **1.7**(0) | **1.4**(0) | **1.2**(0) | 10(3) | **1.6**(1) | 15/15 |
| IPOP-10DDr | **0.77**(0.9) | 2.7(2) | 2.9(1) | **5.0**(2) | 4.6(4) | 15/15 |
| IPOP-500 l | **0.77**(0.9) | 2.7(2) | 2.9(1) | **5.0**(2) | 4.6(4) | 15/15 |
| IPOP-tany | **0.77**(0.9) | **1.1**(0.7) | 3.2(1) | 19(20) | 8.5(8) | 15/15 |
| IPOP-texp | **0.46**(0.3) | **0.89**(0.8) | **1.6**(1) | 15(13) | **2.5**(2) | 15/15 |
| IPOP lia | **0.77**(0.9) | 2.7(2) | 2.9(1) | **5.0**(2) | 4.6(4) | 15/15 |
| MLSL pal | **1.7**(0) | **1.4**(0) | **1.2**(0) | 8.6(2) | **1.5**(2) | 15/15 |
| OQNLP pal | 3.5(0) | 3.0(0) | **2.2**(0) | 7.6(2) | **2.0**(2) | 15/15 |
| P-DCN tra | **1.4**(1) | **2.3**(2) | 3.9(3) | 14(26) | 485(928) | 15/15 |
| P-zero tra | **1.4**(1) | **2.6**(3) | 6.5(6) | 8924(2e4) | 3223(3570) | 15/15 |
| SMAC hut | **1.2**(0.4) | **1.2**(0.4) | **1.4**(2) | 6.4(6) | 5.7(6) | 2/15 |
| U-DCN tra | **1.4**(1) | **2.3**(2) | 3.5(3) | 7.2(8) | 8.7(2) | 15/15 |
| U-zero tra | **1.4**(1) | **2.2**(2) | **2.9**(2) | 19(19) | 30(18) | 15/15 |
| fmincon pa | **1.7**(6) | **1.4**(0) | **1.2**(0) | 8.7(6) | **1.6**(1) | 15/15 |
| fminunc pa | **1.4**(0) | **1.2**(0) | **2.9**(0) | 9.1(2) | **2.2**(2) | 15/15 |
| ga100 hol | **1.7**(2) | **1.5**(2) | 12(13) | 14(10) | 3.9(3) | 15/15 |
| grid100 ho | **1.9**(2) | **1.8**(2) | 11(14) | 35(20) | 8.0(7) | 15/15 |
| grid16 hol | **1.5**(1) | **1.3**(1) | 6.2(7) | 15(5) | 4.0(4) | 15/15 |
| hill hol | **2.8**(3) | **2.8**(3) | 3.8(3) | **5.1**(4) | 8.2(16) | 15/15 |
| lmmCMA aug | **1.4**(0.7) | **1.3**(0.7) | **1.6**(1.0) | 15(24) | 8.6(8) | 7/15 |
| memPSODE v | **2.6**(2) | **2.9**(2) | 4.1(2) | 14(25) | 7.0(6) | 15/15 |
| prcga saw | **0.81**(0.7) | **0.95**(0.8) | **1.9**(2) | 16(8) | 8.1(13) | 15/15 |
| ring100 ho | **0.98**(0.9) | **0.89**(0.7) | 7.2(6) | 22(12) | 6.3(3) | 15/15 |
| ring16 hol | **1.3**(1) | **1.7**(2) | 7.1(7) | 12(6) | **2.2**(1) | 15/15 |
| simplex pa | 10(0.3) | 8.9(0.2) | 5.2(2) | 14(11) | 3.6(3) | 15/15 |

Table 22: 03-D, running time excess ERT/ERT$_{\text{best 2009}}$ on $f_{21}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding ERT$_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f21** | *1.6e+1*:2.5 | *1.0e+1*:5.9 | *6.3e+0*:14 | *2.5e+0*:41 | *1.6e+0*:167 | 15/15 |
| BIPOP-aCMA | 3.8(5) | **2.6**(3) | **2.4**(2) | 4.9(10) | 4.5(6) | 15/15 |
| BIPOP-saAC | **1.3**(1) | **1.1**(0.9) | **1.3**(1) | **0.94**(1) | **2.1**(5) | 15/15 |
| CMAES hut | 3.4(3) | **2.1**(0.9) | **1.7**(1) | **2.1**(4) | **1.4**(2) | 10/15 |
| DE pal | **2.1**(3) | **2.1**(2) | **2.4**(2) | **1.7**(1) | **2.2**(1) | 15/15 |
| HCMA los | 3.4(3) | **2.3**(2) | **2.1**(2) | **1.2**(1) | **1.4**(2) | 15/15 |
| HMLSL pal | 5.2(3) | 4.2(6) | 4.1(4) | **2.9**(3) | **1.9**(1) | 15/15 |
| IPOP-10DDr | **1.9**(2) | **1.6**(1) | **2.0**(2) | 3.2(3) | **2.0**(3) | 15/15 |
| IPOP-500 l | **1.9**(2) | **1.6**(1) | **2.0**(2) | 3.2(3) | **2.0**(3) | 15/15 |
| IPOP-tany | **1.3**(1.0) | **1.1**(1) | **1.5**(2) | **2.6**(2) | **2.3**(3) | 15/15 |
| IPOP-texp | **1.8**(2) | **1.3**(2) | 4.8(1) | 5.6(11) | **2.5**(6) | 15/15 |
| IPOP lia | **1.9**(2) | **1.6**(1) | **2.0**(2) | 3.2(3) | **2.0**(7) | 15/15 |
| MLSL pal | 5.1(3) | 4.0(6) | 4.7(5) | **2.3**(2) | **1.1**(1.0) | 15/15 |
| OQNLP pal | 5.1(4) | 4.0(4) | **2.7**(2) | **2.7**(3) | **1.3**(1) | 15/15 |
| P-DCN tra | **1.7**(2) | **1.5**(2) | **2.5**(4) | 1.1e4(4e4) | 2.7e4(4e4) | 6/15 |
| P-zero tra | **1.7**(2) | **1.4**(2) | **1.8**(3) | 1.1e4(4e4) | 2.0e4(3e4) | 7/15 |
| SMAC hut | **1.2**(1.0) | **1.2**(1) | **1.8**(2) | **0.93**(0.7) | **0.68**(0.4) | 15/15 |
| U-DCN tra | **1.5**(2) | **1.2**(2) | **1.4**(2) | **2.0**(3) | **1.8**(1) | 15/15 |
| U-zero tra | **1.6**(2) | **0.99**(1) | **0.88**(1) | **2.3**(3) | 3.7(6) | 15/15 |
| fmincon pa | 5.1(2) | 4.3(6) | 4.5(4) | **2.6**(3) | **1.5**(1) | 15/15 |
| fminunc pa | 4.4(6) | 4.7(7) | 4.5(4) | **2.4**(2) | **1.4**(0.9) | 15/15 |
| ga100 hol | **1.8**(2) | **0.87**(0.8) | **1.5**(2) | **2.1**(2) | **2.5**(4) | 15/15 |
| grid100 ho | **1.2**(1) | **1.3**(2) | **1.2**(1) | **1.8**(1) | 5.3(3) | 15/15 |
| grid16 hol | **1.4**(1.0) | **1.1**(0.9) | **1.2**(1) | **2.3**(2) | **1.9**(2) | 15/15 |
| hill hol | 5.7(7) | 5.5(9) | 3.4(6) | 3.4(4) | 67(5) | 14/15 |
| lmmCMA aug | **2.2**(2) | **2.2**(2) | **2.9**(2) | **1.6**(3) | **0.69**(1) | 15/15 |
| memPSODE v | **2.6**(2) | **2.3**(2) | 3.3(3) | 7.4(6) | 3.5(6) | 15/15 |
| prcga saw | **1.4**(1.0) | **0.72**(0.9) | **1.4**(2) | **1.6**(2) | 10(10) | 15/15 |
| ring100 ho | **2.2**(2) | **1.5**(2) | **1.6**(2) | **2.9**(6) | **1.7**(2) | 15/15 |
| ring16 hol | **2.2**(3) | **1.5**(2) | **1.9**(2) | **1.6**(2) | **1.9**(2) | 15/15 |
| simplex pa | 20(20) | 19(21) | 13(10) | 6.9(5) | **2.4**(2) | 15/15 |

Table 23: 03-D, running time excess $\mathrm{ERT}/\mathrm{ERT}_{\text{best 2009}}$ on $f_{22}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\mathrm{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f22** | *4.0e+1*:2.9 | *2.5e+1*:5.2 | *1.0e+1*:18 | *6.3e+0*:33 | *1.0e+0*:170 | 5/5 |
| BIPOP-aCMA | **1.7**(2) | **2.2**(2) | **1.4**(1.0) | 3.0(2) | 6.9(7) | 15/15 |
| BIPOP-saAC | 10(4) | 6.1(2) | **2.4**(1) | **1.8**(1) | 4.5(5) | 15/15 |
| CMAES hut | **2.8**(3) | **2.3**(3) | **3.0**(3) | **2.1**(2) | **1.7**(2) | 9/15 |
| DE pal | **1.7**(1) | **1.3**(1) | **1.4**(1) | **1.5**(2) | 56(177) | 13/15 |
| HCMA los | **2.6**(2) | **2.3**(1.0) | **1.3**(1) | **1.9**(1) | 3.5(8) | 15/15 |
| HMLSL pal | 4.2(4) | 4.1(8) | **2.3**(3) | 3.1(3) | **1.7**(2) | 15/15 |
| IPOP-10DDr | **2.0**(2) | **1.5**(2) | **1.7**(2) | **1.5**(1) | 3.4(3) | 15/15 |
| IPOP-500 l | **2.0**(2) | **1.5**(2) | **1.7**(2) | **1.5**(1) | 3.4(3) | 15/15 |
| IPOP-tany | **1.8**(2) | **1.2**(0.9) | **1.4**(2) | 6.5(13) | 8.3(9) | 15/15 |
| IPOP-texp | **1.5**(0.9) | **1.8**(2) | 5.0(2) | 6.5(14) | 11(12) | 15/15 |
| IPOP lia | **2.0**(2) | **1.5**(2) | **1.7**(2) | **1.5**(1) | 3.4(3) | 15/15 |
| MLSL pal | 4.3(4) | 4.0(8) | **2.0**(2) | **2.9**(3) | **1.3**(0.8) | 15/15 |
| OQNLP pal | 4.9(4) | 5.8(8) | **3.0**(4) | **2.7**(3) | 3.3(4) | 13/15 |
| P-DCN tra | **1.1**(0.9) | **1.3**(2) | **2.0**(3) | 6496(3) | 1.2e4(2e4) | 9/15 |
| P-zero tra | **1.1**(0.9) | **1.5**(2) | **2.3**(2) | 2.3e4(5e4) | 3.5e4(4e4) | 5/15 |
| SMAC hut | **1.4**(1) | **0.96**(0.8) | **0.80**(0.8) | **0.85**(0.6) | **0.58**(0.6) | 15/15 |
| U-DCN tra | **1.1**(0.9) | **0.96**(1.0) | **1.4**(2) | **1.9**(2) | **2.3**(2) | 15/15 |
| U-zero tra | **1.1**(0.9) | **1.5**(2) | **1.8**(2) | **2.7**(2) | 3.5(3) | 15/15 |
| fmincon pa | 4.3(4) | 4.2(8) | **2.4**(2) | **2.5**(2) | **1.1**(0.8) | 15/15 |
| fminunc pa | 3.5(4) | 3.7(5) | **1.8**(2) | **2.7**(3) | **1.2**(1.0) | 15/15 |
| ga100 hol | **1.7**(2) | **1.6**(1) | **1.7**(1) | **1.7**(2) | 65(3) | 14/15 |
| grid100 ho | **1.4**(1) | **1.2**(1) | **1.6**(2) | **1.9**(2) | **2.7**(3) | 15/15 |
| grid16 hol | **1.0**(0.9) | **0.83**(0.5) | **1.8**(2) | 3.3(4) | 7.4(4) | 15/15 |
| hill hol | 4.9(5) | 4.2(4) | **2.1**(2) | **1.7**(2) | 298(442) | 12/15 |
| lmmCMA aug | **1.6**(1) | **1.7**(2) | **1.3**(1.0) | **1.5**(0.8) | 5.1(7) | 12/15 |
| memPSODE v | **2.7**(3) | **2.9**(2) | **1.2**(0.9) | **1.0**(1) | 17(26) | 15/15 |
| prcga saw | **1.2**(0.5) | **1.6**(2) | **1.5**(2) | **1.6**(2) | 9.4(20) | 15/15 |
| ring100 ho | **1.3**(1) | **1.4**(1) | **2.0**(2) | **2.2**(2) | 3.3(4) | 15/15 |
| ring16 hol | **0.98**(0.7) | **1.8**(1) | **3.0**(3) | 3.7(5) | 4.2(8) | 15/15 |
| simplex pa | 24(30) | 21(31) | 10(9) | 9.1(6) | 3.3(3) | 15/15 |

Table 24: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_{23}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f23** | *1.0e+1*:2.6 | *6.3e+0*:16 | *4.0e+0*:44 | *2.5e+0*:79 | *1.6e+0*:198 | 15/15 |
| BIPOP-aCMA | 5.9(6) | **1.6**(2) | **1.7**(2) | 3.0(3) | 6.2(7) | 15/15 |
| BIPOP-saAC | 3.4(3) | **2.2**(3) | 3.5(4) | 7.2(7) | 6.3(6) | 15/15 |
| CMAES hut | 3.7(3) | **2.7**(4) | **2.9**(4) | 12(13) | ∞ *303* | 0/15 |
| DE pal | 4.1(4) | **1.7**(1) | **2.2**(2) | **3.0**(3) | 5.2(5) | 15/15 |
| HCMA los | 7.4(8) | 3.2(3) | 3.5(4) | 5.2(6) | 5.0(5) | 15/15 |
| HMLSL pal | 14(16) | 6.2(8) | 3.2(4) | 3.8(3) | **2.0**(2) | 15/15 |
| IPOP-10DDr | 3.8(4) | **1.8**(1) | **2.1**(2) | 5.1(5) | 5.4(6) | 15/15 |
| IPOP-500 l | 3.8(4) | **1.8**(1) | **2.1**(2) | 5.1(5) | 5.4(6) | 15/15 |
| IPOP-tany | **2.9**(2) | **2.1**(3) | **2.1**(2) | 4.4(4) | 6.0(4) | 15/15 |
| IPOP-texp | 3.7(4) | **2.5**(4) | **1.5**(1) | 4.9(5) | 4.8(3) | 15/15 |
| IPOP lia | 3.8(4) | **1.8**(1) | **2.1**(2) | 5.1(5) | 5.4(6) | 15/15 |
| MLSL pal | 15(16) | 6.4(9) | 3.3(4) | **3.0**(3) | **1.7**(1) | 15/15 |
| OQNLP pal | 14(33) | 4.5(8) | 4.9(5) | 4.5(4) | **2.9**(4) | 15/15 |
| P-DCN tra | 3.6(5) | **2.3**(2) | **1.9**(2) | **2.6**(2) | 3.2(2) | 15/15 |
| P-zero tra | 3.8(4) | **1.8**(1) | **1.4**(1) | 3.9(5) | 4.7(6) | 15/15 |
| SMAC hut | 3.5(3) | **1.5**(2) | **2.0**(2) | 4.5(5) | 11(11) | 2/15 |
| U-DCN tra | **2.9**(3) | **1.9**(2) | **1.9**(2) | 4.2(6) | 5.2(4) | 15/15 |
| U-zero tra | **2.6**(3) | **1.5**(1) | **1.8**(3) | 3.0(2) | 9.3(17) | 15/15 |
| fmincon pa | 13(15) | 4.3(8) | 3.2(4) | **2.4**(2) | **1.6**(2) | 15/15 |
| fminunc pa | 11(21) | 5.0(6) | 3.2(3) | 3.1(2) | **1.7**(1) | 15/15 |
| ga100 hol | 4.7(3) | **1.4**(1) | **1.4**(1) | 4.7(7) | 9.0(10) | 15/15 |
| grid100 ho | 4.2(3) | **1.7**(3) | **1.8**(2) | **2.3**(2) | 12(12) | 15/15 |
| grid16 hol | 3.3(5) | **1.5**(2) | **2.0**(2) | 7.1(5) | 13(17) | 15/15 |
| hill hol | 6.4(7) | **2.7**(3) | **1.5**(2) | 4.6(6) | 6.3(10) | 15/15 |
| lmmCMA aug | 5.5(5) | **2.0**(1) | **2.9**(3) | **2.7**(2) | 3.9(5) | 13/15 |
| memPSODE v | **2.7**(3) | **1.8**(2) | **2.1**(0.7) | **2.8**(0.3) | **2.6**(5) | 15/15 |
| prcga saw | 4.5(5) | **2.1**(3) | **2.5**(3) | 4.1(4) | 4.7(6) | 15/15 |
| ring100 ho | **3.2**(3) | **2.3**(2) | **1.7**(2) | 3.9(5) | 5.3(7) | 15/15 |
| ring16 hol | 4.2(6) | **1.8**(2) | **2.8**(4) | 7.6(7) | 7.4(6) | 15/15 |
| simplex pa | 80(104) | 19(18) | 10(7) | **7.7**(3) | 3.2(1) | 15/15 |

Table 25: 03-D, running time excess $\text{ERT}/\text{ERT}_{\text{best 2009}}$ on $f_{24}$ for given run-length based budgets (0.5D, 1.2D, 3D, 10D, and 50D function evaluations). The ERT and in braces, as dispersion measure, the half difference between 90 and 10%-tile of bootstrapped run lengths appear for each algorithm and run-length based target, the corresponding $\text{ERT}_{\text{best 2009}}$ (preceded by the target $\Delta f$-value in *italics*) in the first row. #succ is the number of trials that reached the target value of the last column. The median number of conducted function evaluations is additionally given in *italics*, if the target in the last column was never reached. Entries with succeeding star are statistically significantly better (according to the rank-sum test) compared to all other algorithms in the table, with $p = 0.05$ or $p = 10^{-k}$ when the number $k$ following the star is larger than 1, with Bonferroni correction by the number of instances.

| #FEs/D | 0.5 | 1.2 | 3 | 10 | 50 | #succ |
|---|---|---|---|---|---|---|
| **f24** | *4.0e+1*:4.6 | *2.5e+1*:13 | *1.6e+1*:47 | *1.6e+1*:47 | *6.3e+0*:382 | 15/15 |
| BIPOP-aCMA | **2.6**(2) | **3.0**(1) | **1.9**(1) | **1.9**(1) | **1.5**(1) | 15/15 |
| BIPOP-saAC | **2.8**(3) | **2.2**(2) | **1.3**(0.8) | **1.3**(0.8) | **2.1**(3) | 15/15 |
| CMAES hut | **1.2**(1) | **1.9**(2) | **1.5**(1.0) | **1.5**(1) | **1.4**(1) | 7/15 |
| DE pal | **1.6**(1) | **1.9**(1) | **2.6**(1) | **2.6**(1) | **2.3**(2) | 15/15 |
| HCMA los | **1.8**(1) | **1.2**(0.7) | **1.8**(1) | **1.8**(1) | **1.3**(1) | 15/15 |
| HMLSL pal | 3.8(3) | **2.9**(1) | **2.3**(3) | **2.3**(3) | **1.7**(0.8) | 15/15 |
| IPOP-10DDr | **1.4**(2) | **2.1**(1) | **1.5**(0.8) | **1.5**(0.8) | **2.4**(3) | 15/15 |
| IPOP-500 l | **1.4**(2) | **2.1**(1) | **1.5**(0.8) | **1.5**(0.8) | **2.4**(3) | 15/15 |
| IPOP-tany | **1.4**(2) | **2.1**(2) | **1.3**(0.6) | **1.3**(0.6) | **2.2**(2) | 15/15 |
| IPOP-texp | **0.74**(0.5) | **1.2**(1) | **1.0**(0.8) | **1.0**(0.8) | **2.1**(3) | 15/15 |
| IPOP lia | **1.4**(2) | **2.1**(1) | **1.5**(0.8) | **1.5**(0.8) | **2.4**(3) | 15/15 |
| MLSL pal | 3.7(3) | **2.9**(1) | **2.4**(3) | **2.4**(3) | **1.6**(2) | 15/15 |
| OQNLP pal | **2.5**(2) | **2.2**(2) | 5.8(2) | 5.8(2) | **1.3**(0.6) | 15/15 |
| P-DCN tra | **2.5**(2) | 3.4(3) | 8.3(19) | 8.3(19) | 64(109) | 15/15 |
| P-zero tra | **2.8**(2) | 3.1(2) | 120(181) | 120(181) | 264(262) | 15/15 |
| SMAC hut | **2.0**(2) | **2.6**(2) | **2.2**(1) | **2.2**(1) | 3.6(4) | 3/15 |
| U-DCN tra | **2.0**(1) | **3.0**(1) | **2.7**(3) | **2.7**(3) | 6.2(10) | 15/15 |
| U-zero tra | **2.0**(1) | **1.7**(1) | **1.5**(2) | **1.5**(2) | 4.4(4) | 15/15 |
| fmincon pa | 3.7(3) | **2.9**(1) | **2.1**(2) | **2.1**(2) | **1.2**(1) | 15/15 |
| fminunc pa | **2.0**(2) | **2.7**(3) | **3.0**(3) | **3.0**(3) | **2.5**(2) | 15/15 |
| ga100 hol | **1.6**(2) | **2.4**(2) | 3.7(3) | 3.7(3) | 6.3(6) | 15/15 |
| grid100 ho | **2.3**(3) | 3.6(3) | 5.8(7) | 5.8(7) | 14(13) | 15/15 |
| grid16 hol | **2.7**(3) | 4.3(4) | **2.8**(3) | **2.8**(3) | 6.0(7) | 15/15 |
| hill hol | **2.6**(3) | **2.5**(3) | 3.6(4) | 3.6(4) | 5.8(6) | 15/15 |
| lmmCMA aug | **1.5**(1) | **2.3**(2) | **1.7**(1) | **1.7**(1) | **0.98**(1) | 15/15 |
| memPSODE v | **2.5**(2) | 5.1(4) | 10(20) | 10(20) | 6.9(8) | 15/15 |
| prcga saw | **1.8**(2) | **2.3**(2) | **1.4**(2) | **1.4**(2) | 4.6(10) | 15/15 |
| ring100 ho | **2.1**(3) | 3.6(3) | 4.7(5) | 4.7(5) | 6.2(4) | 15/15 |
| ring16 hol | **2.3**(3) | 3.2(3) | **2.8**(2) | **2.8**(2) | 3.8(3) | 15/15 |
| simplex pa | 6.3(6) | 5.5(2) | 8.1(2) | 8.1(2) | 3.1(3) | 15/15 |

# References

[1] Anne Auger, Dimo Brockhoff, and Nikolaus Hansen. Benchmarking the local metamodel CMA-ES on the noiseless BBOB'2013 test bed. In Blum and Alba [3], pages 1225–1232.

[2] Anne Auger, Steffen Finck, Nikolaus Hansen, and Raymond Ros. BBOB 2009: Comparison tables of all algorithms on all noiseless functions. Technical Report RT-0383, INRIA, April 2010.

[3] Christian Blum and Enrique Alba, editors. *Genetic and Evolutionary Computation Conference, GECCO '13, Amsterdam, The Netherlands, July 6-10, 2013, Companion Material Proceedings.* ACM, 2013.

[4] 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.

[5] N. Hansen, A. Auger, S. Finck, and R. Ros. Real-parameter black-box optimization benchmarking 2012: Experimental setup. Technical report, INRIA, 2012.

[6] 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.

[7] Neal J. Holtschulte and Melanie Moses. Benchmarking cellular genetic algorithms on the BBOB noiseless testbed. In Blum and Alba [3], pages 1201–1208.

[8] Frank Hutter, Holger Hoos, and Kevin Leyton-Brown. An evaluation of sequential model-based optimization for expensive blackbox functions. In Blum and Alba [3], pages 1209–1216.

[9] Tianjun Liao and Thomas Stützle. Bounding the population size of IPOP-CMA-ES on the noiseless BBOB testbed. In Blum and Alba [3], pages 1161–1168.

[10] Tianjun Liao and Thomas Stützle. Testing the impact of parameter tuning on a variant of IPOP-CMA-ES with a bounded maximum population size on the noiseless BBOB testbed. In Blum and Alba [3], pages 1169–1176.

[11] Ilya Loshchilov, Marc Schoenauer, and Michèle Sebag. Bi-population CMA-ES agorithms with surrogate models and line searches. In Blum and Alba [3], pages 1177–1184.

[12] László Pál. Benchmarking a hybrid multi level single linkage algorithm on the BBOB noiseless testbed. In Blum and Alba [3], pages 1145–1152.

[13] László Pál. Comparison of multistart global optimization algorithms on the BBOB noiseless testbed. In Blum and Alba [3], pages 1153–1160.

[14] Babatunde A. Sawyerr, Aderemi Oluyinka Adewumi, and Montaz M. Ali. Benchmarking projection-based real coded genetic algorithm on BBOB-2013 noiseless function testbed. In Blum and Alba [3], pages 1193–1200.

[15] Thanh-Do Tran, Dimo Brockhoff, and Bilel Derbel. Multiobjectivization with NSGA-II on the noiseless BBOB testbed. In Blum and Alba [3], pages 1217–1224.

[16] Costas Voglis. Adapt-MEMPSODE: a memetic algorithm with adaptive selection of local searches. In Blum and Alba [3], pages 1137–1144.