# Supplementary materials of 3004 for IJCAI 2020 - Differential Evolution with Individuals Redistribution for Real Parameter Single Objective Optimization

| | |
|---|---|
| L-SHADE-RSP | 0.111601182 |
| L-SHADE-EpSin | 0.164073579 |
| L-SHADE | 0.16945768 |
| MLCC-SI | 0.246572549 |
| SaDE/Mexp | 0.341789903 |
| CoBiDE | 0.371153213 |
| NDE | 0.378045475 |
| MPEDE | 0.398172761 |
| ETI-JADE | 0.413083498 |
| EDEV | 0.419915175 |

Table 1: Friedman rank sum test at a 0.05 significance level of results of the ten DE algorithms for the CEC 2014 benchmark test suite
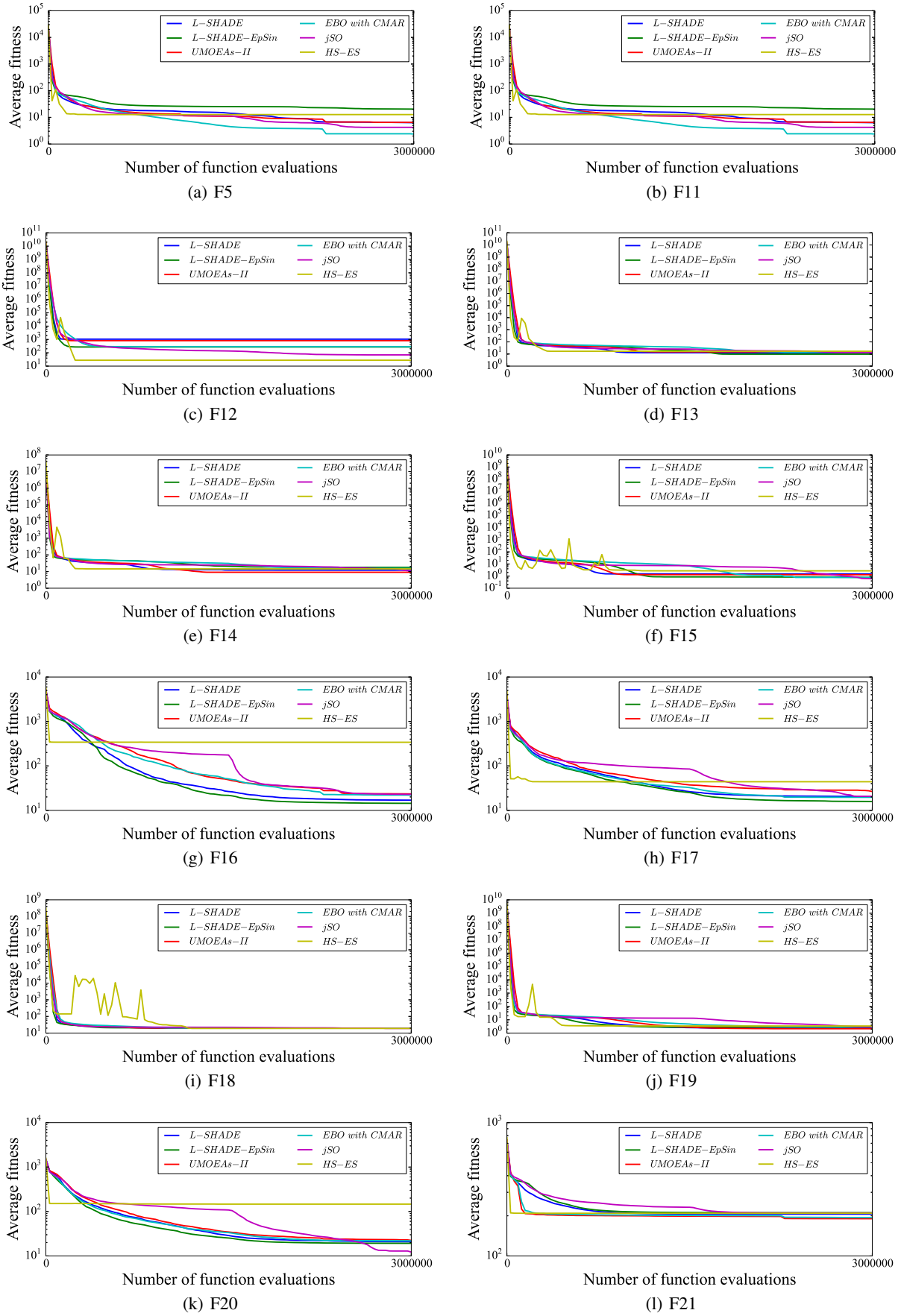
Figure 1: Convergence graphs of the six metaheuristics for 21 functions in the CEC 2017 benchmark test suite (the first part)
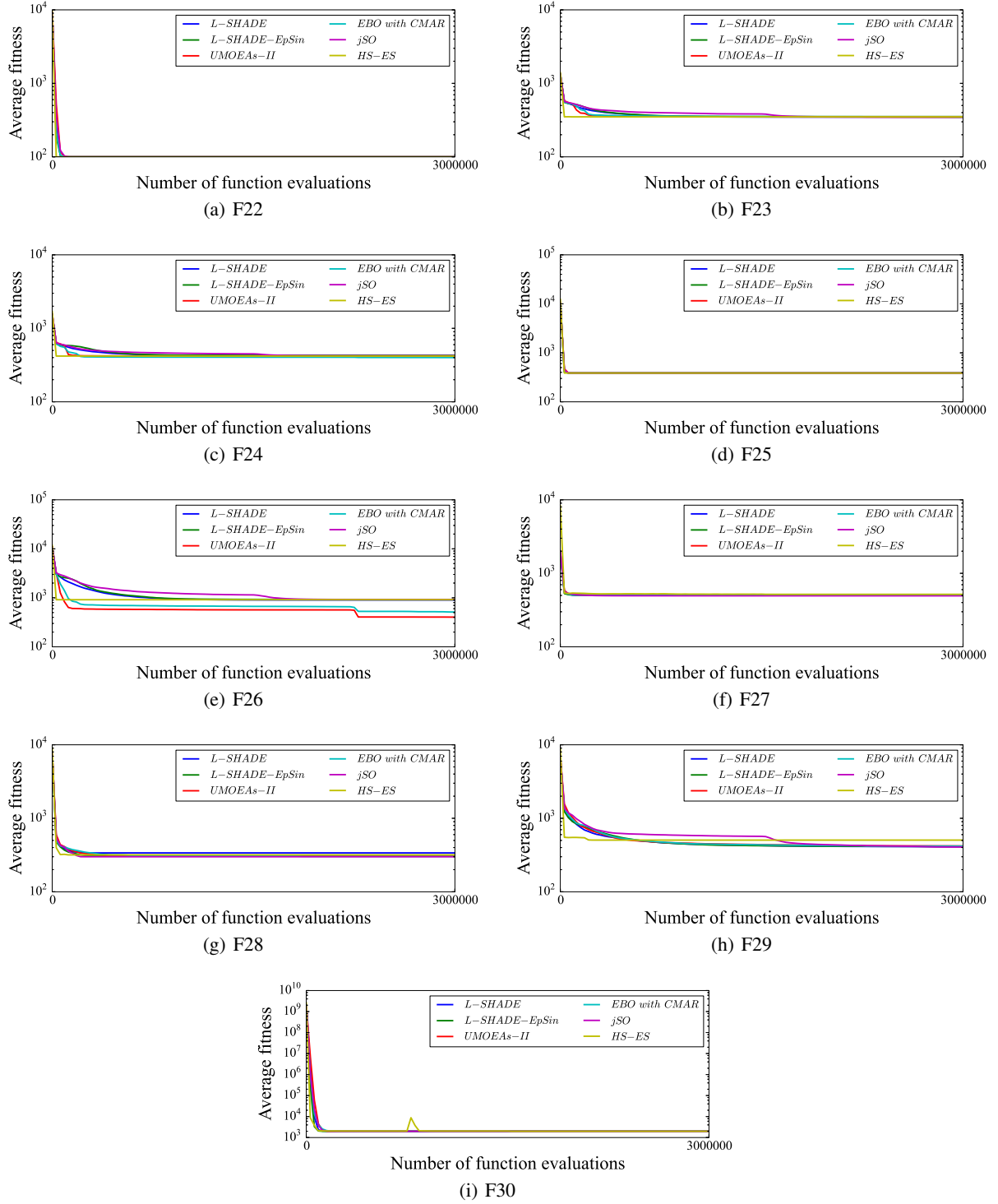
(a) F22

(b) F23

(c) F24

(d) F25

(e) F26

(f) F27

(g) F28

(h) F29

(i) F30

Figure 1: Convergence graphs of the six metaheuristics for 21 functions in the CEC 2017 benchmark test suite (the second part)

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 5.86E+01 (0.00E+00) | 5.86E+01 (0.00E+00)≈ | 5.86E+01 (3.32E-14)≈≈ | 5.86E+01 (3.73E-14)≈≈ |
| F5 | 5.37E+00 (1.16E+00) | 4.46E+00 (8.54E-01)≈ | 4.77E+00 (1.06E+00)− | 6.14E+00 (1.59E+00)−− |
| F6 | 1.14E-13 (0.00E+00) | 1.06E-13 (2.88E-14)≈ | 7.61E-12 (2.36E-11)≈≈ | 7.13E-12 (2.15E-11)≈≈ |
| F7 | 3.66E+01 (1.48E+00) | 3.56E+01 (7.77E-01)+ | 3.58E+01 (9.91E-01)+ | 3.59E+01 (7.27E-01)+ ≈ |
| F8 | 6.20E+00 (1.27E+00) | 4.60E+00 (1.03E+00)+ | 5.62E+00 (1.31E+00)− | 6.24E+00 (1.72E+00)≈ − |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 1.09E+03 (1.57E+02) | 1.01E+03 (1.83E+02)≈ | 1.03E+03 (2.63E+02)≈≈ | 9.87E+02 (3.34E+02)≈≈ |
| F11 | 6.34E+00 (1.08E+01) | 2.75E+00 (1.13E+00)+ | 1.05E+01 (2.07E+01)≈≈ | 1.37E+01 (2.39E+01)− ≈ |
| F12 | 1.05E+03 (3.92E+02) | 4.36E+02 (1.70E+02)+ | 5.47E+02 (1.68E+02)+ ≈ | 5.23E+02 (2.08E+02)+ ≈ |
| F13 | 1.27E+01 (6.28E+00) | 4.98E+00 (3.98E+00)+ | 3.73E+00 (2.95E+00)+ ≈ | 8.81E+00 (6.71E+00)≈≈ |
| F14 | 1.21E+01 (9.96E+00) | 1.32E+01 (6.63E+00)≈ | 1.49E+01 (8.82E+00)− ≈ | 1.72E+01 (7.80E+00)−− |
| F15 | 1.52E+00 (1.04E+00) | 9.75E-01 (5.45E-01)≈ | 1.19E+00 (6.70E-01)≈≈ | 1.27E+00 (7.12E-01)≈≈ |
| F16 | 1.69E+01 (1.03E+01) | 1.67E+01 (4.61E+00)≈ | 1.46E+01 (2.04E+00)≈ + | 2.65E+01 (3.21E+01)≈≈ |
| F17 | 2.05E+01 (6.64E+00) | 1.94E+01 (4.64E+00)≈ | 3.21E+01 (6.67E+00)−− | 1.05E+01 (7.68E+00)++ |
| F18 | 1.97E+01 (5.32E+00) | 1.94E+01 (4.00E+00)+ | 2.02E+01 (3.61E+00)− | 2.08E+01 (5.62E-01)≈ − |
| F19 | 2.34E+00 (1.07E+00) | 3.16E+00 (3.50E-01)− | 3.36E+00 (1.7E+00)≈ ≈ | 2.94E+00 (4.76E-01)− + |
| F20 | 2.09E+01 (7.30E+00) | 1.64E+01 (6.04E+00)+ | 2.92E+01 (7.07E+00)−− | 9.84E+00 (7.88E+00)++ |
| F21 | 2.06E+02 (1.41E+00) | 2.05E+02 (1.00E+00)≈ | 2.06E+02 (9.93E-01)≈≈ | 2.06E+02 (1.13E+00)≈ − |
| F22 | 1.00E+02 (0.00E+00) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| F23 | 3.48E+02 (2.34E+00) | 3.46E+02 (2.08E+00)+ | 3.48E+02 (1.54E+00)≈ − | 3.48E+02 (2.13E+00)≈ − |
| F24 | 4.25E+02 (1.48E+00) | 4.24E+02 (7.32E-01)+ | 4.25E+02 (8.46E-01)≈ − | 4.25E+02 (1.22E+00)≈ − |
| F25 | 3.87E+02 (2.19E-02) | 3.87E+02 (1.06E-02)+ | 3.87E+02 (1.26E-02)+ ≈ | 3.87E+02 (4.90E-03)++ |
| F26 | 9.02E+02 (3.06E+01) | 8.83E+02 (2.12E+01)+ | 9.09E+02 (2.78E+01)− | 8.81E+02 (2.29E+01)+ ≈ |
| F27 | 5.04E+02 (6.67E+00) | 4.92E+02 (2.28E+00)+ | 4.85E+02 (7.12E+00)++ | 4.88E+02 (1.09E+01)+ ≈ |
| F28 | 3.38E+02 (5.52E+01) | 3.00E+02 (2.31E-13)+ | 3.00E+02 (2.60E-13)+ ≈ | 3.00E+02 (2.60E-13)+ ≈ |
| F29 | 4.11E+02 (1.54E+01) | 4.10E+02 (1.63E+01)≈ | 4.18E+02 (1.55E+01)−− | 4.25E+02 (8.97E+00)−− |
| F30 | 1.99E+03 (6.39E+01) | 1.94E+03 (2.90E+00)+ | 1.94E+03 (4.43E+00)+ ≈ | 1.94E+03 (3.58E+00)+ ≈ |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 1.89E-15 (1.04E-14)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 5.87E+01 (1.01E+00)≈≈ | 5.86E+01 (0.00E+00)≈≈ | 5.86E+01 (0.00E+00)≈≈ | 5.86E+01 (0.00E+00)≈≈ | 5.86E+01 (0.00E+00)≈≈ |
| 5.38E+00 (1.51E+00)− | 5.84E+00 (1.10E+00)≈ − | 5.77E+00 (1.64E+00)≈ − | 5.90E+00 (1.36E+00)≈ − | 6.34E+00 (1.12E+00)−− |
| 1.70E-12 (6.05E-12)≈≈ | 1.59E-12 (5.66E-12)≈≈ | 4.77E-13 (1.91E-12)≈≈ | 1.17E-13 (2.08E-14)≈≈ | 8.98E-13 (2.53E-12)≈≈ |
| 3.68E+01 (9.90E-01)≈ − | 3.62E+01 (1.15E+00)≈ − | 3.66E+01 (1.33E+00)≈ − | 3.71E+01 (1.26E+00)≈ − | 3.69E+01 (1.52E+00)≈ − |
| 6.61E+00 (1.67E+00)≈ − | 7.07E+00 (1.58E+00)≈ − | 6.67E+00 (1.75E+00)≈ − | 7.01E+00 (1.54E+00)≈ − | 6.20E+00 (1.73E+00)≈ − |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.02E+03 (2.70E+02)≈≈ | 8.96E+02 (2.89E+02)++ | 1.04E+03 (2.52E+02)≈≈ | 1.04E+03 (2.18E+02)≈≈ | 9.71E+02 (3.37E+02)≈≈ |
| 1.64E+01 (2.17E+01)−− | 1.58E+01 (2.08E+01)−− | 1.81E+01 (2.44E+01)−− | 2.12E+01 (2.54E+01)−− | 1.82E+01 (2.47E+01)−− |
| 6.93E+02 (3.07E+02)+ − | 8.74E+02 (3.87E+02)− | 9.95E+02 (3.62E+02)− | 1.07E+03 (3.96E+02)− | 1.07E+03 (3.37E+02)− |
| 1.30E+01 (6.34E+00)≈ − | 1.38E+01 (6.41E+00)≈ − | 1.42E+01 (5.64E+00)− | 1.56E+01 (5.01E+00)−− | 1.51E+01 (5.38E+00)−− |
| 1.97E+01 (6.19E+00)−− | 2.07E+01 (4.92E+00)−− | 1.91E+01 (7.23E+00)−− | 2.13E+01 (3.82E+00)−− | 1.87E+01 (7.69E+00)−− |
| 1.81E+00 (9.77E-01)− | 2.43E+00 (1.29E+00)−− | 2.34E+01 (1.01E+00)−− | 2.54E+00 (1.12E+00)−− | 3.28E+00 (1.27E+00)−− |
| 1.39E+01 (4.09E+00)++ | 1.44E+01 (3.69E+00)++ | 1.49E+01 (3.48E+00)≈ + | 1.40E+01 (3.84E+00)++ | 2.20E+01 (4.06E+01)−− |
| 9.08E+00 (8.38E+00)++ | 1.61E+01 (1.18E+01)≈≈ | 1.05E+01 (7.30E+00)++ | 1.34E+01 (8.85E+00)++ | 1.21E+01 (9.67E+00)++ |
| 2.12E+01 (8.95E-01)− | 2.17E+01 (8.09E-01)−− | 2.15E+01 (8.43E-01)−− | 2.16E+01 (1.30E+00)−− | 2.19E+01 (1.45E+00)−− |
| 5.01E+00 (1.56E+00)−− | 5.03E+00 (1.43E+00)−− | 5.18E+00 (1.74E+00)−− | 4.93E+00 (1.33E+00)−− | 4.81E+00 (1.43E+00)−− |
| 1.17E+01 (1.12E+01)++ | 1.25E+01 (1.02E+01)+ ≈ | 1.03E+01 (1.13E+01)++ | 1.05E+01 (1.10E+01)++ | 1.19E+01 (1.08E+01)++ |
| 1.64E+02 (5.30E+01)+ ≈ | 1.71E+02 (5.12E+01)≈≈ | 1.61E+02 (5.39E+01)≈≈ | 1.60E+02 (5.35E+01)+ ≈ | 1.86E+02 (4.35E+01)≈ + |
| 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| 3.13E+02 (8.28E+01)+ | 3.43E+02 (4.08E+01)++ | 3.42E+02 (3.81E+01)≈ + | 3.41E+02 (4.55E+01)≈ + | 3.41E+02 (4.56E+01)≈ + |
| 3.88E+02 (8.55E+01)+ | 3.85E+02 (9.41E+01)+ | 3.95E+02 (7.79E+01)≈ + | 3.88E+02 (8.57E+01)≈ + | 4.18E+02 (4.13E+01)++ |
| 3.87E+02 (1.64E-03)++ | 3.87E+02 (1.87E-03)++ | 3.87E+02 (1.50E-02)++ | 3.87E+02 (1.85E-02)≈ − | 3.87E+02 (1.88E-02)− |
| 5.27E+02 (3.05E+02)++ | 5.97E+02 (3.03E+02)++ | 6.26E+02 (3.11E+02)+ ≈ | 6.97E+02 (3.09E+02)≈≈ | 6.11E+02 (3.18E+02)+ ≈ |
| 5.01E+02 (6.05E+00)− | 5.01E+02 (8.15E+00)≈ − | 5.01E+02 (5.43E+00)≈ − | 5.03E+02 (5.86E+00)≈ − | 5.02E+02 (5.33E+00)≈ − |
| 3.36E+02 (5.17E+01)≈ − | 3.30E+02 (5.12E+01)≈ − | 3.18E+02 (4.00E+01)≈ − | 3.34E+02 (5.31E+01)≈ − | 3.36E+02 (5.17E+01)≈ − |
| 4.05E+02 (9.46E+00)++ | 4.04E+02 (1.64E+01)++ | 4.07E+02 (1.73E+01)++ | 4.11E+02 (7.25E+00)≈≈ | 4.07E+02 (1.84E+01)+ ≈ |
| 1.95E+03 (1.03E+01)+ ≈ | 1.95E+03 (3.05E+01)+ ≈ | 1.97E+03 (4.52E+01)≈ − | 1.96E+03 (2.26E+01)+ ≈ | 1.98E+03 (4.88E+01)≈ − |

Table 2: The results of the three versions of L-SHADE for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution 1.00E-01 | 5.00E-02 |
|---|---|---|---|---|
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 3.79E-15 (1.23E-14) | 9.47E-16 (5.19E-15)≈ | 9.47E-16 (5.19E-15)≈≈ | 3.79E-15 (1.23E-14)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 4.84E+01 (2.41E+01) | 1.83E-07 (1.00E-06)+ | 2.62E+00 (1.12E+01)+ ≈ | 1.95E+00 (1.07E+01)+ ≈ |
| F5 | 3.96E+01 (8.69E+00) | 2.31E+01 (3.44E+00)+ | 2.36E+01 (3.39E+00)+ ≈ | 2.42E+01 (4.86E+00)+ ≈ |
| F6 | 1.14E-13 (0.00E+00) | 1.14E-13 (0.00E+00)≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ |
| F7 | 6.77E+01 (8.73E+00) | 5.41E+01 (3.87E+00)+ | 5.49E+01 (4.81E+00)+ ≈ | 5.53E+01 (5.08E+00)+ ≈ |
| F8 | 3.87E+01 (7.07E+00) | 2.40E+01 (3.50E+00)+ | 2.42E+01 (3.75E+00)+ ≈ | 2.47E+01 (4.17E+00)+ ≈ |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 2.08E+03 (5.98E+02) | 1.10E+03 (2.00E+02)+ | 1.22E+03 (2.33E+02)+− | 1.17E+03 (2.54E+02)+ ≈ |
| F11 | 1.47E+01 (1.27E+01) | 5.89E+00 (1.53E+00)+ | 6.06E+00 (1.87E+00)+ ≈ | 5.81E+00 (1.66E+00)+ ≈ |
| F12 | 3.05E+02 (1.58E+02) | 1.96E+02 (1.22E+02)+ | 1.72E+02 (1.45E+02)+ ≈ | 1.58E+02 (1.28E+02)+ ≈ |
| F13 | 2.23E+01 (7.89E+00) | 1.15E+01 (4.43E+00)+ | 1.10E+01 (4.55E+00)+ ≈ | 1.33E+01 (4.85E+00)+ ≈ |
| F14 | 9.60E+00 (4.62E+00) | 4.48E+00 (1.43E+00)+ | 4.71E+00 (1.25E+00)+ ≈ | 5.27E+00 (1.68E+00)+ ≈ |
| F15 | 7.12E+00 (3.12E+00) | 4.04E+00 (1.13E+00)+ | 3.76E+00 (1.07E+00)+ ≈ | 3.85E+00 (1.49E+00)+ ≈ |
| F16 | 3.91E+02 (1.53E+02) | 1.04E+02 (7.90E+01)+ | 7.59E+01 (8.27E+01)+ ≈ | 1.41E+02 (1.02E+02)+ ≈ |
| F17 | 2.25E+02 (2.14E+01) | 9.96E+00 (5.12E+00)+ | 7.89E+00 (3.02E+00)+ ≈ | 9.32E+00 (3.29E+00)+ ≈ |
| F18 | 1.89E+01 (9.34E+00) | 5.76E+00 (7.50E+00)+ | 3.93E+00 (3.84E+00)+ ≈ | 6.91E+00 (7.69E+00)+ ≈ |
| F19 | 4.22E+01 (1.53E+00) | 2.33E+00 (8.27E-01)+ | 2.25E+00 (9.66E-01)+ ≈ | 2.36E+00 (8.12E-01)+ ≈ |
| F20 | 5.17E+01 (6.71E+01) | 1.77E+00 (6.93E-01)+ | 2.26E+00 (9.90E-01)+ ≈ | 1.28E+01 (3.10E+01)+− |
| F21 | 2.40E+02 (1.07E+01) | 2.25E+02 (3.39E+00)+ | 1.58E+02 (6.36E+01)++ | 1.38E+02 (5.87E+01)++ |
| F22 | 1.00E+02 (0.00E+00) | 1.00E+02 (2.71E-06)≈ | 1.00E+02 (3.96E-06)≈≈ | 1.00E+02 (4.18E-06)≈≈ |
| F23 | 3.86E+02 (1.05E+01) | 3.69E+02 (5.24E+00)+ | 3.68E+02 (5.47E+00)+ ≈ | 1.00E+02 (4.31E-06)++ |
| F24 | 4.65E+02 (1.28E+01) | 4.41E+02 (4.08E+00)+ | 4.41E+02 (4.72E+00)+ ≈ | 4.42E+02 (4.08E+00)+ ≈ |
| F25 | 3.87E+02 (6.19E-01) | 3.86E+02 (1.01E+00)+ | 3.87E+02 (6.03E-01)+ ≈ | 3.87E+02 (6.05E-01)+ ≈ |
| F26 | 1.35E+03 (2.47E+02) | 5.00E+02 (3.73E+02)+ | 8.62E+02 (4.16E+02)+− | 3.00E+02 (8.66E-06)++ |
| F27 | 4.95E+02 (4.01E+01) | 4.75E+02 (5.71E+00)+ | 4.67E+02 (3.81E+00)++ | 4.63E+02 (3.74E+00)++ |
| F28 | 3.25E+02 (4.58E+01) | 3.00E+02 (1.10E-05)≈ | 3.00E+02 (1.32E-05)≈≈ | 3.00E+02 (1.00E-05)≈≈ |
| F29 | 4.26E+02 (3.92E+01) | 3.57E+02 (2.40E+01)+ | 3.50E+02 (2.70E+01)+ ≈ | 3.48E+02 (2.77E+01)++ |
| F30 | 2.04E+03 (7.44E+01) | 1.96E+03 (1.69E+01)+ | 1.96E+03 (2.09E+01)+ ≈ | 1.96E+03 (1.53E+01)+ ≈ |

| Individuals redistribution 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
|---|---|---|---|---|
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 1.89E-15 (7.21E-15)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 9.30E-01 (1.71E+00)+ ≈ | 4.70E+00 (1.47E+01)+ ≈ | 3.45E+01 (2.96E+01)− | 4.04E+01 (2.83E+01)≈ − | 3.00E+01 (2.95E+01)+− |
| 2.37E+01 (4.86E+00)+ ≈ | 2.41E+01 (4.38E+00)+ ≈ | 3.36E+01 (6.16E+00)+− | 2.95E+01 (7.23E+00)+− | 2.98E+01 (6.72E+00)+− |
| 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ |
| 5.62E+01 (4.77E+00)+− | 5.54E+01 (4.68E+00)+ ≈ | 5.67E+01 (7.89E+00)+− | 5.99E+01 (7.89E+00)+− | 6.36E+01 (9.64E+00)≈ − |
| 2.51E+01 (5.09E+00)+ ≈ | 2.40E+01 (3.96E+00)+ ≈ | 3.33E+01 (9.14E+00)+− | 3.44E+01 (8.42E+00)+− | 3.46E+01 (6.94E+00)+− |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.16E+03 (2.56E+02)+ ≈ | 9.51E+02 (3.00E+02)++ | 1.47E+03 (4.80E+02)+− | 1.32E+03 (4.87E+02)+− | 1.19E+03 (3.56E+02)+ ≈ |
| 6.57E+00 (1.76E+00)+ ≈ | 8.33E+00 (2.08E+00)+− | 1.25E+01 (5.81E+00)≈ − | 1.04E+01 (4.38E+00)≈ − | 8.82E+00 (3.70E+00)+− |
| 2.31E+02 (1.45E+02)≈≈ | 1.92E+02 (1.27E+02)+ ≈ | 1.76E+02 (1.04E+02)+ ≈ | 2.76E+02 (1.92E+02)≈≈ | 2.30E+02 (2.29E+02)+ ≈ |
| 1.18E+01 (4.36E+00)+ ≈ | 9.54E+00 (4.89E+00)++ | 1.19E+01 (5.67E+00)+ ≈ | 1.15E+01 (4.71E+00)+ ≈ | 1.32E+01 (6.25E+00)+ ≈ |
| 4.78E+00 (1.34E+00)+ ≈ | 4.94E+00 (1.24E+00)+ ≈ | 4.54E+00 (1.54E+00)+ ≈ | 4.31E+00 (1.23E+00)+ ≈ | 4.64E+00 (1.12E+00)+ ≈ |
| 3.85E+00 (1.18E+00)+ ≈ | 3.87E+00 (1.23E+00)+ ≈ | 3.92E+00 (1.27E+00)+ ≈ | 3.94E+00 (1.29E+00)+ ≈ | 3.70E+00 (1.38E+00)+ ≈ |
| 1.09E+02 (9.51E+01)+ ≈ | 1.19E+02 (9.98E+01)+ ≈ | 1.16E+02 (8.76E+01)+ ≈ | 1.25E+02 (9.57E+01)+ ≈ | 1.11E+02 (7.87E+01)+ ≈ |
| 9.73E+00 (4.21E+00)+ ≈ | 9.05E+00 (4.09E+00)+ ≈ | 8.92E+00 (4.13E+00)+ ≈ | 1.01E+01 (4.57E+00)+ ≈ | 1.14E+01 (6.09E+00)+ ≈ |
| 4.94E+00 (5.09E+00)++ | 5.49E+00 (6.67E+00)+ ≈ | 4.62E+00 (6.00E+00)+ ≈ | 4.78E+00 (6.02E+00)+ ≈ | 5.99E+00 (7.05E+00)+ ≈ |
| 2.61E+00 (8.21E-01)+ ≈ | 2.58E+00 (8.29E-01)+ ≈ | 2.51E+00 (7.15E-01)+ ≈ | 2.66E+00 (7.97E-01)+ ≈ | 2.54E+00 (8.15E-01)+ ≈ |
| 3.80E+01 (6.38E+01)≈ − | 4.18E+01 (5.75E+01)≈ − | 2.91E+01 (5.13E+01)+− | 3.20E+01 (5.08E+01)+− | 3.38E+01 (5.09E+01)≈ − |
| 1.09E+02 (3.25E+01)++ | 1.67E+02 (6.87E+01)+ ≈ | 1.45E+02 (6.53E+01)++ | 1.55E+02 (6.82E+01)+ ≈ | 1.36E+02 (6.06E+01)++ |
| 1.00E+02 (3.79E-06)≈≈ | 1.00E+02 (2.65E-06)≈≈ | 1.00E+02 (3.46E-06)≈≈ | 1.00E+02 (2.94E-06)≈≈ | 1.00E+02 (3.49E-06)≈≈ |
| 1.00E+02 (4.25E-06)++ | 1.00E+02 (6.25E-06)++ | 1.84E+02 (1.31E+02)++ | 2.33E+02 (1.45E+02)+ ≈ | 2.42E+02 (1.42E+02)+ ≈ |
| 4.01E+02 (9.18E+01)+ ≈ | 4.45E+02 (4.69E+01)+− | 4.31E+02 (7.87E+01)++ | 4.50E+02 (4.85E+01)+− | 4.02E+02 (1.03E+02)+ ≈ |
| 3.87E+02 (4.90E-03)−− | 3.87E+02 (2.37E-03)−− | 3.87E+02 (2.26E-03)−− | 3.87E+02 (1.37E-02)− ≈ | 3.87E+02 (4.96E-02)≈ − |
| 3.00E+02 (9.84E-06)++ | 3.95E+02 (2.90E+02)+ ≈ | 5.84E+02 (4.88E+02)+ ≈ | 4.73E+02 (3.95E+02)+ ≈ | 3.00E+02 (1.98E-01)+ ≈ |
| 4.73E+02 (1.13E+01)+ ≈ | 4.85E+02 (1.05E+01)+− | 4.87E+02 (1.45E+01)+− | 4.86E+02 (1.28E+01)+− | 4.82E+02 (1.12E+01)+− |
| 3.21E+02 (4.28E+01)≈ − | 3.29E+02 (4.89E+01)≈ − | 3.48E+02 (5.68E+01)−− | 3.18E+02 (4.16E+01)≈≈ | 3.07E+02 (2.76E+01)≈≈ |
| 3.54E+02 (3.52E+01)+ ≈ | 3.64E+02 (3.11E+01)+ ≈ | 3.65E+02 (3.43E+01)+ ≈ | 3.91E+02 (3.77E+01)+− | 3.94E+02 (3.47E+01)+− |
| 1.97E+03 (2.19E+01)+ ≈ | 1.97E+03 (1.73E+01)+ ≈ | 1.96E+03 (1.77E+01)+ ≈ | 1.96E+03 (1.61E+01)+ ≈ | 1.97E+03 (1.98E+01)+ ≈ |

Table 3: The results of the three versions of CoBiDE for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)$hlineapprox$ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 5.86E+01 (0.00E+00) | 6.14E+00 (1.73E+01)+ | 5.86E+01 (3.25E-14)≈ − | 3.32E+01 (2.95E+01)+ ≈ |
| F5 | 1.01E+01 (1.43E+00) | 9.95E+00 (1.61E+00)≈ | 5.84E+00 (1.77E+00)++ | 1.06E+01 (1.59E+00)−− |
| F6 | 1.10E-13 (2.08E-14) | 9.85E-14 (3.93E-14)≈ | 3.45E-11 (2.62E-11)−− | 2.70E-11 (1.50E-11)−− |
| F7 | 4.10E+01 (1.69E+00) | 4.11E+01 (1.28E+00)≈ | 3.64E+01 (1.07E+00)++ | 3.69E+01 (1.24E+00)++ |
| F8 | 1.11E+01 (1.61E+00) | 1.08E+01 (1.63E+00)≈ | 6.62E+00 (1.45E+00)++ | 1.34E+01 (1.82E+00)−− |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 1.08E+03 (1.85E+02) | 1.06E+03 (1.81E+02)≈ | 8.84E+02 (1.94E+02)++ | 8.33E+02 (1.87E+02)++ |
| F11 | 2.04E+01 (2.68E+01) | 7.87E+00 (1.52E+01)≈ | 7.16E+00 (1.48E+01)≈≈ | 5.59E+00 (1.49E+01)+ ≈ |
| F12 | 2.73E+02 (1.52E+02) | 2.35E+02 (1.36E+02)≈ | 3.08E+02 (1.60E+02)≈≈ | 2.93E+02 (1.49E+02)≈≈ |
| F13 | 9.72E+00 (7.07E+00) | 9.11E+00 (5.54E+00)≈ | 6.34E+00 (5.64E+00)≈ + | 1.08E+01 (7.30E+00)− ≈ |
| F14 | 1.80E+01 (6.50E+00) | 1.77E+01 (6.72E+00)≈ | 1.89E+01 (5.84E+00)− ≈ | 1.71E+01 (8.38E+00)+ ≈ |
| F15 | 7.73E-01 (7.15E-01) | 8.52E-01 (8.84E-01)≈ | 1.15E+00 (8.06E-01)≈≈ | 1.30E+00 (7.58E-01)−− |
| F16 | 1.44E+01 (2.38E+00) | 1.43E+01 (2.47E+00)≈ | 1.33E+01 (3.86E+00)≈≈ | 2.33E+01 (3.08E+01)−− |
| F17 | 1.58E+01 (5.56E+00) | 1.55E+01 (5.53E+00)≈ | 1.06E+01 (2.90E+00)++ | 1.29E+01 (8.80E+00)++ |
| F18 | 1.98E+01 (3.67E+00) | 2.06E+01 (3.33E-01)− | 2.07E+01 (3.91E-01)− ≈ | 2.01E+01 (3.40E+00)≈≈ |
| F19 | 2.80E+00 (8.53E-01) | 2.71E+00 (8.59E-01)≈ | 3.53E+00 (6.92E-01)−− | 3.13E+00 (7.03E-01)−− |
| F20 | 1.92E+01 (8.07E+00) | 2.05E+01 (7.19E+00)≈ | 2.46E+01 (1.03E+01)− ≈ | 9.07E+00 (8.80E+00)++ |
| F21 | 2.11E+02 (1.38E+00) | 2.11E+02 (1.72E+00)≈ | 2.06E+02 (1.68E+00)++ | 1.82E+02 (5.01E+01)≈≈ |
| F22 | 1.00E+02 (0.00E+00) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| F23 | 3.53E+02 (2.04E+00) | 3.53E+02 (2.53E+00)≈ | 3.50E+02 (2.01E+00)++ | 3.51E+02 (2.81E+00)+ ≈ |
| F24 | 4.28E+02 (2.10E+00) | 4.28E+02 (1.56E+00)≈ | 4.26E+02 (1.59E+00)++ | 4.27E+02 (2.14E+00)++ |
| F25 | 3.87E+02 (7.25E-03) | 3.84E+02 (1.08E+00)+ | 3.87E+02 (1.85E-03)+− | 3.87E+02 (1.79E-03)+− |
| F26 | 9.25E+02 (3.56E+01) | 8.69E+02 (1.85E+02)≈ | 9.06E+02 (3.70E+01)+ ≈ | 8.73E+02 (1.14E+02)+ ≈ |
| F27 | 5.06E+02 (4.65E+00) | 4.92E+02 (3.44E+00)≈ | 4.89E+02 (5.95E+00)++ | 4.90E+02 (6.08E+00)+ ≈ |
| F28 | 3.11E+02 (3.26E+01) | 3.00E+02 (2.83E-13)≈ | 3.00E+02 (2.83E-13)≈≈ | 3.08E+02 (2.89E+01)≈≈ |
| F29 | 4.13E+02 (7.73E+00) | 4.14E+02 (8.29E+00)≈ | 4.21E+02 (5.81E+00)−− | 4.11E+02 (2.15E+01)≈≈ |
| F30 | 1.98E+03 (5.01E+01) | 1.95E+03 (1.45E+01)+ | 1.94E+03 (2.25E-01)+ ≈ | 1.94E+03 (7.29E+00)+ ≈ |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − |
| 8.54E+01 (2.09E+00)++ | 1.08E+01 (1.75E+00)≈≈ | 1.07E+01 (1.72E+00)≈≈ | 1.06E+01 (1.87E+00)≈≈ | 1.06E+01 (1.93E+00)≈≈ |
| 2.26E-11 (1.06E-11)−− | 1.84E-11 (6.28E-12)−− | 1.76E-11 (8.65E-12)−− | 1.46E-11 (5.83E-12)−− | 9.63E-12 (4.16E-12)−− |
| 3.99E+01 (2.71E+00)++ | 3.95E+01 (2.03E+00)++ | 4.11E+01 (2.23E+00)≈≈ | 4.13E+01 (1.66E+00)≈≈ | 4.12E+01 (2.19E+00)≈≈ |
| 9.36E+00 (2.03E+00)++ | 1.13E+01 (2.12E+00)≈≈ | 1.18E+01 (1.83E+00)≈≈ | 1.15E+01 (1.88E+00)≈≈ | 1.20E+01 (1.49E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 9.05E+02 (2.02E+02)++ | 7.92E+02 (2.45E+02)++ | 8.98E+02 (1.87E+02)++ | 8.14E+02 (2.52E+02)++ | 9.04E+02 (1.45E+02)++ |
| 8.03E+00 (1.35E+01)≈ − | 7.51E+00 (1.47E+01)≈≈ | 1.09E+01 (1.99E+01)≈≈ | 1.21E+01 (2.26E+01)≈≈ | 1.02E+01 (2.06E+01)+ ≈ |
| 3.41E+02 (2.17E+02)≈ − | 3.16E+02 (2.27E+02)≈≈ | 3.81E+02 (1.98E+02)−− | 3.98E+02 (2.62E+02)−− | 3.92E+02 (1.85E+02)−− |
| 1.32E+01 (5.71E+00)−− | 1.29E+01 (7.96E+00)−− | 1.33E+01 (6.28E+00)−− | 1.59E+01 (8.82E+00)−− | 1.34E+01 (5.81E+00)−− |
| 2.06E+01 (5.15E+00)− ≈ | 1.95E+01 (6.27E+00)− ≈ | 2.04E+01 (5.43E+00)−− | 1.94E+01 (7.32E+00)−− | 2.08E+01 (4.81E+00)−− |
| 4.44E+00 (3.54E+00)−− | 4.33E+00 (2.76E+00)−− | 4.24E+00 (2.92E+00)−− | 4.01E+00 (2.55E+00)−− | 4.02E+00 (2.50E+00)−− |
| 1.56E+01 (4.48E+00)≈≈ | 1.31E+01 (3.35E+00)≈≈ | 1.26E+01 (3.75E+00)++ | 1.50E+01 (5.90E+00)≈≈ | 1.36E+01 (5.04E+00)++ |
| 7.36E+00 (5.86E+00)++ | 8.19E+00 (6.25E+00)++ | 7.67E+00 (6.29E+00)++ | 9.46E+00 (6.02E+00)++ | 8.37E+00 (5.64E+00)++ |
| 2.12E+01 (7.20E-01)−− | 2.09E+01 (7.54E-01)−− | 2.10E+01 (7.93E-01)≈≈ | 2.10E+01 (6.72E-01)≈≈ | 2.12E+01 (7.19E-01)−− |
| 4.91E+00 (1.41E+00)−− | 4.81E+00 (1.18E+00)−− | 4.64E+00 (1.12E+00)−− | 4.73E+00 (1.60E+00)−− | 4.45E+00 (1.29E+00)−− |
| 8.06E+00 (8.21E+00)++ | 8.92E+00 (1.09E+01)++ | 8.30E+00 (9.27E+00)++ | 6.09E+00 (5.73E+00)++ | 6.46E+00 (6.24E+00)++ |
| 2.08E+02 (2.05E+01)++ | 1.97E+02 (3.86E+01)≈≈ | 2.05E+02 (2.85E+01)≈ + | 2.12E+02 (1.79E+00)−− | 2.08E+02 (2.05E+01)++ |
| 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| 3.52E+02 (4.56E+00)≈≈ | 3.53E+02 (3.60E+00)≈≈ | 3.52E+02 (3.94E+00)≈≈ | 3.53E+02 (3.26E+00)≈≈ | 3.52E+02 (4.40E+00)≈≈ |
| 4.02E+02 (8.14E+01)≈≈ | 4.14E+02 (5.82E+01)≈≈ | 4.28E+02 (2.31E+00)≈≈ | 4.22E+02 (4.19E+01)≈≈ | 4.30E+02 (2.26E+00)−− |
| 3.87E+02 (1.92E-03)+− | 3.87E+02 (1.91E-03)+− | 3.87E+02 (1.80E-03)+− | 3.87E+02 (5.77E-03)≈ − | 3.87E+02 (5.78E-03)≈ − |
| 6.00E+02 (2.92E+02)++ | 6.36E+02 (3.01E+02)++ | 8.13E+02 (1.80E+02)++ | 7.52E+02 (2.66E+02)+ ≈ | 7.97E+02 (2.19E+02)+ ≈ |
| 5.03E+02 (5.48E+00)+− | 5.05E+02 (4.70E+00)≈ − | 5.06E+02 (4.79E+00)≈ − | 5.04E+02 (4.76E+00)≈ − | 5.06E+02 (4.59E+00)≈ − |
| 3.14E+02 (3.76E+01)≈≈ | 3.25E+02 (4.65E+01)≈≈ | 3.07E+02 (2.76E+01)≈≈ | 3.27E+02 (4.90E+01)≈≈ | 3.22E+02 (4.50E+01)≈≈ |
| 4.02E+02 (1.84E+01)++ | 4.10E+02 (1.01E+01)++ | 4.10E+02 (8.65E+00)++ | 4.09E+02 (8.70E+00)++ | 4.08E+02 (5.39E+00)++ |
| 1.95E+03 (2.60E+01)≈≈ | 1.95E+03 (2.29E+01)≈≈ | 1.98E+03 (4.73E+01)≈ − | 1.98E+03 (4.75E+01)≈ − | 1.97E+03 (3.96E+01)≈ − |

Table 4: The results of the three versions of L-SHADE-EpSin for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 2.69E-11 (9.54E-11) | 6.49E-13 (2.11E-12)+ | 0.00E+00 (0.00E+00)++ | 9.47E-16 (5.19E-15)++ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 2.79E+00 (1.86E+00) | 5.93E-13 (2.84E-12)+ | 5.05E+00 (1.20E+01)≈ − | 2.92E+00 (1.79E+00)≈ − |
| F5 | 2.64E+01 (5.63E+00) | 2.13E+01 (3.19E+00)+ | 1.93E+01 (4.34E+00)++ | 1.96E+01 (3.26E+00)+ ≈ |
| F6 | 0.00E+00 (0.00E+00) | 4.17E-14 (5.57E-14)− | 6.44E-14 (5.73E-14)− ≈ | 7.96E-14 (5.30E-14)−− |
| F7 | 5.64E+01 (6.30E+00) | 5.14E+01 (3.38E+00)+ | 4.92E+01 (3.81E+00)++ | 5.00E+01 (2.97E+00)+ ≈ |
| F8 | 2.93E+01 (6.21E+00) | 2.16E+01 (4.08E+00)+ | 2.14E+01 (4.12E+00)+ ≈ | 2.04E+01 (4.46E+00)+ ≈ |
| F9 | 1.06E-01 (1.86E-01) | 0.00E+00 (0.00E+00)+ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ |
| F10 | 1.51E+03 (4.01E+02) | 1.55E+03 (4.49E+02)≈ | 1.57E+03 (4.84E+02)≈≈ | 1.66E+03 (5.53E+02)≈≈ |
| F11 | 3.56E+01 (2.54E+01) | 1.26E+01 (4.09E+00)+ | 9.24E+00 (8.41E+00)++ | 8.25E+00 (3.10E+00)++ |
| F12 | 9.08E+02 (4.93E+02) | 6.15E+02 (3.27E+02)+ | 1.01E+03 (5.32E+02)≈ − | 8.71E+02 (3.33E+02)≈ − |
| F13 | 4.43E+01 (2.89E+01) | 2.09E+01 (7.21E+00)+ | 1.80E+01 (8.55E+00)+ ≈ | 1.82E+01 (8.01E+00)+ ≈ |
| F14 | 3.89E+01 (1.86E+01) | 1.10E+01 (3.55E+00)+ | 7.71E+00 (2.81E+00)++ | 1.10E+01 (5.05E+00)+ ≈ |
| F15 | 4.01E+01 (2.87E+01) | 1.40E+01 (5.08E+00)+ | 9.88E+00 (4.55E+00)++ | 1.05E+01 (7.02E+00)++ |
| F16 | 2.72E+02 (1.06E+02) | 1.96E+02 (8.64E+01)+ | 1.61E+02 (1.20E+02)+ ≈ | 2.18E+02 (1.11E+02)+ ≈ |
| F17 | 9.68E+00 (5.63E+00) | 8.23E+00 (4.45E+00)≈ | 8.61E+00 (4.31E+00)≈≈ | 8.04E+00 (4.33E+00)≈≈ |
| F18 | 4.14E+01 (3.39E+01) | 1.76E+01 (1.09E+01)+ | 2.91E+01 (1.68E+01)≈ − | 3.15E+01 (1.54E+01)≈ − |
| F19 | 2.91E+01 (2.00E+01) | 8.20E+00 (3.18E+00)+ | 5.51E+00 (2.20E+00)++ | 8.49E+00 (3.84E+00)+ ≈ |
| F20 | 2.05E+01 (4.23E+01) | 6.38E+00 (2.19E+01)+ | 1.76E+00 (1.88E+00)+ ≈ | 3.07E+00 (3.08E+00)≈≈ |
| F21 | 2.27E+02 (5.22E+00) | 2.22E+02 (3.22E+00)+ | 2.01E+02 (4.62E+01)++ | 1.94E+02 (5.24E+01)+ ≈ |
| F22 | 1.00E+02 (4.48E-01) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (1.39E-13)≈≈ | 1.00E+02 (8.30E-14)≈≈ |
| F23 | 3.74E+02 (7.98E+00) | 3.63E+02 (5.02E+00)+ | 3.62E+02 (6.25E+00)++ | 3.59E+02 (5.52E+00)++ |
| F24 | 4.39E+02 (8.43E+00) | 4.29E+02 (7.58E+00)+ | 4.28E+02 (7.57E+00)+ ≈ | 4.28E+02 (6.19E+00)+ ≈ |
| F25 | 3.87E+02 (1.90E+00) | 3.84E+02 (1.55E+00)+ | 3.87E+02 (1.71E+00)+− | 3.87E+02 (8.55E-01)+− |
| F26 | 9.39E+02 (4.67E+02) | 2.00E+02 (1.54E-13)+ | 7.16E+02 (4.18E+02)+− | 7.64E+02 (3.86E+02)+− |
| F27 | 5.03E+02 (7.40E+00) | 4.87E+02 (7.72E+00)+ | 4.88E+02 (1.03E+01)+ ≈ | 4.89E+02 (1.03E+01)+ ≈ |
| F28 | 3.14E+02 (3.57E+01) | 3.00E+02 (2.27E-13)≈ | 3.21E+02 (4.28E+01)≈≈ | 3.14E+02 (3.67E+01)≈≈ |
| F29 | 4.16E+02 (2.24E+01) | 4.09E+02 (2.37E+01)≈ | 4.04E+02 (2.55E+01)+ ≈ | 3.93E+02 (3.54E+01)+ ≈ |
| F30 | 2.16E+03 (1.42E+02) | 2.08E+03 (7.30E+01)+ | 2.15E+03 (9.37E+01)≈ − | 2.14E+03 (1.11E+02)≈ − |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 4.06E-11 (2.22E-10)−− | 0.00E+00 (0.00E+00)++ | 5.48E-12 (3.00E-11)+− | 1.89E-15 (1.04E-14)++ | 7.78E-11 (4.24E-10)−− |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 3.32E+00 (1.51E+00)≈ − | 7.85E+00 (1.69E+01)≈ − | 5.45E+00 (1.19E+01)≈ − | 3.32E+00 (1.51E+00)≈ − | 3.32E+00 (1.51E+00)≈ − |
| 2.01E+01 (3.79E+00)+ ≈ | 2.23E+01 (4.96E+00)+ ≈ | 2.65E+01 (6.42E+00)≈ − | 2.48E+01 (5.87E+00)+ ≈ | 2.34E+01 (4.32E+00)+ ≈ |
| 6.06E-14 (5.77E-14)− ≈ | 6.82E-14 (5.66E-14)− ≈ | 7.58E-14 (5.45E-14)−− | 6.82E-14 (5.66E-14)− ≈ | 6.44E-14 (5.73E-14)− ≈ |
| 5.03E+01 (5.47E+00)+ ≈ | 5.01E+01 (4.77E+00)+ ≈ | 5.04E+01 (3.93E+00)+ ≈ | 5.33E+01 (5.64E+00)≈≈ | 5.46E+01 (4.02E+00)≈≈ |
| 2.05E+01 (3.72E+00)+ ≈ | 2.13E+01 (4.98E+00)+ ≈ | 2.55E+01 (4.74E+00)+− | 2.52E+01 (5.38E+00)+− | 2.53E+01 (5.00E+00)+− |
| 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 3.03E-02 (1.15E-01)≈≈ | 1.51E-02 (8.29E-02)+ ≈ |
| 1.61E+03 (6.32E+02)≈≈ | 1.44E+03 (5.46E+02)≈≈ | 1.59E+03 (6.53E+02)≈≈ | 1.76E+03 (8.62E+02)≈≈ | 1.41E+03 (3.74E+02)≈≈ |
| 2.44E+01 (1.36E+01)≈ − | 2.74E+01 (1.34E+01)≈ − | 2.99E+01 (1.30E+01)≈ − | 2.94E+01 (1.07E+01)≈ − | 3.08E+01 (1.64E+01)≈ − |
| 9.23E+02 (4.28E+02)≈ − | 8.12E+02 (4.06E+02)≈≈ | 7.80E+02 (4.01E+02)≈≈ | 8.09E+02 (4.52E+02)≈≈ | 8.31E+02 (4.03E+02)≈≈ |
| 2.08E+01 (1.59E+01)+ ≈ | 1.96E+01 (1.03E+01)+ ≈ | 2.02E+01 (8.91E+00)+ ≈ | 1.97E+01 (8.80E+00)+ ≈ | 2.92E+01 (1.30E+01)+− |
| 1.23E+01 (6.86E+00)+ ≈ | 1.44E+01 (7.48E+00)+ ≈ | 1.31E+01 (5.44E+00)+ ≈ | 1.14E+01 (6.45E+00)+ ≈ | 1.37E+01 (8.59E+00)+ ≈ |
| 1.72E+01 (1.26E+01)+ ≈ | 2.67E+01 (1.90E+01)+− | 1.98E+01 (1.18E+01)+ ≈ | 2.95E+01 (1.67E+01)≈ − | 2.38E+01 (1.44E+01)+− |
| 2.22E+02 (1.11E+02)+ ≈ | 1.87E+02 (1.26E+02)+ ≈ | 2.11E+02 (1.19E+02)+ ≈ | 2.00E+02 (1.05E+02)+ ≈ | 1.77E+02 (1.26E+02)+ ≈ |
| 1.03E+01 (6.29E+00)≈≈ | 9.78E+00 (5.38E+00)≈≈ | 1.05E+01 (4.94E+00)− ≈ | 9.11E+00 (4.45E+00)≈≈ | 1.01E+01 (4.12E+00)− ≈ |
| 2.90E+01 (2.08E+01)− ≈ | 2.67E+01 (1.68E+01)≈ − | 2.95E+01 (1.66E+01)− ≈ | 3.07E+01 (1.91E+01)− ≈ | 3.66E+01 (2.03E+01)− ≈ |
| 1.44E+01 (1.05E+01)+− | 1.11E+01 (8.86E+00)+ ≈ | 1.71E+01 (1.32E+01)+− | 1.24E+01 (1.03E+01)+ ≈ | 1.77E+01 (1.13E+01)+− |
| 1.10E+01 (3.08E+01)≈ − | 6.36E+00 (2.16E+01)≈≈ | 6.30E+00 (2.21E+01)≈≈ | 4.05E+00 (9.51E+00)+ ≈ | 8.00E+00 (2.22E+01)≈≈ |
| 2.10E+02 (3.78E+01)+ ≈ | 2.27E+02 (7.39E+00)≈≈ | 2.26E+02 (5.63E+00)− ≈ | 2.07E+02 (4.29E+01)+ ≈ | 2.13E+02 (3.87E+01)≈ + |
| 1.00E+02 (8.3E-14)≈≈ | 1.00E+02 (8.30E-14)≈≈ | 1.00E+02 (1.39E-13)≈≈ | 1.00E+02 (1.96E-13)≈≈ | 1.00E+02 (1.15E-13)≈≈ |
| 3.56E+02 (7.46E+00)++ | 3.64E+02 (7.95E+00)+ ≈ | 3.71E+02 (6.33E+00)+− | 3.70E+02 (8.55E+00)+− | 3.67E+02 (7.56E+00)+− |
| 4.28E+02 (7.37E+00)+ ≈ | 4.43E+02 (7.60E+00)−− | 4.39E+02 (6.17E+00)≈≈ | 4.38E+02 (6.56E+00)≈≈ | 4.38E+02 (7.10E+00)≈≈ |
| 3.87E+02 (1.68E+00)+− | 3.87E+02 (8.64E-01)+− | 3.87E+02 (6.19E-01)+− | 3.87E+02 (6.17E-01)+− | 3.87E+02 (6.32E-01)+− |
| 8.54E+02 (2.84E+02)+− | 8.42E+02 (4.69E+02)− ≈ | 8.59E+02 (4.73E+02)− ≈ | 9.19E+02 (4.18E+02)≈≈ | 8.15E+02 (4.77E+02)− ≈ |
| 5.01E+02 (7.52E+00)− ≈ | 5.00E+02 (6.51E+00)+− | 4.95E+02 (7.63E+00)+− | 4.95E+02 (8.15E+00)+− | 4.96E+02 (8.47E+00)+− |
| 3.24E+02 (4.51E+01)≈≈ | 3.21E+02 (4.35E+01)≈≈ | 3.12E+02 (3.75E+01)≈≈ | 3.14E+02 (3.67E+01)≈≈ | 3.14E+02 (3.57E+01)≈≈ |
| 4.08E+02 (2.12E+01)+ ≈ | 4.08E+02 (1.95E+01)+ ≈ | 4.10E+02 (2.45E+01)≈≈ | 4.07E+02 (2.56E+01)+ ≈ | 4.16E+02 (1.61E+01)≈≈ |
| 2.17E+03 (1.30E+02)≈ − | 2.14E+03 (1.06E+02)≈ − | 2.12E+03 (8.35E+01)≈ − | 2.15E+03 (1.35E+02)≈ − | 2.14E+03 (1.11E+02)≈ − |

Table 5: The results of the three versions of SaDE/Mexp for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution 1.00E-01 | 5.00E-02 |
|---|---|---|---|---|
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 1.14E-14 (1.42E-14) | 0.0E+00 (0.0E+00)+ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ |
| F3 | 2.84E-14 (2.89E-14) | 1.33E-14 (2.45E-14)≈ | 1.71E-14 (2.65E-14)≈≈ | 1.33E-14 (2.45E-14)≈≈ |
| F4 | 1.14E-14 (2.31E-14) | 5.75E+00 (6.43E+00)− | 2.14E+01 (2.81E+01)− ≈ | 3.99E-01 (1.22E+00)≈ + |
| F5 | 2.64E+01 (7.45E+00) | 2.36E+01 (4.96E+00)+ | 2.22E+01 (4.78E+00)+ ≈ | 2.26E+01 (4.94E+00)+ ≈ |
| F6 | 4.56E-09 (2.5E-08) | 1.14E-13 (0.00E+00)≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ |
| F7 | 5.41E+01 (6.61E+00) | 5.50E+01 (4.25E+00)≈ | 5.23E+01 (5.56E+00)≈ + | 5.12E+01 (4.41E+00)≈ + |
| F8 | 2.84E+01 (7.85E+00) | 2.58E+01 (5.46E+00)≈ | 2.10E+01 (5.04E+00)++ | 2.43E+01 (4.74E+00)≈≈ |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 1.60E+03 (3.06E+02) | 1.32E+03 (2.76E+02)+ | 1.42E+03 (2.33E+02)+ ≈ | 1.34E+03 (3.63E+02)+ ≈ |
| F11 | 1.51E+01 (6.77E+00) | 1.09E+01 (3.46E+00)+ | 8.06E+00 (3.31E+00)++ | 8.16E+00 (3.03E+00)++ |
| F12 | 9.85E+02 (3.77E+02) | 5.04E+02 (1.85E+02)+ | 5.19E+02 (2.66E+02)+ ≈ | 4.67E+02 (2.18E+02)+ ≈ |
| F13 | 2.26E+01 (4.51E+00) | 1.00E+01 (3.86E+00)+ | 8.77E+00 (4.53E+00)+ ≈ | 1.27E+01 (7.77E+00)+ ≈ |
| F14 | 2.67E+01 (2.91E+00) | 4.70E+00 (1.66E+00)+ | 4.31E+00 (4.25E+00)++ | 1.08E+01 (7.69E+00)+− |
| F15 | 7.85E+00 (3.81E+00) | 4.20E+00 (1.38E+00)+ | 3.74E+00 (1.18E+00)+ ≈ | 3.67E+00 (1.45E+00)+ ≈ |
| F16 | 4.06E+02 (1.78E+02) | 2.40E+02 (1.62E+02)+ | 1.96E+02 (1.34E+02)+ ≈ | 2.55E+02 (1.76E+02)+ ≈ |
| F17 | 4.49E+01 (1.58E+01) | 1.72E+01 (8.86E+00)+ | 1.50E+01 (9.17E+00)+ ≈ | 1.70E+01 (9.98E+00)+ ≈ |
| F18 | 2.37E+01 (2.51E+00) | 1.63E+01 (9.08E+00)+ | 1.63E+01 (9.38E+00)+ ≈ | 1.61E+01 (9.55E+00)+ ≈ |
| F19 | 3.19E+00 (1.64E+00) | 3.34E+00 (1.23E+00)≈ | 3.13E+00 (9.92E-01)≈≈ | 2.60E+00 (6.96E-01)≈ + |
| F20 | 5.37E+01 (4.79E+01) | 6.17E+00 (6.17E+00)+ | 5.27E+00 (5.71E+00)+ ≈ | 2.25E+01 (3.95E+01)+ ≈ |
| F21 | 2.26E+02 (7.73E+00) | 2.23E+02 (5.14E+00)≈ | 1.99E+02 (5.08E+01)≈≈ | 2.12E+02 (3.81E+01)≈≈ |
| F22 | 1.00E+02 (0.00E+00) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| F23 | 3.77E+02 (8.16E+00) | 3.70E+02 (6.82E+00)+ | 3.72E+02 (6.32E+00)+ ≈ | 3.74E+02 (6.09E+00)≈ − |
| F24 | 4.50E+02 (8.62E+00) | 4.39E+02 (4.08E+00)+ | 4.37E+02 (4.82E+00)+ ≈ | 4.40E+02 (5.16E+00)+ ≈ |
| F25 | 3.78E+02 (4.46E-02) | 3.77E+02 (1.56E+00)+ | 3.78E+02 (9.12E-03)+− | 3.78E+02 (1.04E-02)+− |
| F26 | 1.33E+03 (2.06E+02) | 2.80E+02 (4.07E+01)+ | 1.15E+03 (5.90E+01)+− | 1.09E+03 (1.66E+02)+− |
| F27 | 5.00E+02 (2.58E-04) | 4.65E+02 (3.15E+01)≈ | 4.86E+02 (9.65E+00)+ ≈ | 4.86E+02 (1.02E+01)+ ≈ |
| F28 | 4.95E+02 (9.54E+00) | 3.00E+02 (2.80E-13)+ | 3.00E+02 (2.31E-13)+ ≈ | 3.24E+02 (4.44E+01)+ ≈ |
| F29 | 2.70E+02 (4.08E+01) | 2.92E+02 (5.13E+01)≈ | 3.95E+02 (3.74E+01)−− | 3.97E+02 (3.28E+01)−− |
| F30 | 2.06E+02 (1.36E+00) | 3.04E+02 (1.04E+02)− | 1.95E+03 (1.05E+01)−− | 1.96E+03 (1.41E+01)−− |

| Individuals redistribution 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
|---|---|---|---|---|
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 9.47E-16 (5.19E-15)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ |
| 1.14E-14 (2.31E-14)+ ≈ | 7.58E-15 (1.97E-14)+ ≈ | 1.14E-14 (2.31E-14)+ ≈ | 1.33E-14 (2.45E-14)≈≈ | 7.58E-15 (1.97E-14)+ ≈ |
| 4.89E+01 (2.22E+01)−− | 5.36E+01 (1.78E+01)−− | 4.76E+01 (2.43E+01)−− | 5.20E+01 (2.05E+01)−− | 5.04E+01 (2.27E+01)−− |
| 2.24E+01 (6.39E+00)+ ≈ | 2.77E+01 (6.74E+00)≈ − | 2.89E+01 (9.06E+00)≈ − | 2.53E+01 (6.62E+00)≈ − | 2.65E+01 (7.23E+00)≈ − |
| 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ |
| 5.10E+01 (4.72E+00)≈ + | 5.11E+01 (4.67E+00)≈ + | 5.38E+01 (6.78E+00)≈≈ | 5.39E+01 (6.71E+00)≈≈ | 5.47E+01 (5.64E+00)≈≈ |
| 2.42E+01 (6.64E+00)≈ ≈ | 2.52E+01 (7.22E+00)≈≈ | 3.00E+01 (7.78E+00)≈ − | 2.85E+01 (7.71E+00)≈≈ | 2.82E+01 (6.76E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.06E+03 (3.45E+02)++ | 1.28E+03 (3.40E+02)+ ≈ | 1.47E+03 (3.36E+02)≈ − | 1.37E+03 (3.17E+02)+ ≈ | 1.35E+03 (3.07E+02)+ ≈ |
| 2.34E+01 (1.24E+01)−− | 2.40E+01 (1.10E+01)−− | 3.38E+01 (1.95E+01)−− | 2.69E+01 (1.84E+01)−− | 2.47E+01 (1.75E+01)−− |
| 7.42E+02 (2.89E+02)+− | 9.11E+02 (3.24E+02)≈ − | 8.94E+02 (3.42E+02)≈ − | 9.93E+02 (3.66E+02)≈ − | 9.30E+02 (3.24E+02)≈ − |
| 1.46E+01 (6.94E+00)+ ≈ | 1.33E+01 (7.91E+00)+ ≈ | 1.66E+01 (6.52E+00)+− | 1.52E+01 (8.03E+00)+− | 1.99E+01 (8.48E+00)≈ − |
| 7.95E+00 (7.26E+00)+− | 5.49E+00 (2.20E+00)+ ≈ | 5.08E+00 (1.72E+00)+ ≈ | 5.11E+00 (2.12E+00)+ ≈ | 4.80E+00 (1.50E+00)+ ≈ |
| 3.52E+00 (1.52E+00)++ | 3.35E+00 (1.39E+00)++ | 4.53E+00 (2.20E+00)+ ≈ | 4.13E+00 (1.75E+00)+ ≈ | 6.66E+00 (3.14E+00)≈ − |
| 2.29E+02 (1.41E+02)+ ≈ | 1.64E+02 (1.39E+02)+ ≈ | 1.72E+02 (1.31E+02)+ ≈ | 1.60E+02 (1.40E+02)++ | 2.02E+02 (1.43E+02)+ ≈ |
| 2.27E+01 (1.28E+01)+ ≈ | 2.43E+01 (1.35E+01)+− | 2.55E+01 (1.38E+01)+− | 2.89E+01 (1.29E+01)+− | 2.18E+01 (1.20E+01)+ ≈ |
| 1.57E+01 (9.53E+00)+ ≈ | 1.64E+01 (8.96E+00)+ ≈ | 1.87E+01 (6.98E+00)+ ≈ | 1.90E+01 (7.07E+00)+ ≈ | 2.14E+01 (6.87E+00)+ ≈ |
| 2.78E+00 (9.19E-01)≈ + | 2.45E+00 (1.56E+00)≈ + | 2.31E+00 (1.02E+00)++ | 2.53E+00 (1.01E+00)≈ + | 4.14E+00 (2.01E+00)≈≈ |
| 3.05E+01 (4.94E+01)+ ≈ | 3.88E+01 (5.57E+01)+− | 1.56E+01 (2.31E+01)+− | 3.42E+01 (4.25E+01)+− | 2.96E+01 (4.11E+01)+− |
| 2.27E+02 (8.69E+00)≈ − | 2.28E+02 (8.72E+00)≈ − | 2.24E+02 (2.47E+01)≈ ≈ | 2.28E+02 (9.04E+00)≈ − | 1.68E+02 (6.49E+01)++ |
| 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| 3.71E+02 (9.56E+00)+ ≈ | 3.77E+02 (1.17E+01)≈ − | 3.77E+02 (9.49E+00)≈ − | 3.78E+02 (7.46E+00)≈ − | 3.80E+02 (8.88E+00)≈ − |
| 4.41E+02 (8.29E+00)+ ≈ | 4.43E+02 (9.57E+00)+ ≈ | 4.44E+02 (8.25E+00)+− | 4.45E+02 (1.23E+01)+ ≈ | 4.34E+02 (4.50E+01)+ ≈ |
| 3.78E+02 (8.25E-03)+ ≈ | 3.78E+02 (5.82E-01)+ ≈ | 3.78E+02 (1.18E-02)+− | 3.78E+02 (3.35E-02)+ − | 3.78E+02 (3.51E-02)≈ − |
| 1.15E+03 (1.05E+02)+− | 1.2E+03 (2.01E+02)+− | 1.22E+03 (9.96E+01)+− | 1.20E+03 (1.30E+02)+− | 1.19E+03 (1.00E+02)+− |
| 4.98E+02 (9.18E+00)≈ − | 5.01E+02 (7.33E+00)≈ − | 5.01E+02 (5.94E+00)≈ − | 5.03E+02 (7.62E+00)−− | 5.00E+02 (8.44E+00)≈ − |
| 3.51E+02 (5.52E+01)+− | 3.36E+02 (5.22E+01)+− | 3.26E+02 (4.78E+01)+ ≈ | 3.28E+02 (5.14E+01)+ ≈ | 3.25E+02 (4.65E+01)+ ≈ |
| 4.08E+02 (3.09E+01)−− | 4.20E+02 (3.26E+01)−− | 4.32E+02 (1.54E+01)−− | 4.32E+02 (1.72E+01)−− | 4.33E+02 (2.55E+01)−− |
| 1.96E+03 (1.75E+01)−− | 1.96E+03 (1.29E+01)−− | 1.98E+03 (5.03E+01)−− | 1.98E+03 (4.29E+01)−− | 2.00E+03 (8.52E+01)−− |

Table 6: The results of the three versions of MPEDE for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution 1.00E-01 | 5.00E-02 |
|---|---|---|---|---|
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 1.89E-15 (4.91E-15)≈≈ | 1.89E-15 (4.91E-15)≈≈ |
| F2 | 1.82E-13 (3.01E-13) | 4.17E-14 (3.71E-14)+ | 2.84E-14 (1.83E-14)+ ≈ | 2.94E-14 (1.90E-14)+ ≈ |
| F3 | 1.31E-13 (3.70E-13) | 7.44E-12 (3.84E-11)≈ | 9.42E-13 (4.93E-12)≈≈ | 4.55E-14 (1.10E-13)≈ + |
| F4 | 4.79E+01 (2.41E+01) | 1.33E-01 (7.28E-01)+ | 5.99E+00 (1.78E+01)+ ≈ | 9.47E-15 (2.15E-14)++ |
| F5 | 2.17E+01 (5.46E+00) | 1.46E+01 (3.29E+00)+ | 1.90E+01 (3.90E+00)− | 1.84E+01 (4.00E+00)+− |
| F6 | 1.10E-13 (2.08E-14) | 1.14E-13 (0.00E+00)≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ |
| F7 | 5.19E+01 (4.82E+00) | 4.46E+01 (2.48E+00)+ | 4.87E+01 (4.51E+00)+− | 4.89E+01 (4.02E+00)+− |
| F8 | 2.18E+01 (4.45E+00) | 1.49E+01 (2.71E+00)+ | 1.89E+01 (3.66E+00)+− | 1.97E+01 (4.05E+00)≈ − |
| F9 | 5.97E-03 (2.27E-02) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 1.22E+03 (3.65E+02) | 7.87E+02 (2.17E+02)+ | 9.12E+02 (2.30E+02)+− | 8.72E+02 (1.68E+02)+ ≈ |
| F11 | 1.94E+01 (2.08E+01) | 9.25E+00 (3.22E+00)+ | 9.28E+00 (3.50E+00)+ ≈ | 9.85E+00 (3.90E+00)≈≈ |
| F12 | 1.12E+03 (3.91E+02) | 6.08E+02 (1.97E+02)+ | 6.67E+02 (2.21E+02)+ ≈ | 6.35E+02 (2.37E+02)+ ≈ |
| F13 | 4.13E+01 (1.63E+01) | 1.62E+01 (5.47E+00)+ | 1.69E+01 (6.26E+00)+ ≈ | 1.89E+01 (7.12E+00)+ ≈ |
| F14 | 2.51E+02 (7.30E+02) | 1.64E+02 (4.25E+02)≈ | 1.25E+02 (2.64E+02)+ ≈ | 1.58E+02 (5.39E+02)≈≈ |
| F15 | 9.89E+01 (2.43E+02) | 1.15E+02 (3.37E+02)− | 1.70E+02 (6.65E+02)−− | 2.08E+02 (5.98E+02)− ≈ |
| F16 | 2.32E+02 (1.58E+02) | 1.43E+02 (9.88E+01)+ | 1.83E+02 (1.04E+02)+ ≈ | 1.21E+02 (1.01E+02)+ ≈ |
| F17 | 3.61E+01 (3.72E+01) | 1.21E+01 (7.01E+00)+ | 1.50E+01 (7.36E+00)+ ≈ | 1.40E+01 (9.09E+00)+ ≈ |
| F18 | 7.03E+03 (1.51E+04) | 3.81E+03 (1.17E+04)+ | 2.47E+03 (6.61E+03)+ ≈ | 3.28E+03 (6.45E+03)+ ≈ |
| F19 | 1.07E+03 (5.20E+03) | 1.60E+02 (3.93E+02)+ | 9.86E+01 (1.20E+02)+ ≈ | 1.63E+02 (4.13E+02)+ ≈ |
| F20 | 5.32E+02 (6.36E+01) | 3.07E+00 (2.17E+00)+ | 9.12E+00 (2.32E+01)+ ≈ | 5.75E+01 (5.94E+01)≈ − |
| F21 | 2.23E+02 (3.96E+00) | 2.17E+02 (2.98E+00)+ | 1.00E+02 (6.50E-07)++ | 1.00E+02 (6.25E-07)++ |
| F22 | 1.00E+02 (8.30E-14) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| F23 | 3.71E+02 (7.64E+00) | 3.61E+02 (3.71E+00)+ | 3.38E+02 (8.09E+01)++ | 1.00E+02 (5.57E-07)++ |
| F24 | 4.40E+02 (6.05E+00) | 4.31E+02 (3.29E+00)+ | 2.24E+02 (7.41E+01)++ | 2.00E+02 (8.30E-07)++ |
| F25 | 3.87E+02 (1.61E-01) | 3.86E+02 (1.01E+00)+ | 3.86E+02 (1.41E+00)+ ≈ | 3.87E+02 (6.06E-01)+ ≈ |
| F26 | 1.13E+03 (8.81E+01) | 9.77E+02 (1.90E+02)+ | 5.00E+02 (3.55E+02)++ | 3.00E+02 (1.56E-06)++ |
| F27 | 5.04E+02 (7.86E+00) | 4.87E+02 (4.59E+00)+ | 4.77E+02 (1.20E+01)++ | 4.72E+02 (1.31E+01)++ |
| F28 | 3.52E+02 (6.17E+01) | 3.00E+02 (2.83E-13)+ | 3.00E+02 (2.31E-13)+ ≈ | 3.03E+02 (1.89E+01)+ ≈ |
| F29 | 4.17E+02 (3.23E+01) | 3.87E+02 (3.52E+01)+ | 3.42E+02 (1.66E+01)++ | 3.48E+02 (2.27E+01)++ |
| F30 | 2.16E+03 (1.61E+02) | 1.96E+03 (3.47E+01)+ | 1.99E+03 (1.87E+02)+ ≈ | 2.06E+03 (5.63E+02)+ ≈ |

| Individuals redistribution 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
|---|---|---|---|---|
| 2.37E-15 (5.39E-15)≈≈ | 2.37E-15 (5.39E-15)≈≈ | 1.42E-15 (4.34E-15)≈≈ | 1.42E-15 (4.34E-15)≈≈ | 1.89E-15 (4.91E-15)≈≈ |
| 2.94E-14 (1.75E-14)+ ≈ | 3.85E-08 (2.11E-07)− ≈ | 1.14E-14 (1.60E-14)++ | 1.14E-14 (1.60E-14)++ | 2.84E-15 (8.67E-15)++ |
| 1.55E-13 (5.91E-13)≈ + | 1.38E-13 (5.41E-13)≈≈ | 5.31E-14 (1.45E-13)≈ + | 5.31E-14 (1.45E-13)≈ + | 3.83E-13 (1.21E-12)≈≈ |
| 3.40E+01 (2.92E+01)≈ − | 4.87E+01 (2.39E+01)≈ − | 4.38E+01 (2.63E+01)≈ − | 3.63E+01 (2.94E+01)≈ − | 4.04E+01 (2.86E+01)≈ − |
| 1.97E+01 (3.24E+00)− | 1.76E+01 (3.69E+00)+− | 1.75E+01 (3.53E+00)+− | 1.72E+01 (3.05E+00)+− | 1.73E+01 (4.03E+00)+− |
| 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ | 1.14E-13 (0.00E+00)≈≈ |
| 4.91E+01 (3.24E+00)+− | 4.97E+01 (3.06E+00)≈ − | 4.74E+01 (5.28E+00)+− | 4.81E+01 (4.32E+00)+− | 4.75E+01 (3.77E+00)+− |
| 1.91E+01 (2.98E+00)+− | 1.56E+01 (3.66E+00)+ ≈ | 1.76E+01 (4.95E+00)+− | 1.73E+01 (3.96E+00)+− | 1.64E+01 (3.70E+00)+ ≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 5.97E-03 (2.27E-02)≈≈ |
| 6.45E+02 (3.00E+02)++ | 6.06E+02 (2.33E+02)++ | 6.63E+02 (1.99E+02)++ | 6.38E+02 (2.23E+02)++ | 6.30E+02 (2.41E+02)++ |
| 1.22E+01 (1.28E+01)+ ≈ | 1.49E+01 (1.40E+01)≈≈ | 1.22E+01 (1.40E+01)≈≈ | 1.48E+01 (1.84E+01)≈≈ | 1.27E+01 (9.44E+00)≈≈ |
| 6.94E+02 (2.10E+02)+ ≈ | 7.49E+02 (3.00E+02)+− | 1.02E+03 (3.74E+02)≈ − | 1.16E+03 (4.47E+02)≈ − | 1.12E+03 (3.36E+02)≈ − |
| 1.05E+02 (4.01E+02)− | 2.59E+01 (1.14E+01)+− | 3.16E+02 (1.60E+03)−− | 5.74E+01 (1.55E+02)−− | 5.39E+01 (9.69E+01)≈ − |
| 2.15E+02 (9.13E+02)+ ≈ | 8.46E+01 (1.66E+02)+ ≈ | 8.47E+01 (1.74E+02)+ ≈ | 1.35E+02 (3.26E+02)+ ≈ | 4.66E+01 (7.97E+01)+ ≈ |
| 7.38E+01 (3.38E+02)+ ≈ | 8.87E+01 (2.67E+02)+ ≈ | 2.94E+02 (8.28E+02)− ≈ | 1.09E+02 (2.16E+02)− ≈ | 1.98E+02 (3.95E+02)≈ − |
| 1.64E+02 (1.29E+02)≈ | 1.72E+02 (1.26E+02)≈≈ | 1.95E+02 (1.47E+02)≈≈ | 2.19E+02 (1.17E+02)≈ − | 2.10E+02 (1.58E+02)≈≈ |
| 1.59E+01 (1.03E+01)+ ≈ | 1.51E+01 (9.25E+00)+ ≈ | 1.29E+01 (1.01E+01)+ ≈ | 2.16E+01 (3.32E+01)+ ≈ | 1.73E+01 (9.97E+00)+− |
| 7.12E+02 (3.05E+03)++ | 4.86E+03 (1.25E+04)+ ≈ | 6.63E+02 (2.24E+03)+ ≈ | 2.35E+03 (8.32E+03)+ ≈ | 9.61E+02 (3.32E+03)+ ≈ |
| 2.06E+01 (7.21E+01)≈ | 2.25E+02 (8.78E+02)+ ≈ | 8.78E+01 (3.89E+02)+ ≈ | 1.32E+02 (4.96E+02)+ ≈ | 5.72E+01 (1.58E+02)≈ + |
| 4.85E+01 (6.00E+01)≈ − | 6.91E+01 (1.26E+02)≈≈ | 4.62E+01 (5.73E+01)≈ − | 5.97E+01 (7.57E+01)≈ − | 6.85E+01 (7.04E+01)≈ − |
| 1.00E+02 (5.50E-07)++ | 1.00E+02 (6.10E-07)++ | 1.00E+02 (5.92E-07)++ | 1.00E+02 (5.51E-07)++ | 1.00E+02 (4.91E-07)++ |
| 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (8.30E-14)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| 1.00E+02 (8.41E-07)++ | 1.00E+02 (7.67E-07)++ | 1.00E+02 (1.23E-06)++ | 1.34E+02 (8.94E+01)++ | 1.89E+02 (1.24E+02)++ |
| 2.00E+02 (9.44E-07)++ | 1.93E+02 (2.54E+01)++ | 1.97E+02 (1.83E+01)++ | 1.97E+02 (1.83E+01)++ | 2.08E+02 (4.40E+01)++ |
| 3.87E+02 (1.34E-02)+ ≈ | 3.87E+02 (9.98E-03)+− | 3.87E+02 (6.07E-01)+− | 3.87E+02 (8.51E-02)+− | 3.87E+02 (1.44E-01)≈ − |
| 3.00E+02 (1.25E-06)++ | 3.00E+02 (1.41E-06)++ | 3.00E+02 (1.60E-06)++ | 3.00E+02 (1.35E-06)++ | 3.00E+02 (1.11E-06)++ |
| 4.91E+02 (1.41E+01)+− | 4.94E+02 (1.20E+01)+ ≈ | 4.92E+02 (1.69E+01)+− | 4.97E+02 (1.39E+01)+− | 4.91E+02 (1.89E+01)+− |
| 3.45E+02 (5.65E+01)≈ − | 3.51E+02 (5.58E+01)≈ − | 3.30E+02 (5.12E+01)≈ − | 3.27E+02 (4.96E+01)≈ − | 3.42E+02 (5.64E+01)≈ − |
| 3.47E+02 (2.51E+01)++ | 3.47E+02 (2.36E+01)++ | 3.57E+02 (2.73E+01)++ | 3.53E+02 (2.45E+01)++ | 3.55E+02 (2.89E+01)++ |
| 1.95E+03 (2.11E+01)+ ≈ | 1.99E+03 (1.62E+02)+ ≈ | 1.96E+03 (2.19E+01)+ ≈ | 2.16E+03 (6.52E+02)+− | 2.07E+03 (2.77E+02)+− |

Table 7: The results of the three versions of ETI-JADE for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 5.86E+01 (0.00E+00) | 1.30E+01 (2.31E+01)+ | 5.86E+01 (3.61E-14)≈ − | 5.86E+01 (0.00E+00)≈ − |
| F5 | 7.86E+00 (1.06E+00) | 7.26E+00 (1.82E+00)≈ | 2.68E+00 (1.33E+00)++ | 6.05E+00 (1.60E+00)++ |
| F6 | 1.14E-13 (0.00E+00) | 1.4E-13 (7.72E-14)≈ | 3.15E-11 (7.45E-12)−− ≈ | 2.25E-11 (4.75E-12)−− |
| F7 | 3.87E+01 (1.40E+00) | 3.87E+01 (2.18E+00)≈ | 3.53E+01 (7.89E-01)++ | 3.51E+01 (7.52E-01)++ |
| F8 | 7.56E+00 (1.21E+00) | 7.66E+00 (1.92E+00)≈ | 3.03E+00 (1.49E+00)++ | 7.87E+00 (2.23E+00)≈≈ |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 1.03E+03 (1.78E+02) | 1.02E+03 (1.78E+02)≈ | 1.85E+03 (2.78E+02)−− | 1.61E+03 (4.84E+02)−− |
| F11 | 2.30E+01 (2.70E+01) | 8.38E+00 (1.04E+01)≈ | 5.38E+00 (1.49E+01)++ | 3.29E+00 (1.08E+01)++ |
| F12 | 1.17E+02 (8.27E+01) | 8.69E+01 (9.33E+01)≈ | 5.86E+01 (5.66E+01)+ ≈ | 4.70E+01 (7.27E+01)++ |
| F13 | 1.97E+01 (1.28E+00) | 1.93E+01 (3.02E+00)≈ | 6.18E+00 (5.8E+00)++ | 1.14E+01 (5.76E+00)++ |
| F14 | 1.51E+01 (7.78E+00) | 1.64E+01 (6.03E+00)≈ | 1.57E+01 (8.52E+00)− ≈ | 2.07E+01 (6.98E+00)−− |
| F15 | 3.97E+00 (3.44E-01) | 4.66E+00 (1.93E+00)− | 5.34E-01 (3.8E-01)++ | 4.61E-01 (2.97E-01)++ |
| F16 | 1.43E+01 (2.44E+00) | 1.69E+01 (4.86E+00)− | 1.42E+01 (4.85E+00)≈ + | 3.75E+01 (2.63E+01)−− |
| F17 | 2.10E+01 (6.90E+00) | 2.22E+01 (6.13E+00)≈ | 2.10E+01 (9.83E+00)≈≈ | 4.78E+01 (1.26E+01)−− |
| F18 | 1.98E+01 (3.65E+00) | 1.97E+01 (3.36E+00)+ | 1.81E+01 (6.58E+00)++ | 1.93E+01 (5.02E+00)+ ≈ |
| F19 | 4.07E+00 (5.74E-01) | 3.89E+00 (1.18E+00)≈ | 2.30E+00 (3.44E-01)++ | 4.30E+00 (1.59E+00)≈≈ |
| F20 | 1.71E+01 (7.44E+00) | 2.03E+01 (6.02E+00)≈ | 4.25E+00 (6.79E+00)++ | 4.82E+01 (2.35E+01)−− |
| F21 | 2.09E+02 (1.40E+00) | 2.10E+02 (1.77E+00)≈ | 2.04E+02 (1.38E+00)++ | 2.08E+02 (1.62E+00)++ |
| F22 | 1.00E+02 (0.00E+00) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| F23 | 3.51E+02 (1.77E+00) | 3.52E+02 (2.71E+00)≈ | 3.49E+02 (3.44E+00)++ | 3.50E+02 (2.25E+00)≈ + |
| F24 | 4.26E+02 (1.58E+00) | 4.27E+02 (1.58E+00)− | 4.25E+02 (1.00E+00)≈ + | 4.25E+02 (1.18E+00)≈ + |
| F25 | 3.87E+02 (3.33E-03) | 3.84E+02 (1.32E+00)+ | 3.87E+02 (1.67E-03)+− | 3.87E+02 (1.75E-03)+− |
| F26 | 9.33E+02 (3.85E+01) | 8.16E+02 (2.55E+02)≈ | 9.21E+02 (2.61E+01)≈≈ | 8.80E+02 (2.94E+01)+− |
| F27 | 5.00E+02 (8.19E+00) | 4.92E+02 (3.57E+00)+ | 4.91E+02 (6.27E+00)+ ≈ | 4.96E+02 (7.50E+00)≈≈ |
| F28 | 3.08E+02 (2.89E+01) | 3.00E+02 (2.31E-13)≈ | 3.00E+02 (4.08E-10)≈≈ | 3.00E+02 (4.53E-10)≈≈ |
| F29 | 4.14E+02 (1.74E+01) | 4.17E+02 (1.36E+01)≈ | 4.14E+02 (4.59E+00)− + | 4.93E+02 (2.95E+01)−− |
| F30 | 1.97E+03 (3.61E+01) | 1.95E+03 (1.04E+01)≈ | 1.94E+03 (3.78E-01)++ | 1.94E+03 (6.07E+00)++ |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − | 5.86E+01 (0.00E+00)≈ − |
| 1.26E+01 (2.98E+00)−− | 1.14E+01 (2.61E+00)−− | 1.19E+01 (3.34E+00)−− | 1.14E+01 (3.03E+00)−− | 1.20E+01 (2.87E+00)−− |
| 1.49E-11 (2.90E-12)−− | 1.44E-11 (3.63E-12)−− | 9.35E-12 (2.28E-12)−− | 9.85E-12 (2.45E-12)−− | 6.48E-12 (2.65E-12)−− |
| 4.54E+01 (3.77E+00)−− | 4.40E+01 (3.30E+00)−− | 4.41E+01 (3.68E+00)−− | 4.35E+01 (3.36E+00)−− | 4.28E+01 (3.22E+00)−− |
| 1.33E+01 (3.92E+00)−− | 1.11E+01 (2.79E+00)−− | 1.19E+01 (3.77E+00)−− | 1.09E+01 (3.26E+00)−− | 1.15E+01 (2.87E+00)−− |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.16E+03 (5.44E+02)≈≈ | 1.42E+03 (5.05E+02)−− | 1.71E+03 (3.31E+02)−− | 1.68E+03 (5.02E+02)−− | 1.61E+03 (4.89E+02)−− |
| 2.09E+01 (2.41E+01)≈≈ | 1.80E+01 (2.30E+01)−− | 2.14E+01 (2.65E+01)−− | 3.10E+01 (3.31E+01)−− | 2.20E+01 (2.67E+01)−− |
| 1.17E+02 (7.90E+01)≈≈ | 1.27E+02 (8.12E+01)≈ − | 1.12E+02 (7.75E+01)≈≈ | 1.73E+02 (9.82E+01)−− | 1.32E+02 (9.92E+01)≈≈ |
| 1.54E+01 (1.08E+00)++ | 2.30E+01 (2.84E+00)−− | 1.82E+01 (3.82E+00)≈≈ | 1.69E+01 (2.94E+00)++ | 1.53E+01 (1.31E+00)++ |
| 2.15E+01 (1.16E+00)−− | 1.64E+01 (8.86E+00)≈≈ | 1.91E+01 (5.96E+00)≈≈ | 2.07E+01 (4.07E+00)−− | 2.13E+01 (1.00E+00)−− |
| 5.27E+00 (2.21E+00)− ≈ | 4.79E+00 (2.53E+00)− ≈ | 2.65E+00 (2.60E+00)≈ + | 1.72E+00 (2.21E+00)++ | 1.94E+00 (2.38E+00)++ |
| 2.54E+01 (2.44E+01)− ≈ | 2.05E+01 (9.29E+00)− ≈ | 2.05E+01 (8.31E+00)−− | 2.02E+01 (6.85E+00)− ≈ | 2.05E+01 (7.00E+00)−− |
| 2.41E+01 (1.80E+01)≈≈ | 3.13E+01 (1.42E+01)−− | 3.17E+01 (1.37E+01)−− | 3.56E+01 (1.37E+01)−− | 3.53E+01 (8.11E+00)−− |
| 2.09E+01 (1.98E-01)−− | 2.08E+01 (1.83E-01)−− | 2.05E+01 (3.36E-02)−− | 2.05E+01 (3.79E-02)−− | 2.05E+01 (3.86E-02)−− |
| 5.87E+00 (3.25E+00)≈≈ | 5.23E+00 (2.42E+00)≈≈ | 4.84E+00 (2.22E+00)≈≈ | 4.59E+00 (2.12E+00)≈≈ | 5.07E+00 (2.28E+00)−− |
| 2.57E+01 (1.46E+01)− ≈ | 2.70E+01 (1.28E+01)−− | 2.74E+01 (1.11E+01)−− | 3.26E+01 (1.45E+01)−− | 3.54E+01 (1.05E+01)−− |
| 1.07E+02 (2.74E+01)++ | 1.37E+02 (5.32E+01)++ | 2.02E+02 (3.45E+01)++ | 2.04E+02 (2.85E+01)++ | 2.01E+02 (3.44E+01)++ |
| 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| 3.42E+02 (6.12E+01)++ | 3.36E+02 (7.05E+01)++ | 3.60E+02 (5.30E+00)−− | 3.60E+02 (5.74E+00)−− | 3.59E+02 (5.66E+00)−− |
| 1.95E+02 (2.41E+01)++ | 2.98E+02 (1.22E+02)≈≈ | 3.54E+02 (1.11E+02)≈≈ | 3.85E+02 (9.32E+01)++ | 3.77E+02 (9.89E+01)++ |
| 3.87E+02 (1.32E-03)+− | 3.87E+02 (1.76E-03)+− | 3.87E+02 (1.42E-03)+− | 3.87E+02 (3.84E-03)+− | 3.87E+02 (6.14E-03)≈ − |
| 2.97E+02 (1.49E+01)++ | 2.99E+02 (4.64E+00)++ | 4.93E+02 (3.26E+02)+ ≈ | 5.46E+02 (3.55E+02)+ ≈ | 4.96E+02 (3.32E+02)+ ≈ |
| 4.98E+02 (7.50E+00)− | 4.99E+02 (6.68E+00)≈ − | 5.00E+02 (6.74E+00)≈ − | 5.03E+02 (5.38E+00)≈ − | 5.02E+02 (5.93E+00)≈ − |
| 3.11E+02 (3.37E+01)≈≈ | 3.07E+02 (2.76E+01)≈≈ | 3.11E+02 (3.26E+01)≈≈ | 3.07E+02 (2.76E+01)≈≈ | 3.08E+02 (2.89E+01)≈≈ |
| 4.35E+02 (3.84E+01)≈≈ | 4.23E+02 (2.40E+01)≈≈ | 4.37E+02 (1.96E+01)−− | 4.41E+02 (1.56E+01)−− | 4.39E+02 (1.95E+01)−− |
| 1.95E+03 (1.09E+01)≈ + | 1.95E+03 (2.77E+01)≈ − | 1.96E+03 (2.74E+01)≈≈ | 1.96E+03 (2.73E+01)≈≈ | 1.96E+03 (2.70E+01)≈≈ |

Table 8: The results of the three versions of L-SHADE-RSP for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 9.47E-16 (3.61E-15) | 0.00E+00 (0.00E+00)≈ | 9.47E-16 (3.61E-15)≈≈ | 4.74E-16 (2.59E-15)≈≈ |
| F2 | 1.02E-10 (2.84E-10) | 8.53E-15 (1.52E-14)+ | 1.65E-13 (7.09E-13)+ ≈ | 1.20E-13 (5.63E-13)+ ≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 1.86E+00 (2.02E+00) | 7.97E-01 (1.62E+00)+ | 1.20E+00 (1.86E+00)≈ − | 1.06E+00 (1.79E+00)≈ − |
| F5 | 2.61E+01 (6.06E+00) | 1.61E+01 (2.63E+00)+ | 1.63E+01 (3.38E+00)+ ≈ | 1.58E+01 (3.53E+00)+ ≈ |
| F6 | 3.03E-14 (5.11E-14) | 9.85E-14 (3.93E-14)− | 7.96E-14 (5.3E-14)− − | 8.34E-14 (5.11E-14)− ≈ |
| F7 | 6.01E+01 (8.83E+00) | 4.75E+01 (2.83E+00)+ | 4.56E+01 (2.91E+00)++ | 4.63E+01 (2.21E+00)+ ≈ |
| F8 | 2.89E+01 (6.83E+00) | 1.72E+01 (2.68E+00)+ | 1.60E+01 (3.04E+00)+ ≈ | 1.59E+01 (2.83E+00)+ ≈ |
| F9 | 1.54E-01 (2.59E-01) | 2.98E-03 (1.63E-02)+ | 3.63E-02 (1.16E-01)+ ≈ | 7.23E-02 (2.04E-01)≈≈ |
| F10 | 1.79E+03 (3.39E+02) | 1.31E+03 (2.25E+02)+ | 1.16E+03 (2.16E+02)++ | 1.02E+03 (2.78E+02)++ |
| F11 | 1.51E+01 (8.76E+00) | 8.04E+00 (3.88E+00)+ | 1.32E+01 (5.30E+00)− | 1.53E+01 (8.35E+00)≈ − |
| F12 | 1.09E+03 (3.73E+02) | 5.21E+02 (2.32E+02)+ | 1.22E+03 (3.76E+02)≈ − | 9.99E+02 (4.8E+02)≈ − |
| F13 | 2.61E+01 (9.48E+00) | 1.34E+01 (6.87E+00)+ | 2.45E+01 (9.98E+00)≈ − | 2.69E+01 (9.85E+00)≈ − |
| F14 | 1.07E+01 (7.59E+00) | 5.87E+00 (2.36E+00)+ | 5.91E+00 (3.61E+00)+ ≈ | 8.41E+00 (4.97E+00)≈ − |
| F15 | 8.46E+00 (6.43E+00) | 3.89E+00 (1.22E+00)+ | 4.02E+00 (1.93E+00)+ ≈ | 3.76E+00 (1.55E+00)+ ≈ |
| F16 | 3.47E+02 (1.59E+02) | 1.86E+02 (1.35E+02)+ | 2.33E+02 (1.54E+02)+ ≈ | 2.11E+02 (1.51E+02)+ ≈ |
| F17 | 2.58E+01 (2.36E+01) | 1.08E+01 (5.34E+00)+ | 8.22E+00 (5.84E+00)++ | 7.16E+00 (3.35E+00)++ |
| F18 | 1.72E+01 (9.17E+00) | 1.63E+01 (9.79E+00)≈ | 1.04E+01 (9.80E+00)++ | 1.2E+01 (1.03E+01)++ |
| F19 | 5.71E+00 (4.05E+00) | 3.77E+00 (1.44E+00)+ | 4.03E+00 (1.74E+00)≈≈ | 3.56E+00 (1.57E+00)+ ≈ |
| F20 | 4.87E+01 (5.69E+01) | 2.17E+00 (1.15E+00)+ | 9.34E-01 (6.32E-01)++ | 1.31E+01 (3.10E+01)+ ≈ |
| F21 | 2.3E+02 (6.11E+00) | 2.17E+02 (3.15E+00)+ | 2.19E+02 (3.23E+00)+ − | 2.18E+02 (2.92E+00)+ ≈ |
| F22 | 1.00E+02 (0.00E+00) | 1.00E+02 (1.15E-13)≈ | 1.00E+02 (2.27E-13)≈≈ | 1.00E+02 (2.29E-13)≈≈ |
| F23 | 3.76E+02 (7.11E+00) | 3.6E+02 (4.12E+00)+ | 3.63E+02 (4.53E+00)+ − | 3.59E+02 (4.82E+00)+ ≈ |
| F24 | 4.49E+02 (7.85E+00) | 4.33E+02 (3.17E+00)+ | 4.38E+02 (3.34E+00)+ − | 4.37E+02 (4.32E+00)+ − |
| F25 | 3.78E+02 (6.57E-01) | 3.78E+02 (1.11E+00)+ | 3.78E+02 (8.17E-01)+ − | 3.78E+02 (9.70E-01)+ − |
| F26 | 1.25E+03 (1.05E+02) | 9.25E+02 (6.04E+01)+ | 9.65E+02 (1.48E+02)+ − | 9.75E+02 (7.50E+01)+ − |
| F27 | 4.97E+02 (1.21E+01) | 5.00E+02 (1.25E-04)− | 4.97E+02 (1.27E+01)++ | 4.91E+02 (2.31E+01)+ ≈ |
| F28 | 3.58E+02 (7.13E+01) | 4.30E+02 (6.94E+01)− | 3.50E+02 (6.60E+01)≈ + | 3.49E+02 (6.96E+01)≈ + |
| F29 | 3.45E+02 (5.60E+01) | 2.89E+02 (3.49E+01)+ | 2.95E+02 (4.51E+01)+ ≈ | 2.87E+02 (5.21E+01)+ ≈ |
| F30 | 3.21E+02 (3.45E+02) | 2.07E+02 (1.39E+00)+ | 2.10E+02 (3.72E+00)+ − | 2.09E+02 (2.93E+00)+ − |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 1.89E-15 (1.04E-14)≈≈ | 1.89E-15 (6.17E-15)≈≈ | 2.84E-15 (6.88E-15)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 6.16E-14 (1.23E-13)+ − | 2.99E-13 (1.55E-12)+ ≈ | 1.80E-14 (2.17E-14)+ ≈ | 6.02E-12 (3.29E-11)+ ≈ | 1.14E-14 (2.65E-14)+ ≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.20E+00 (1.86E+00)≈ − | 1.86E+00 (2.02E+00)≈ − | 9.30E-01 (1.71E+00)≈ − | 1.59E+00 (1.99E+00)≈ − | 1.06E+00 (1.79E+00)≈ − |
| 1.36E+01 (4.04E+00)++ | 2.31E+01 (6.58E+00)≈ − | 2.86E+01 (7.44E+00)≈ − | 2.86E+01 (6.94E+00)≈ − | 2.72E+01 (7.14E+00)≈ − |
| 8.34E-14 (5.11E-14)− ≈ | 8.34E-14 (5.11E-14)− ≈ | 8.34E-14 (5.11E-14)− ≈ | 8.34E-14 (5.11E-14)− ≈ | 6.82E-14 (5.66E-14)− ≈ |
| 4.52E+01 (2.49E+00)++ | 4.46E+01 (3.13E+00)++ | 5.34E+01 (6.29E+00)+ − | 5.62E+01 (6.47E+00)+ − | 5.51E+01 (6.27E+00)+ − |
| 1.23E+01 (3.11E+00)++ | 2.30E+01 (5.42E+00)+ − | 2.70E+01 (6.65E+00)≈ − | 2.66E+01 (7.13E+00)≈ − | 2.66E+01 (5.76E+00)≈ − |
| 2.09E-02 (3.85E-02)≈≈ | 8.95E-03 (2.73E-02)+ ≈ | 1.12E-01 (3.56E-01)≈≈ | 7.55E-02 (2.02E-01)≈≈ | 1.42E-01 (2.17E-01)≈≈ |
| 7.33E+02 (3.00E+02)++ | 9.21E+02 (2.94E+02)++ | 1.33E+03 (4.30E+02)+ ≈ | 1.36E+03 (4.18E+02)+ ≈ | 1.23E+03 (3.26E+02)+ ≈ |
| 1.39E+01 (6.48E+00)− | 1.44E+01 (1.34E+01)≈ − | 1.55E+01 (9.85E+00)− | 1.71E+01 (9.82E+00)≈ − | 1.30E+01 (4.77E+00)≈ − |
| 1.15E+03 (2.98E+02)≈ − | 9.69E+02 (3.43E+02)≈ − | 1.11E+03 (4.38E+02)≈ − | 1.07E+03 (3.4E+02)≈ − | 1.01E+03 (4.57E+02)≈ − |
| 2.51E+01 (9.51E+00)≈ − | 2.60E+01 (9.06E+00)≈ − | 2.50E+01 (1.10E+01)≈ − | 2.30E+01 (1.02E+01)≈ − | 2.49E+01 (1.50E+01)≈ − |
| 7.23E+00 (4.70E+00)+ ≈ | 7.46E+00 (4.16E+00)≈≈ | 6.88E+00 (4.21E+00)+ ≈ | 6.71E+00 (2.68E+00)+ ≈ | 7.14E+00 (4.54E+00)+ ≈ |
| 8.78E+00 (2.66E+01)− ≈ | 3.19E+00 (1.17E+00)++ | 3.90E+00 (2.09E+00)+ ≈ | 4.95E+00 (2.80E+00)+ ≈ | 5.60E+00 (4.29E+00)+ ≈ |
| 1.62E+02 (1.08E+02)+ ≈ | 1.92E+02 (1.44E+02)+ ≈ | 1.84E+02 (1.18E+02)+ ≈ | 1.86E+02 (1.12E+02)+ ≈ | 1.64E+02 (1.16E+02)+ ≈ |
| 1.24E+01 (7.55E+00)+ ≈ | 2.01E+01 (2.26E+01)≈ − | 1.41E+01 (8.33E+00)+ ≈ | 1.94E+01 (8.67E+00)≈ − | 1.64E+01 (1.03E+01)+ ≈ |
| 1.09E+01 (1.04E+01)++ | 1.32E+01 (1.01E+01)+ ≈ | 1.29E+01 (9.85E+00)+ ≈ | 2.08E+01 (1.28E+01)≈≈ | 1.57E+01 (1.34E+01)≈≈ |
| 4.67E+00 (2.96E+00)≈≈ | 4.22E+00 (1.89E+00)≈≈ | 5.48E+00 (3.88E+00)≈ − | 5.54E+00 (5.24E+00)≈≈ | 5.97E+00 (5.52E+00)≈≈ |
| 1.77E+01 (4.12E+01)+ ≈ | 9.71E+00 (2.99E+01)+ ≈ | 1.43E+01 (3.65E+01)+ ≈ | 2.58E+01 (4.80E+01)+ ≈ | 1.09E+01 (2.97E+01)+ ≈ |
| 2.27E+02 (5.35E+00)+ − | 2.31E+02 (7.75E+00)≈ − | 2.30E+02 (6.77E+00)≈ − | 2.31E+02 (7.00E+00)≈ − | 2.28E+02 (6.78E+00)≈ − |
| 1.00E+02 (2.31E-13)≈≈ | 1.00E+02 (2.29E-13)≈≈ | 1.00E+02 (2.31E-13)≈≈ | 1.00E+02 (2.12E-13)≈≈ | 1.00E+02 (2.31E-13)≈≈ |
| 3.63E+02 (5.96E+00)+ ≈ | 3.72E+02 (8.72E+00)≈≈ | 3.78E+02 (7.99E+00)≈ − | 3.76E+02 (6.75E+00)≈ − | 3.73E+02 (8.72E+00)≈ − |
| 4.42E+02 (7.10E+00)+ − | 4.49E+02 (7.69E+00)≈ − | 4.48E+02 (8.22E+00)≈ − | 4.48E+02 (7.55E+00)≈ − | 4.49E+02 (5.82E+00)≈ − |
| 3.78E+02 (4.64E-02)+ − | 3.78E+02 (8.05E-01)+ − | 3.79E+02 (4.67E+00)− − | 3.78E+02 (8.53E-01)+ − | 3.78E+02 (1.17E+00)+ − |
| 1.07E+03 (8.45E+01)+ − | 1.26E+03 (1.14E+02)≈ − | 1.27E+03 (1.19E+02)≈ − | 1.26E+03 (7.86E+01)≈ − | 1.22E+03 (2.04E+02)≈ − |
| 4.99E+02 (5.96E+00)− + | 4.98E+02 (1.15E+01)− ≈ | 5.00E+02 (9.40E-05)− ≈ | 4.96E+02 (1.71E+01)++ | 4.90E+02 (2.23E+01)++ |
| 3.67E+02 (7.19E+01)≈ + | 3.50E+02 (7.57E+01)≈ + | 3.67E+02 (7.81E+01)≈ + | 3.27E+02 (5.78E+01)≈ + | 3.68E+02 (7.70E+01)≈ + |
| 2.86E+02 (4.11E+01)+ ≈ | 3.08E+02 (5.44E+01)+ ≈ | 2.92E+02 (4.83E+01)+ ≈ | 3.02E+02 (5.11E+01)+ ≈ | 2.79E+02 (4.65E+01)++ |
| 2.11E+02 (6.72E+00)+ − | 2.09E+02 (2.63E+00)+ − | 2.09E+02 (1.92E+00)+ − | 2.09E+02 (3.20E+00)+ − | 2.10E+02 (7.05E+00)+ − |

Table 9: The results of the three versions of EDEV for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 9.47E-16 (3.6E-15) | 3.79E-15 (6.39E-15)≈ | 1.42E-14 (5.28E-15)−− | 1.28E-14 (5.72E-15)−− |
| F2 | 7.77E-14 (7.72E-14) | 6.88E-12 (6.07E-12)− | 3.17E-11 (5.32E-11)−− | 2.23E-11 (2.95E-11)−− |
| F3 | 3.79E-14 (2.73E-14) | 1.34E-13 (6.59E-14)− | 6.25E-14 (1.39E-13)≈ + | 2.84E-14 (2.89E-14)≈ + |
| F4 | 3.65E+01 (2.98E+01) | 1.33E-01 (7.28E-01)+ | 3.50E+01 (3.04E+01)≈ − | 3.32E+01 (3.01E+01)≈ − |
| F5 | 2.14E+01 (4.01E+00) | 1.86E+01 (4.00E+00)+ | 2.85E+01 (8.11E+00)−− | 2.38E+01 (6.24E+00)≈ − |
| F6 | 1.14E-13 (0.00E+00) | 7.62E-06 (1.84E-06)− | 9.64E-10 (3.27E-09)−+ | 3.20E-10 (4.98E-10)−+ |
| F7 | 5.22E+01 (4.13E+00) | 4.97E+01 (3.46E+00)+ | 6.06E+01 (8.75E+00)−− | 5.9E+01 (9.08E+00)−− |
| F8 | 2.28E+01 (4.68E+00) | 2.09E+01 (3.41E+00)≈ | 2.82E+01 (8.18E+00)−− | 2.53E+01 (5.15E+00)≈ − |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 1.81E+03 (3.70E+02) | 1.50E+03 (2.09E+02)≈ | 1.89E+03 (3.60E+02)≈ − | 1.84E+03 (4.18E+02)≈ − |
| F11 | 1.25E+01 (1.79E+01) | 4.03E+00 (1.17E+00)+ | 1.42E+01 (1.86E+01)≈ − | 6.40E+00 (2.76E+00)≈ − |
| F12 | 4.01E+02 (1.85E+02) | 3.23E+02 (1.79E+02)≈ | 4.15E+02 (2.30E+02)≈≈ | 3.57E+02 (2.20E+02)≈≈ |
| F13 | 2.20E+01 (8.03E+00) | 9.39E+00 (3.98E+00)+ | 1.84E+01 (7.13E+00)≈ − | 1.72E+01 (6.71E+00)+− |
| F14 | 1.83E+01 (1.10E+01) | 5.56E+00 (1.86E+00)+ | 1.09E+01 (8.59E+00)+− | 7.40E+00 (2.60E+00)+− |
| F15 | 4.72E+00 (2.24E+00) | 2.98E+00 (9.96E-01)+ | 5.73E+00 (2.66E+00)≈ − | 5.25E+00 (2.53E+00)≈ − |
| F16 | 2.09E+02 (1.11E+02) | 1.37E+02 (1.03E+02)+ | 1.90E+02 (1.41E+02)≈≈ | 1.57E+02 (1.42E+02)≈≈ |
| F17 | 2.85E+01 (1.15E+01) | 1.00E+01 (2.23E+00)+ | 2.76E+01 (1.22E+01)≈ − | 2.69E+01 (1.11E+01)≈ − |
| F18 | 2.24E+01 (6.25E+00) | 1.70E+01 (8.10E+00)+ | 1.99E+01 (8.68E+00)− | 2.15E+01 (7.39E+00)≈ − |
| F19 | 5.66E+00 (2.02E+00) | 3.41E+00 (8.00E-01)+ | 5.94E+00 (1.78E+00)≈ − | 5.74E+00 (2.20E+00)≈ − |
| F20 | 2.79E+01 (2.30E+01) | 3.54E+00 (1.73E+00)+ | 1.95E+01 (3.07E+01)+− | 2.40E+01 (3.27E+01)+− |
| F21 | 2.23E+02 (4.23E+00) | 2.21E+02 (3.77E+00)≈ | 1.76E+02 (6.31E+01)≈≈ | 1.37E+02 (5.72E+01)++ |
| F22 | 1.00E+02 (8.30E-14) | 1.00E+02 (3.68E-11)≈ | 1.00E+02 (1.14E-12)≈≈ | 1.00E+02 (1.94E-12)≈≈ |
| F23 | 3.67E+02 (6.39E+00) | 3.62E+02 (5.22E+00)+ | 3.31E+02 (1.05E+02)++ | 2.18E+02 (1.37E+02)+ + |
| F24 | 4.38E+02 (3.70E+00) | 4.35E+02 (4.00E+00)+ | 4.27E+02 (7.76E+01)++ | 3.21E+02 (1.23E+02)≈≈ |
| F25 | 3.87E+02 (1.10E-01) | 3.87E+02 (1.97E-02)+ | 3.87E+02 (8.75E-02)≈ − | 3.87E+02 (8.51E-02)≈ − |
| F26 | 1.10E+03 (4.96E+01) | 1.1E+03 (4.27E+01)≈ | 1.17E+03 (3.18E+02)−− | 3.58E+02 (2.20E+02)++ |
| F27 | 4.98E+02 (7.10E+00) | 4.88E+02 (5.17E+00)+ | 4.96E+02 (6.86E+00)≈ − | 4.94E+02 (6.44E+00)+− |
| F28 | 3.07E+02 (2.76E+01) | 3.00E+02 (1.99E-12)≈ | 3.25E+02 (4.51E+01)≈≈ | 3.10E+02 (3.15E+01)≈≈ |
| F29 | 4.38E+02 (2.86E+01) | 4.18E+02 (1.49E+01)+ | 4.35E+02 (2.87E+01)≈ − | 4.26E+02 (3.11E+01)+− |
| F30 | 2.01E+03 (5.63E+01) | 1.95E+03 (1.09E+01)+ | 2.04E+03 (5.63E+01)≈ − | 3.02E+03 (1.51E+03)−− |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 1.14E-14 (5.78E-15)−− | 1.33E-14 (5.19E-15)−− | 1.33E-14 (3.60E-15)−− | 1.28E-14 (4.34E-15)−− | 1.28E-14 (4.34E-15)−− |
| 2.76E-11 (6.74E-11)−− | 3.86E-11 (7.58E-11)−− | 3.43E-11 (4.28E-11)−− | 1.98E-11 (2.51E-11)−− | 1.01E-11 (1.01E-11)− ≈ |
| 1.42E-13 (4.13E-13)≈ − | 3.83E-13 (1.24E-12)− | 3.98E-14 (3.70E-14)≈ + | 7.20E-14 (1.26E-13)≈ + | 2.25E-13 (4.23E-13)−− |
| 3.87E+01 (2.92E+01)≈ − | 1.65E+01 (2.70E+01)≈≈ | 3.72E+01 (2.96E+01)≈ − | 3.66E+01 (2.90E+01)≈ − | 2.50E+01 (2.90E+01)≈ − |
| 2.39E+01 (6.86E+00)≈ − | 2.35E+01 (5.33E+00)≈ − | 2.31E+01 (5.07E+00)≈ − | 2.21E+01 (4.62E+00)≈ − | 2.26E+01 (4.82E+00)≈ − |
| 3.48E-10 (6.34E-10)−+ | 5.21E-10 (9.75E-10)−+ | 2.82E-09 (1.23E-08)−+ | 3.68E-10 (5.87E-10)−+ | 9.54E-10 (2.27E-09)−+ |
| 5.43E+01 (5.08E+00)−− | 5.43E+01 (4.79E+00)−− | 5.54E+01 (5.91E+00)−− | 5.42E+01 (5.52E+00)−− | 5.38E+01 (3.36E+00)≈ − |
| 2.45E+01 (4.17E+00)≈ − | 2.55E+01 (5.79E+00)−− | 2.52E+01 (5.82E+00)≈ − | 2.45E+01 (4.82E+00)≈ − | 2.42E+01 (3.95E+00)≈ − |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.79E+03 (4.27E+02)≈ − | 1.92E+03 (3.43E+02)≈ − | 1.72E+03 (2.90E+02)≈ − | 1.56E+03 (3.32E+02)+ ≈ | 1.69E+03 (2.27E+02)≈ − |
| 7.04E+00 (4.03E+00)≈ − | 6.20E+00 (4.08E+00)≈ − | 6.47E+00 (3.21E+00)≈ − | 6.19E+00 (4.14E+00)≈ − | 5.57E+00 (2.29E+00)+− |
| 4.75E+02 (3.05E+02)≈ − | 4.17E+02 (2.22E+02)≈≈ | 3.55E+02 (2.70E+02)≈≈ | 3.55E+02 (2.02E+02)≈≈ | 2.48E+02 (2.20E+02)++ |
| 1.81E+01 (6.13E+00)+− | 1.43E+01 (6.27E+00)+− | 1.35E+01 (6.48E+00)+− | 1.38E+01 (7.21E+00)+− | 1.12E+01 (4.55E+00)+ ≈ |
| 5.73E+00 (1.91E+00)+ − | 5.35E+00 (2.74E+00)+ − | 5.58E+00 (1.74E+00)+ − | 5.61E+00 (1.82E+00)+ − | 5.95E+00 (1.73E+00)+ ≈ |
| 4.05E+00 (1.91E+00)≈ − | 3.80E+00 (1.62E+00)≈ − | 3.87E+00 (1.47E+00)≈ − | 3.36E+00 (1.11E+00)≈ − | 3.25E+00 (1.18E+00)+ ≈ |
| 1.35E+02 (1.07E+02)+ − | 1.63E+02 (1.31E+02)≈≈ | 1.45E+02 (9.07E+01)+ ≈ | 1.51E+02 (9.81E+01)+ ≈ | 1.14E+02 (9.63E+01)+ ≈ |
| 2.24E+01 (9.16E+00)+− | 2.11E+01 (1.09E+01)+− | 1.91E+01 (9.14E+00)+− | 1.77E+01 (8.24E+00)+− | 1.40E+01 (6.19E+00)+− |
| 1.96E+01 (7.08E+00)≈≈ | 1.99E+01 (6.72E+00)≈≈ | 1.89E+01 (7.33E+00)≈≈ | 1.68E+01 (8.66E+00)+ ≈ | 1.99E+01 (6.70E+00)≈≈ |
| 4.04E+00 (1.16E+00)+ ≈ | 3.96E+00 (1.15E+00)+ ≈ | 3.60E+00 (9.77E-01)+ ≈ | 3.88E+00 (8.37E-01)+− | 3.53E+00 (9.72E-01)+ ≈ |
| 1.46E+01 (1.24E+01)+− | 2.54E+01 (3.42E+01)≈ − | 2.10E+01 (3.38E+01)+− | 2.17E+01 (1.36E+01)+− | 1.99E+01 (2.48E+01)+− |
| 1.33E+02 (5.59E+01)++ | 1.32E+02 (5.49E+01)++ | 1.05E+02 (2.30E+01)++ | 1.00E+02 (4.10E-07)++ | 1.04E+02 (2.30E+01)++ |
| 9.91E+01 (4.91E+00)≈≈ | 1.00E+02 (2.41E-12)≈≈ | 9.66E+01 (1.23E+01)≈≈ | 9.51E+01 (1.54E+01)≈≈ | 9.22E+01 (1.58E+01)≈≈ |
| 2.51E+02 (1.34E+02)+ ≈ | 2.44E+02 (1.37E+02)+ ≈ | 1.98E+02 (1.30E+02)++ | 1.18E+02 (6.90E+01)++ | 1.18E+02 (6.91E+01)++ |
| 3.75E+02 (1.07E+02)≈≈ | 3.26E+02 (1.24E+02)++ | 2.08E+02 (4.28E+01)++ | 2.00E+02 (2.55E-10)++ | 1.97E+02 (1.83E+01)++ |
| 3.87E+02 (8.02E-02)≈ − | 3.87E+02 (9.18E-02)≈ − | 3.87E+02 (6.07E-02)≈ − | 3.87E+02 (7.62E-02)≈ − | 3.87E+02 (8.83E-02)≈ − |
| 3.81E+02 (2.49E+02)++ | 3.00E+02 (9.57E-02)++ | 3.00E+02 (9.57E-02)++ | 2.97E+02 (1.82E+01)++ | 3.00E+02 (1.42E-02)++ |
| 4.94E+02 (5.81E+00)+− | 4.95E+02 (6.07E+00)+− | 4.95E+02 (5.12E+00)+− | 4.93E+02 (5.81E+00)+− | 4.91E+02 (7.10E+00)+ ≈ |
| 3.15E+02 (3.85E+01)≈≈ | 3.20E+02 (4.10E+01)≈≈ | 3.10E+02 (3.03E+01)≈≈ | 3.14E+02 (3.41E+01)≈≈ | 3.07E+02 (2.62E+01)≈≈ |
| 4.26E+02 (2.28E+01)+− | 4.27E+02 (2.50E+01)+− | 4.13E+02 (3.54E+01)+ ≈ | 4.18E+02 (2.27E+01)+ ≈ | 4.26E+02 (2.35E+01)+− |
| 2.01E+03 (4.62E+01)≈ − | 2.01E+03 (5.32E+01)≈ − | 1.98E+03 (3.55E+01)≈ − | 1.99E+03 (4.25E+01)≈ − | 1.98E+03 (2.64E+01)+− |

Table 10: The results of the three versions of MLCC-SI for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 0.00E+00 (0.00E+00) | 9.89E-13 (2.97E-12)− | 1.44E-13 (4.66E-13)−+ | 5.78E-14 (1.77E-13)−+ |
| F3 | 0.00E+00 (0.00E+00) | 8.28E-11 (4.36E-10)− | 0.00E+00 (0.00E+00)≈ + | 0.00E+00 (0.00E+00)≈ + |
| F4 | 5.91E+01 (1.70E+00) | 5.66E+01 (1.07E+01)≈ | 5.48E+01 (1.44E+01)≈≈ | 4.89E+01 (2.19E+01)≈≈ |
| F5 | 4.58E+01 (1.49E+01) | 2.60E+01 (5.62E+00)+ | 2.54E+01 (5.80E+00)+ ≈ | 2.45E+01 (5.22E+00)+ ≈ |
| F6 | 1.06E-13 (2.88E-14) | 2.01E-13 (9.29E-14)− | 1.14E-13 (0.00E+00)≈ + | 1.10E-13 (2.08E-14)≈ + |
| F7 | 7.15E+01 (9.99E+00) | 5.24E+01 (4.96E+00)+ | 5.38E+01 (4.61E+00)+ ≈ | 5.22E+01 (5.55E+00)+ ≈ |
| F8 | 4.80E+01 (1.72E+01) | 2.44E+01 (4.67E+00)+ | 2.58E+01 (5.93E+00)+ ≈ | 2.39E+01 (4.34E+00)+ ≈ |
| F9 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F10 | 2.15E+03 (5.73E+02) | 1.57E+03 (2.30E+02)+ | 1.56E+03 (2.58E+02)+ ≈ | 1.37E+03 (2.59E+02)++ |
| F11 | 1.04E+01 (3.89E+00) | 5.51E+00 (1.86E+00)+ | 6.20E+00 (1.84E+00)+ ≈ | 6.17E+00 (2.82E+00)+ ≈ |
| F12 | 2.58E+02 (1.67E+02) | 2.20E+02 (8.96E+01)≈ | 3.00E+02 (1.27E+02)≈ − | 3.09E+02 (1.73E+02)≈ − |
| F13 | 1.74E+01 (8.28E+00) | 1.08E+01 (3.54E+00)+ | 1.24E+01 (4.37E+00)+ ≈ | 1.22E+01 (5.34E+00)+ ≈ |
| F14 | 1.52E+01 (1.06E+01) | 7.70E+00 (2.95E+00)+ | 1.03E+01 (6.11E+00)≈≈ | 1.64E+01 (1.05E+01)≈ − |
| F15 | 7.91E+00 (4.20E+00) | 4.83E+00 (1.79E+00)+ | 4.20E+00 (1.38E+00)++ | 4.25E+00 (1.37E+00)+ ≈ |
| F16 | 6.09E+02 (2.54E+02) | 2.55E+02 (1.30E+02)+ | 1.80E+02 (1.38E+02)+ ≈ | 3.45E+02 (2.00E+02)+ ≈ |
| F17 | 7.50E+01 (8.79E+01) | 2.84E+01 (9.03E+00)+ | 2.61E+01 (8.44E+00)+ ≈ | 2.40E+01 (1.01E+01)+ ≈ |
| F18 | 1.11E+01 (1.03E+01) | 1.86E+01 (7.79E+00)− | 1.90E+01 (7.54E+00)− ≈ | 1.60E+01 (8.91E+00)− ≈ |
| F19 | 3.77E+00 (1.54E+00) | 4.48E+00 (1.16E+00)≈ | 3.84E+00 (8.18E-01)≈ + | 4.24E+00 (8.19E-01)≈≈ |
| F20 | 8.33E+01 (7.57E+01) | 6.91E+00 (6.74E+00)+ | 5.01E+00 (6.55E+00)++ | 1.04E+02 (6.92E+01)≈ − |
| F21 | 2.46E+02 (1.27E+01) | 2.27E+02 (6.56E+00)+ | 2.21E+02 (2.34E+01)+ ≈ | 2.05E+02 (4.79E+01)+ ≈ |
| F22 | 1.00E+02 (8.30E-14) | 1.00E+02 (0.00E+00)≈ | 1.00E+02 (0.0E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| F23 | 3.92E+02 (1.60E+01) | 3.18E+02 (1.11E+02)+ | 3.61E+02 (4.97E+01)+ ≈ | 3.63E+02 (5.01E+01)+ ≈ |
| F24 | 4.70E+02 (1.79E+01) | 4.49E+02 (7.18E+00)+ | 4.50E+02 (7.49E+00)+ ≈ | 4.43E+02 (6.67E+00)++ |
| F25 | 3.87E+02 (2.58E-02) | 3.87E+02 (1.58E-02)≈ | 3.87E+02 (1.71E-02)≈ ≈ | 3.87E+02 (1.88E-02)≈ ≈ |
| F26 | 1.36E+03 (3.34E+02) | 2.93E+02 (2.54E+01)+ | 7.91E+02 (4.40E+02)+− | 9.02E+02 (4.04E+02)+− |
| F27 | 4.87E+02 (7.85E+00) | 4.79E+02 (5.13E+00)+ | 4.69E+02 (3.77E+00)++ | 4.63E+02 (4.09E+00)++ |
| F28 | 3.26E+02 (4.78E+01) | 3.00E+02 (2.86E-13)≈ | 3.00E+02 (2.76E-13)≈≈ | 3.00E+02 (2.83E-13)≈≈ |
| F29 | 4.34E+02 (5.84E+01) | 3.83E+02 (3.40E+01)+ | 4.00E+02 (2.87E+01)+ ≈ | 3.93E+02 (3.51E+01)+ ≈ |
| F30 | 1.97E+03 (1.20E+01) | 1.96E+03 (8.04E+00)≈ | 1.96E+03 (1.27E+01)≈≈ | 1.96E+03 (1.48E+01)≈≈ |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.89E-15 (7.21E-15)≈ + | 9.47E-16 (5.19E-15)≈ + | 0.00E+00 (0.00E+00)≈ + | 0.00E+00 (0.00E+00)≈ + | 0.00E+00 (0.00E+00)≈ + |
| 0.00E+00 (0.00E+00)≈ + | 0.00E+00 (0.00E+00)≈ + | 0.00E+00 (0.00E+00)≈ + | 0.00E+00 (0.00E+00)≈ + | 1.90E+01 (1.04E+02)≈ − |
| 1.45E+01 (2.52E+01)++ | 5.10E+01 (1.95E+01)≈≈ | 5.47E+01 (1.49E+01)≈≈ | 5.34E+01 (1.77E+01)≈≈ | 5.66E+01 (1.07E+01)≈≈ |
| 2.73E+01 (7.30E+00)+ ≈ | 4.10E+01 (1.01E+01)≈ − | 4.33E+01 (1.40E+01)≈ − | 4.36E+01 (1.79E+01)≈ − | 4.53E+01 (1.12E+01)≈ − |
| 9.47E-14 (4.31E-14)≈ + | 1.06E-13 (2.88E-14)≈ + | 9.85E-14 (3.93E-14)≈ + | 1.06E-13 (2.88E-14)≈ + | 1.06E-13 (2.88E-14)≈ + |
| 5.26E+01 (4.13E+00)+ ≈ | 5.49E+01 (4.06E+00)+− | 6.68E+01 (1.22E+01)≈ − | 6.69E+01 (1.10E+01)≈ − | 6.90E+01 (1.32E+01)≈ − |
| 2.91E+01 (9.64E+00)+− | 4.56E+01 (1.43E+01)≈ − | 4.25E+01 (1.23E+01)≈ − | 4.79E+01 (1.70E+01)≈ − | 4.28E+01 (1.57E+01)≈ − |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.26E+03 (3.38E+02)++ | 1.53E+03 (4.99E+02)+ ≈ | 2.11E+03 (5.12E+02)≈ − | 2.16E+03 (4.18E+02)≈ − | 2.16E+03 (4.21E+02)≈ − |
| 5.97E+00 (2.60E+00)+ ≈ | 1.65E+01 (1.22E+01)−− | 1.09E+01 (4.05E+00)≈ − | 1.79E+01 (1.74E+01)−− | 1.45E+01 (1.39E+01)≈ − |
| 2.90E+02 (1.44E+02)≈ − | 3.06E+02 (1.30E+02)≈ − | 4.41E+02 (2.00E+02)−− | 5.42E+02 (2.76E+02)−− | 6.30E+02 (3.18E+02)−− |
| 1.17E+01 (5.03E+00)+ ≈ | 1.13E+01 (5.39E+00)≈ ≈ | 1.46E+01 (6.83E+00)≈ − | 1.27E+01 (6.64E+00)+ ≈ | 1.96E+01 (8.27E+00)≈ − |
| 2.19E+01 (1.11E+01)−− | 2.29E+01 (1.15E+01)−− | 2.63E+01 (1.05E+01)−− | 2.77E+01 (1.23E+01)−− | 2.33E+01 (1.11E+01)−− |
| 3.33E+00 (1.58E+00)++ | 4.06E+00 (1.58E+00)++ | 4.79E+00 (2.04E+00)+ ≈ | 5.76E+00 (1.99E+00)+ ≈ | 8.22E+00 (3.81E+00)≈ − |
| 4.91E+02 (2.51E+02)≈ − | 4.99E+02 (2.08E+02)≈ − | 4.68E+02 (2.24E+02)+− | 5.17E+02 (2.29E+02)≈ − | 4.92E+02 (2.25E+02)+− |
| 3.79E+01 (3.30E+01)+ ≈ | 3.59E+01 (2.41E+01)+ ≈ | 5.13E+01 (5.46E+01)+ ≈ | 7.38E+01 (7.09E+01)≈ − | 5.75E+01 (4.32E+01)≈ − |
| 2.06E+01 (5.70E+00)− ≈ | 2.13E+01 (4.82E+00)− ≈ | 2.04E+01 (6.05E+00)− ≈ | 2.12E+01 (5.25E+00)− ≈ | 2.25E+01 (4.21E+00)−− |
| 4.91E+00 (1.45E+00)− ≈ | 4.77E+00 (1.06E+00)− ≈ | 5.42E+00 (1.25E+00)−− | 5.35E+00 (1.36E+00)−− | 6.08E+00 (1.69E+00)−− |
| 8.31E+01 (8.51E+01)− | 1.09E+02 (6.81E+01)−− | 6.78E+01 (7.79E+01)≈ − | 1.04E+02 (8.60E+01)≈ − | 8.57E+01 (8.21E+01)≈ − |
| 2.47E+02 (1.29E+01)− | 2.47E+02 (1.38E+01)≈ − | 2.50E+02 (1.76E+01)≈ − | 2.50E+02 (1.89E+01)≈ − | 2.49E+02 (1.56E+01)≈ − |
| 9.74E+01 (1.41E+01)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ | 1.00E+02 (0.00E+00)≈≈ |
| 3.71E+02 (9.16E+00)+ ≈ | 3.81E+02 (5.50E+01)≈ − | 3.94E+02 (1.46E+01)≈ − | 3.90E+02 (5.72E+01)≈ − | 3.92E+02 (1.44E+01)≈ − |
| 4.59E+02 (1.24E+01)+− | 4.73E+02 (2.00E+01)≈ − | 4.70E+02 (1.83E+01)≈ − | 4.67E+02 (1.46E+01)≈ − | 4.68E+02 (1.90E+01)≈ − |
| 3.87E+02 (6.46E-03)++ | 3.87E+02 (3.89E-03)++ | 3.87E+02 (1.05E-02)++ | 3.87E+02 (2.14E-02)− | 3.87E+02 (4.64E-02)−− |
| 9.44E+02 (5.06E+02)+− | 1.05E+03 (4.86E+02)+ − | 9.45E+02 (5.47E+02)+− | 9.33E+02 (5.45E+02)+− | 1.27E+03 (4.66E+02)≈ − |
| 4.76E+02 (1.28E+01)+ ≈ | 4.89E+02 (1.00E+01)≈ − | 4.88E+02 (8.70E+00)≈ − | 4.88E+02 (9.53E+00)≈ − | 4.89E+02 (7.44E+00)≈ − |
| 3.28E+02 (4.71E+01)≈ ≈ | 3.07E+02 (2.76E+01)≈≈ | 3.23E+02 (4.74E+01)≈ ≈ | 3.14E+02 (3.76E+01)≈ ≈ | 3.07E+02 (2.76E+01)≈ ≈ |
| 4.23E+02 (4.23E+01)≈ − | 4.31E+02 (4.60E+01)≈ − | 4.38E+02 (4.45E+01)≈ − | 4.47E+02 (4.84E+01)−− | 4.90E+02 (8.58E+01)−− |
| 1.96E+03 (1.17E+01)+ ≈ | 1.96E+03 (9.58E+00)≈≈ | 1.96E+03 (1.23E+01)≈≈ | 1.97E+03 (3.10E+01)≈ − | 1.99E+03 (4.39E+01)−− |

Table 11: The results of the three versions of NDE for the CEC 2017 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F5 | 2.00E+01 (7.77E-04) | 2.00E+01 (1.55E-03)− | 2.00E+01 (3.49E-05)≈ + | 2.00E+01 (3.70E-03)≈ + |
| F6 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 1.53E-02 (8.39E-02)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F7 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F8 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F9 | 1.09E+01 (1.21E+00) | 1.09E+01 (1.41E+00)≈ | 5.82E+00 (2.13E+00)++ | 1.10E+01 (1.42E+00)≈≈ |
| F10 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 1.76E-12 (3.32E-13)−− | 1.58E-12 (6.29E-13)−− |
| F11 | 8.81E+02 (1.30E+02) | 8.52E+02 (1.75E+02)≈ | 6.67E+02 (1.33E+02)++ | 6.37E+02 (1.62E+02)++ |
| F12 | 4.73E-02 (6.91E-03) | 4.98E-02 (9.68E-03)≈ | 2.88E-02 (1.96E-02)++ | 2.45E-02 (1.76E-02)++ |
| F13 | 8.36E-02 (1.06E-02) | 1.14E-01 (1.35E-02)− | 1.03E-01 (1.23E-02)−+ | 1.02E-01 (1.38E-02)−+ |
| F14 | 1.73E-01 (3.06E-02) | 1.70E-01 (1.81E-02)≈ | 1.79E-01 (1.78E-02)≈≈ | 1.77E-01 (1.90E-02)≈≈ |
| F15 | 1.43E+00 (8.94E-02) | 1.41E+00 (1.13E-01)≈ | 1.72E+00 (2.16E-01)−− | 1.73E+00 (1.71E-01)−− |
| F16 | 6.50E+00 (3.93E-01) | 6.52E+00 (5.66E-01)≈ | 7.25E+00 (6.74E-01)−− | 5.43E+00 (4.82E-01)++ |
| F17 | 1.26E+02 (9.08E+01) | 8.12E+01 (4.86E+01)≈ | 4.41E+01 (2.35E+01)++ | 4.75E+01 (3.68E+01)++ |
| F18 | 3.50E+00 (1.48E+00) | 2.78E+00 (1.72E+00)≈ | 2.20E+00 (7.50E-01)+ ≈ | 1.77E+00 (6.01E-01)++ |
| F19 | 2.04E+00 (8.16E-01) | 1.89E+00 (7.24E-01)≈ | 1.46E+00 (4.84E-01)++ | 1.23E+00 (6.41E-01)++ |
| F20 | 1.16E+00 (3.05E-01) | 1.13E+00 (2.73E-01)≈ | 1.05E+00 (2.67E-01)≈≈ | 1.10E+00 (2.78E-01)≈≈ |
| F21 | 5.39E+01 (5.69E+01) | 3.30E+01 (4.26E+01)≈ | 2.99E+00 (5.10E+00)++ | 2.34E+01 (4.39E+01)++ |
| F22 | 3.62E+01 (3.96E+01) | 2.24E+01 (2.17E+01)≈ | 9.84E+00 (7.38E+00)++ | 6.41E+00 (6.79E+00)++ |
| F23 | 2.00E+02 (0.00E+00) | 2.00E+02 (0.00E+00)≈ | 3.15E+02 (2.19E-13)−− | 3.15E+02 (2.38E-13)−− |
| F24 | 2.00E+02 (0.00E+00) | 2.00E+02 (0.00E+00)≈ | 2.01E+02 (5.33E+00)≈≈ | 2.00E+02 (1.47E-09)≈≈ |
| F25 | 2.00E+02 (0.00E+00) | 2.00E+02 (0.00E+00)≈ | 2.03E+02 (9.81E-03)−− | 2.03E+02 (2.68E-02)−− |
| F26 | 1.00E+02 (1.04E-02) | 1.00E+02 (1.46E-02)− | 1.00E+02 (1.49E-02)− ≈ | 1.00E+02 (1.24E-02)−+ |
| F27 | 2.03E+02 (1.83E+01) | 2.13E+02 (3.46E+01)≈ | 3.00E+02 (0.00E+00)−− | 3.00E+02 (0.00E+00)−− |
| F28 | 2.00E+02 (0.00E+00) | 2.00E+02 (0.00E+00)≈ | 8.08E+02 (1.31E+01)−− | 8.03E+02 (1.35E+01)−− |
| F29 | 2.00E+02 (0.00E+00) | 2.00E+02 (0.00E+00)≈ | 7.14E+02 (3.46E-01)−− | 7.14E+02 (2.44E-01)−− |
| F30 | 2.00E+02 (0.00E+00) | 2.00E+02 (0.00E+00)≈ | 6.59E+02 (2.34E+02)−− | 8.77E+02 (2.19E+02)−− |

| | | Individuals redistribution | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 2.00E+01 (5.75E-05)≈ + | 2.00E+01 (5.21E-03)≈ + | 2.00E+01 (8.11E-05)≈ + | 2.00E+01 (1.40E-04)≈ + | 2.00E+01 (4.29E-05)≈ + |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 8.53E+00 (2.46E+00)++ | 1.02E+01 (1.71E+00)++ | 1.03E+01 (1.78E+00)+ | 1.02E+01 (1.45E+00)++ | 9.82E+00 (1.58E+00)++ |
| 1.39E-12 (7.82E-13)−− | 4.61E-12 (1.59E-11)−− | 1.49E-03 (5.45E-03)−− | 1.39E-03 (5.28E-03)≈≈ | 1.39E-03 (5.28E-03)≈≈ |
| 5.95E+02 (1.83E+02)++ | 5.96E+02 (1.56E+02)++ | 6.03E+02 (1.66E+02)++ | 5.50E+02 (2.00E+02)++ | 6.09E+02 (1.81E+02)++ |
| 2.17E-02 (1.82E-02)++ | 1.77E-02 (1.32E-02)++ | 3.31E-03 (5.65E-03)++ | 5.20E-03 (4.92E-03)++ | 1.48E-02 (1.30E-02)++ |
| 3.59E-02 (5.09E-03)++ | 3.76E-02 (5.00E-03)++ | 3.69E-02 (6.58E-03)++ | 3.69E-02 (6.27E-03)++ | 3.77E-02 (4.54E-03)++ |
| 2.50E-02 (4.61E-03)++ | 2.62E-02 (3.76E-03)++ | 2.57E-02 (4.86E-03)++ | 2.64E-02 (3.96E-03)++ | 2.64E-02 (4.21E-03)++ |
| 1.81E+00 (3.17E-01)−− | 1.62E+00 (2.17E-01)−− | 1.64E+00 (1.29E-01)−− | 1.56E+00 (2.10E-01)−− | 1.63E+00 (1.71E-01)−− |
| 5.48E+00 (5.06E-01)++ | 5.50E+00 (5.77E-01)++ | 5.36E+00 (4.88E-01)++ | 5.54E+00 (5.06E-01)++ | 5.37E+00 (5.77E-01)++ |
| 1.01E+02 (7.59E+01)≈≈ | 8.45E+01 (6.75E+01)+ ≈ | 1.63E+02 (9.73E+01)≈ − | 1.56E+02 (1.02E+02)≈ − | 1.28E+02 (9.47E+01)≈ − |
| 4.12E+00 (1.80E+00)− | 4.11E+00 (1.78E+00)≈ − | 3.54E+00 (1.50E+00)≈≈ | 4.38E+00 (1.73E+00)≈ − | 4.28E+00 (1.86E+00)≈ − |
| 1.61E+00 (8.70E-01)≈≈ | 1.50E+00 (5.39E-01)++ | 1.41E+00 (6.46E-01)++ | 1.41E+00 (5.97E-01)++ | 1.37E+00 (6.85E-01)++ |
| 2.19E+00 (7.44E-01)−− | 2.12E+00 (9.55E-01)−− | 1.74E+00 (5.54E-01)−− | 1.64E+00 (8.39E-01)−− | 1.54E+00 (7.31E-01)−− |
| 6.66E+01 (6.70E+01)≈≈ | 8.95E+01 (9.23E+01)≈≈ | 6.12E+01 (6.80E+01)≈≈ | 7.98E+01 (8.16E+01)≈≈ | 7.00E+01 (6.81E+01)≈≈ |
| 4.01E+00 (6.73E+00)++ | 1.04E+01 (9.84E+00)++ | 7.41E+00 (8.56E+00)++ | 9.41E+00 (9.41E+00)++ | 8.03E+00 (9.21E+00)++ |
| 3.15E+02 (1.96E-13)−− | 3.15E+02 (1.88E-13)−− | 3.08E+02 (2.92E+01)−− | 3.08E+02 (2.92E+01)−− | 3.11E+02 (2.10E+01)−− |
| 2.00E+02 (1.56E-10)−− | 2.00E+02 (1.48E-10)−− | 2.00E+02 (3.79E-10)−− | 2.00E+02 (4.26E-07)−− | 2.00E+02 (7.70E-10)≈≈ |
| 2.03E+02 (3.59E-02)−− | 2.03E+02 (3.40E-02)−− | 2.01E+02 (1.23E+00)−− | 2.01E+02 (1.29E+00)−− | 2.01E+02 (1.26E+00)−− |
| 1.00E+02 (4.30E-03)++ | 1.00E+02 (4.48E-03)++ | 1.00E+02 (4.83E-03)++ | 1.00E+02 (3.40E-03)++ | 1.00E+02 (4.66E-03)++ |
| 3.00E+02 (0.00E+00)−− | 3.00E+02 (0.00E+00)−− | 2.00E+02 (1.45E-13)≈≈ | 2.00E+02 (1.45E-13)≈≈ | 2.00E+02 (1.45E-13)≈≈ |
| 8.24E+02 (1.65E+01)−− | 8.33E+02 (1.63E+01)−− | 7.93E+02 (1.63E+02)−− | 7.73E+02 (1.95E+02)−− | 7.89E+02 (1.61E+02)−− |
| 7.14E+02 (8.60E-01)−− | 7.15E+02 (1.51E+00)−− | 7.17E+02 (4.02E+00)−− | 7.15E+02 (3.63E+00)−− | 7.16E+02 (3.02E+00)−− |
| 1.10E+03 (3.62E+02)−− | 1.20E+03 (4.92E+02)−− | 1.30E+03 (5.12E+02)−− | 1.22E+03 (3.91E+02)−− | 1.30E+03 (5.85E+02)−− |

Table 12: The results of the three versions of L-SHADE-EpSin for the CEC 2014 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution 1.00E-01 | 5.00E-02 |
|---|---|---|---|---|
| F1 | 1.33E-14 (6.39E-15) | 9.95E-15 (7.60E-15)≈ | 6.16E-15 (7.16E-15)+ ≈ | 6.16E-15 (7.16E-15)+ ≈ |
| F2 | 9.47E-16 (5.19E-15) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 3.22E-14 (2.86E-14) | 1.52E-14 (2.56E-14)+ | 1.33E-14 (2.45E-14)+ ≈ | 9.47E-15 (2.15E-14)+ ≈ |
| F4 | 5.32E-01 (1.38E+00) | 8.58E+00 (7.18E+00)− | 2.34E+01 (2.92E+01)≈≈ | 2.48E+00 (1.07E+01)≈ + |
| F5 | 2.01E+01 (3.27E-02) | 2.01E+01 (8.39E-02)+ | 2.01E+01 (8.89E-02)++ | 2.00E+01 (6.39E-02)++ |
| F6 | 4.69E+00 (3.03E+00) | 7.62E-01 (7.13E-01)+ | 2.66E-01 (4.72E-01)++ | 2.65E-01 (4.81E-01)++ |
| F7 | 5.75E-04 (2.21E-03) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F8 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F9 | 2.57E+01 (6.00E+00) | 2.37E+01 (4.75E+00)≈ | 2.28E+01 (4.61E+00)≈≈ | 2.35E+01 (4.94E+00)≈≈ |
| F10 | 1.11E-02 (1.31E-02) | 0.00E+00 (0.00E+00)+ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ |
| F11 | 2.14E+03 (4.24E+02) | 1.74E+03 (3.90E+02)+ | 1.86E+03 (3.14E+02)+ ≈ | 1.79E+03 (3.16E+02)+ ≈ |
| F12 | 1.54E-01 (1.11E-01) | 1.59E-01 (1.56E-01)≈ | 5.14E-02 (3.46E-02)++ | 6.78E-02 (4.01E-02)++ |
| F13 | 1.60E-01 (2.82E-02) | 1.93E-01 (2.31E-02)− | 1.68E-01 (2.54E-02)≈ + | 1.76E-01 (2.58E-02)−+ |
| F14 | 2.27E-01 (3.17E-02) | 1.55E-01 (1.46E-02)+ | 1.62E-01 (1.12E-02)+− | 1.57E-01 (1.79E-02)+ ≈ |
| F15 | 2.59E+00 (7.15E-01) | 2.14E+00 (5.23E-01)+ | 1.98E+00 (4.05E-01)+ ≈ | 2.09E+00 (3.82E-01)+ ≈ |
| F16 | 9.80E+00 (5.49E-01) | 9.31E+00 (6.07E-01)+ | 9.26E+00 (5.56E-01)+ ≈ | 9.03E+00 (5.75E-01)++ |
| F17 | 2.65E+02 (1.69E+02) | 9.39E+01 (6.59E+01)+ | 1.05E+02 (6.17E+01)+ ≈ | 1.16E+02 (9.72E+01)+ ≈ |
| F18 | 1.60E+01 (1.18E+01) | 8.52E+00 (2.47E+00)+ | 8.06E+00 (2.58E+00)+ ≈ | 7.60E+00 (2.48E+00)+ ≈ |
| F19 | 2.48E+00 (1.14E+00) | 1.70E+00 (7.00E-01)+ | 1.68E+00 (7.00E-01)+ ≈ | 2.07E+00 (7.70E-01)≈≈ |
| F20 | 1.14E+01 (4.54E+00) | 6.08E+00 (1.78E+00)+ | 4.89E+00 (2.03E+00)++ | 4.53E+00 (1.73E+00)++ |
| F21 | 1.24E+02 (8.60E+01) | 6.01E+01 (5.99E+01)+ | 3.84E+01 (5.19E+01)+ ≈ | 4.53E+01 (5.87E+01)+ ≈ |
| F22 | 2.48E+01 (3.57E+00) | 2.24E+01 (1.70E+00)+ | 2.33E+01 (3.00E+00)+ ≈ | 2.32E+01 (3.36E+00)+ ≈ |
| F23 | 3.30E+02 (1.73E-13) | 3.30E+02 (3.34E-04)≈ | 3.36E+02 (1.92E-10)−− | 3.36E+02 (9.60E-11)−− |
| F24 | 2.01E+02 (5.88E-02) | 2.01E+02 (5.76E-02)− | 2.01E+02 (6.91E-02)− ≈ | 2.01E+02 (5.85E-02)− ≈ |
| F25 | 2.00E+02 (3.07E-03) | 2.00E+02 (5.06E-07)≈ | 2.00E+02 (2.94E-03)≈≈ | 2.00E+02 (3.07E-03)≈≈ |
| F26 | 1.00E+02 (3.06E-02) | 1.00E+02 (2.78E-02)≈ | 1.00E+02 (2.21E-02)− ≈ | 1.00E+02 (2.73E-02)− ≈ |
| F27 | 3.81E+02 (6.88E+01) | 3.03E+02 (3.44E+00)+ | 3.09E+02 (1.74E+01)+ ≈ | 3.18E+02 (3.33E+01)+ ≈ |
| F28 | 3.73E+02 (7.88E-01) | 3.77E+02 (7.46E+00)≈ | 4.16E+02 (1.60E+00)−− | 4.17E+02 (3.19E+00)−− |
| F29 | 2.03E+02 (1.08E+00) | 2.06E+02 (9.86E-01)− | 4.26E+02 (1.24E+00)−− | 4.26E+02 (1.15E+00)−− |
| F30 | 2.56E+02 (5.28E+01) | 3.14E+02 (5.02E+01)− | 3.94E+02 (9.01E+00)−− | 3.97E+02 (1.12E+01)−− |

| Individuals redistribution 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
|---|---|---|---|---|
| 4.74E-15 (6.81E-15)++ | 8.05E-15 (7.16E-15)+ ≈ | 6.63E-15 (7.21E-15)+ ≈ | 7.58E-15 (7.21E-15)+ ≈ | 6.16E-15 (7.16E-15)+ ≈ |
| 9.47E-16 (5.19E-15)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 9.47E-16 (5.19E-15)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 5.68E-15 (1.73E-14)+ ≈ | 1.33E-14 (2.45E-14)+ ≈ | 7.58E-15 (1.97E-14)+ ≈ | 9.47E-15 (2.15E-14)+ ≈ | 9.47E-15 (2.15E-14)+ ≈ |
| 4.38E+01 (2.66E+01)−− | 5.36E+01 (1.83E+01)−− | 5.34E+01 (1.82E+01)−− | 4.81E+01 (2.42E+01)−− | 5.00E+01 (2.29E+01)−− |
| 2.01E+01 (8.26E-02)++ | 2.00E+01 (7.66E-02)++ | 2.01E+01 (8.87E-02)++ | 2.01E+01 (9.60E-02)++ | 2.00E+01 (4.25E-02)++ |
| 7.78E-01 (7.88E-01)+ ≈ | 7.08E-01 (8.19E-01)+ ≈ | 1.11E+00 (1.23E+00)+ ≈ | 9.78E-01 (7.46E-01)+ ≈ | 7.19E-01 (9.59E-01)+ ≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 3.29E-04 (1.80E-03)≈≈ | 1.23E-03 (3.22E-03)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 2.34E+01 (6.74E+00)≈≈ | 2.52E+01 (5.24E+00)≈≈ | 2.68E+01 (9.59E+00)≈≈ | 2.85E+01 (7.42E+00)≈ − | 3.00E+01 (8.04E+00)−− |
| 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ |
| 1.63E+03 (4.23E+02)+ ≈ | 2.04E+03 (3.47E+02)≈ − | 2.03E+03 (4.99E+02)≈ − | 2.14E+03 (5.25E+02)≈ − | 1.98E+03 (3.31E+02)≈ − |
| 6.20E-02 (4.61E-02)++ | 6.92E-02 (4.88E-02)++ | 6.02E-02 (4.87E-02)++ | 4.67E-02 (4.19E-02)++ | 5.68E-02 (3.94E-02)++ |
| 1.71E-01 (2.97E-02)≈ + | 1.88E-01 (2.48E-02)− ≈ | 1.84E-01 (2.01E-02)− ≈ | 1.87E-01 (3.15E-02)− ≈ | 1.78E-01 (3.16E-02)− ≈ |
| 1.56E-01 (1.72E-02)+ ≈ | 1.60E-01 (1.42E-02)+ ≈ | 1.60E-01 (1.97E-02)+ ≈ | 1.58E-01 (1.69E-02)+ ≈ | 1.62E-01 (1.71E-02)+− |
| 1.96E+00 (4.07E-01)+ ≈ | 2.00E+00 (3.42E-01)+ ≈ | 2.64E+00 (5.75E-01)≈ − | 2.81E+00 (6.18E-01)≈ − | 2.68E+00 (6.84E-01)≈ − |
| 9.24E+00 (5.43E-01)+ ≈ | 8.92E+00 (4.80E-01)+ ≈ | 8.79E+00 (5.67E-01)++ | 8.88E+00 (5.11E-01)++ | 9.21E+00 (6.25E-01)+ ≈ |
| 2.36E+02 (1.21E+02)≈ − | 2.45E+02 (1.01E+02)≈ − | 2.29E+02 (9.81E+01)≈ − | 2.48E+02 (9.39E+01)≈ − | 2.32E+02 (1.14E+02)≈ − |
| 6.23E+00 (1.93E+00)++ | 5.80E+00 (2.28E+00)++ | 8.09E+00 (5.35E+00)+ ≈ | 1.02E+01 (1.08E+01)+ ≈ | 9.38E+00 (4.84E+00)+ ≈ |
| 2.56E+00 (7.32E-01)≈ − | 2.23E+00 (8.45E-01)≈ − | 2.23E+00 (1.25E+00)≈≈ | 2.18E+00 (9.05E-01)≈≈ | 2.73E+00 (1.02E+00)≈ − |
| 4.32E+00 (1.81E+00)++ | 5.99E+00 (2.95E+00)++ | 6.29E+00 (3.94E+00)+ ≈ | 8.44E+00 (3.87E+00)+− | 8.74E+00 (3.42E+00)++ |
| 1.39E+02 (8.59E+01)− | 1.48E+02 (7.85E+01)≈ − | 1.33E+02 (6.69E+01)− | 1.02E+02 (9.31E+01)≈ − | 9.32E+01 (7.13E+01)≈≈ |
| 2.31E+01 (2.76E+00)+ ≈ | 2.33E+01 (3.06E+00)+ ≈ | 2.30E+01 (2.28E+00)+ ≈ | 2.21E+01 (1.40E+00)+ ≈ | 2.33E+01 (2.86E+00)≈≈ |
| 3.36E+02 (1.05E-10)−− | 3.36E+02 (1.19E-13)−− | 3.36E+02 (3.75E-10)−− | 3.36E+02 (3.88E-10)−− | 3.36E+02 (1.19E-13)−− |
| 1.53E+02 (1.60E+01)++ | 1.57E+02 (1.47E+01)++ | 1.63E+02 (1.47E+01)++ | 1.62E+02 (1.11E+01)++ | 1.57E+02 (1.33E+01)++ |
| 2.00E+02 (3.28E-03)− | 2.00E+02 (3.18E-03)≈ ≈ | 2.00E+02 (3.35E-03)≈ − | 2.00E+02 (2.94E-03)≈≈ | 2.00E+02 (2.59E-03)≈≈ |
| 1.00E+02 (2.79E-02)− ≈ | 1.00E+02 (3.47E-02)≈≈ | 1.00E+02 (3.08E-02)− ≈ | 1.00E+02 (2.48E-02)−− | 1.00E+02 (2.94E-02)≈≈ |
| 3.22E+02 (3.35E+01)+− | 3.10E+02 (2.01E+01)+ ≈ | 3.17E+02 (2.71E+01)+ ≈ | 3.16E+02 (2.68E+01)+ ≈ | 3.20E+02 (3.01E+01)+− |
| 4.18E+02 (3.20E+00)−− | 4.20E+02 (4.11E+00)−− | 4.23E+02 (4.37E+00)−− | 4.22E+02 (4.34E+00)−− | 4.22E+02 (3.74E+00)−− |
| 4.30E+02 (9.71E+00)−− | 4.27E+02 (4.29E+00)−− | 4.29E+02 (4.98E+00)−− | 4.30E+02 (4.52E+00)−− | 4.31E+02 (1.02E+01)−− |
| 3.92E+02 (9.02E+00)−− | 3.95E+02 (1.79E+01)−− | 4.15E+02 (3.22E+01)−− | 4.01E+02 (1.49E+01)−− | 4.14E+02 (2.71E+01)−− |

Table 13: The results of the three versions of MPEDE for the CEC 2014 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution 1.00E-01 | Individuals redistribution 5.00E-02 |
|---|---|---|---|---|
| F1 | 1.47E-13 (1.37E-13) | 2.46E-13 (2.49E-13)− | 1.77E-13 (1.11E-13)≈≈ | 1.93E-13 (1.18E-13)− ≈ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 1.89E-15 (1.04E-14)≈≈ | 1.89E-15 (1.04E-14)≈≈ |
| F4 | 2.08E-14 (3.80E-14) | 3.79E-15 (1.44E-14)≈ | 5.68E-15 (1.73E-14)≈≈ | 1.33E-14 (2.45E-14)≈≈ |
| F5 | 2.00E+01 (6.71E-04) | 2.00E+01 (4.84E-05)≈ | 2.00E+01 (5.19E-05)≈≈ | 2.00E+01 (1.25E-04)≈≈ |
| F6 | 3.17E-01 (5.80E-01) | 0.00E+00 (0.00E+00)≈ | 4.99E-02 (1.53E-01)≈≈ | 1.53E-02 (8.39E-02)≈≈ |
| F7 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F8 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F9 | 2.28E+01 (5.30E+00) | 1.53E+01 (2.60E+00)+ | 1.79E+01 (3.21E+00)+− | 1.87E+01 (3.96E+00)+− |
| F10 | 3.75E-02 (2.47E-02) | 5.55E-03 (9.36E-03)+ | 8.33E-03 (1.29E-02)+ ≈ | 6.94E-03 (1.26E-02)+ ≈ |
| F11 | 1.11E+03 (3.66E+02) | 6.59E+02 (2.38E+02)+ | 7.27E+02 (2.28E+02)+ ≈ | 8.13E+02 (1.45E+02)+− |
| F12 | 4.51E-02 (1.99E-02) | 2.12E-02 (8.61E-03)+ | 2.16E-02 (8.57E-03)+ ≈ | 2.77E-02 (1.38E-02)+ ≈ |
| F13 | 1.30E-01 (3.03E-02) | 9.22E-02 (1.71E-02)+ | 1.13E-01 (2.05E-02)+− | 1.14E-01 (2.29E-02)+− |
| F14 | 1.34E-01 (1.88E-02) | 1.16E-01 (2.14E-02)≈ | 1.14E-01 (1.78E-02)+ ≈ | 1.15E-01 (1.88E-02)+ ≈ |
| F15 | 2.44E+00 (4.50E-01) | 1.89E+00 (3.79E-01)+ | 2.07E+00 (2.91E-01)+ ≈ | 2.02E+00 (3.73E-01)+ ≈ |
| F16 | 7.73E+00 (9.36E-01) | 6.86E+00 (4.89E-01)+ | 6.68E+00 (6.82E-01)+ ≈ | 6.85E+00 (5.94E-01)+ ≈ |
| F17 | 1.43E+03 (1.88E+03) | 4.31E+02 (1.46E+02)+ | 3.30E+02 (1.22E+02)++ | 3.36E+02 (1.44E+02)++ |
| F18 | 1.48E+02 (3.96E+02) | 1.63E+01 (4.91E+00)+ | 1.78E+01 (6.09E+00)+ ≈ | 6.46E+01 (2.08E+02)+ ≈ |
| F19 | 2.55E+00 (9.24E-01) | 2.73E+00 (6.09E-01)≈ | 2.69E+00 (6.99E-01)≈≈ | 2.74E+00 (6.67E-01)≈≈ |
| F20 | 9.79E+00 (4.01E+00) | 1.01E+01 (3.98E+00)≈ | 7.63E+00 (3.06E+00)++ | 7.90E+00 (3.94E+00)++ |
| F21 | 9.43E+02 (2.10E+03) | 1.02E+03 (3.04E+03)− | 2.79E+03 (6.39E+03)− ≈ | 2.69E+03 (6.65E+03)− ≈ |
| F22 | 1.21E+02 (7.55E+01) | 4.51E+01 (4.79E+01)+ | 5.11E+01 (6.01E+01)+ ≈ | 5.97E+01 (5.69E+01)+ ≈ |
| F23 | 3.15E+02 (1.11E-13) | 3.15E+02 (5.78E-14)≈ | 3.15E+02 (1.11E-13)≈≈ | 3.15E+02 (5.78E-14)≈≈ |
| F24 | 2.24E+02 (1.16E+00) | 2.23E+02 (6.45E-01)+ | 2.23E+02 (7.85E-01)+ ≈ | 2.09E+02 (1.07E+01)++ |
| F25 | 2.04E+02 (1.25E+00) | 2.03E+02 (3.83E-02)+ | 2.03E+02 (3.50E-02)++ | 2.03E+02 (3.67E-02)++ |
| F26 | 1.03E+02 (1.82E+01) | 1.00E+02 (1.65E-02)+ | 1.00E+02 (2.24E-02)≈ − | 1.00E+02 (2.17E-02)+− |
| F27 | 3.34E+02 (4.26E+01) | 3.00E+02 (8.69E-04)+ | 3.25E+02 (3.92E+01)≈ − | 3.24E+02 (4.09E+01)≈ − |
| F28 | 7.63E+02 (5.20E+01) | 6.85E+02 (4.25E+01)+ | 7.36E+02 (3.27E+01)+− | 7.25E+02 (3.19E+01)+− |
| F29 | 7.39E+02 (8.20E+01) | 7.94E+02 (2.58E+02)− | 6.86E+02 (1.90E+02)++ | 7.14E+02 (1.26E+02)++ |
| F30 | 1.57E+03 (7.13E+02) | 7.02E+02 (1.38E+02)+ | 4.91E+02 (9.04E+01)++ | 6.35E+02 (2.42E+02)++ |

| Individuals redistribution 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
|---|---|---|---|---|
| 2.58E-13 (2.25E-13)− ≈ | 1.72E-13 (1.16E-13)≈≈ | 2.21E-13 (1.23E-13)− ≈ | 2.13E-13 (1.53E-13)− ≈ | 1.99E-13 (1.34E-13)− ≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 1.89E-15 (1.04E-14)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 5.68E-15 (1.73E-14)≈≈ | 5.68E-15 (1.73E-14)≈≈ | 1.14E-14 (2.31E-14)≈≈ | 1.14E-14 (2.31E-14)≈≈ | 1.14E-14 (2.31E-14)≈≈ |
| 2.00E+01 (2.69E-05)≈≈ | 2.00E+01 (3.96E-05)≈≈ | 2.00E+01 (1.54E-05)≈≈ | 2.00E+01 (2.28E-05)≈≈ | 2.00E+01 (2.57E-05)≈≈ |
| 2.11E-01 (3.99E-01)≈≈ | 1.41E-01 (3.04E-01)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 8.07E-02 (2.25E-01)≈≈ | 1.67E-01 (3.61E-01)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 3.29E-04 (1.80E-03)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.83E+01 (3.48E+00)+− | 1.62E+01 (3.82E+00)+ ≈ | 1.75E+01 (3.73E+00)+− | 1.94E+01 (4.05E+00)+− | 1.74E+01 (4.15E+00)+ ≈ |
| 6.94E-03 (1.14E-02)+ ≈ | 1.53E-02 (1.33E-02)+− | 3.19E-02 (1.71E-02)≈ − | 3.27E-02 (2.72E-02)≈ − | 3.40E-02 (2.59E-02)≈ − |
| 5.66E+02 (1.71E+02)+ ≈ | 5.53E+02 (2.04E+02)+ ≈ | 5.27E+02 (2.06E+02)++ | 5.15E+02 (2.19E+02)++ | 5.53E+02 (2.43E+02)+ ≈ |
| 2.56E-02 (1.17E-02)+ ≈ | 2.27E-02 (1.06E-02)+ ≈ | 2.06E-02 (7.53E-03)+ ≈ | 1.72E-02 (1.27E-02)+ ≈ | 1.18E-02 (6.70E-03)+ ≈ |
| 1.10E-01 (2.34E-02)+− | 1.21E-01 (2.64E-02)≈ − | 1.15E-01 (2.26E-02)+− | 1.16E-01 (2.06E-02)+− | 1.08E-01 (2.06E-02)+− |
| 1.13E-01 (1.84E-02)+ ≈ | 1.04E-01 (1.97E-02)++ | 1.09E-01 (2.08E-02)+ ≈ | 1.09E-01 (2.04E-02)+ ≈ | 1.03E-01 (1.85E-02)++ |
| 2.16E+00 (4.45E-01)+− | 2.18E+00 (3.65E-01)+− | 2.10E+00 (3.42E-01)+ ≈ | 2.13E+00 (3.55E-01)+− | 1.92E+00 (3.73E-01)+ ≈ |
| 6.42E+00 (5.90E-01)+ ≈ | 6.70E+00 (5.57E-01)+ ≈ | 6.07E+00 (7.78E-01)++ | 6.32E+00 (7.77E-01)+ ≈ | 6.24E+00 (9.39E-01)++ |
| 4.51E+02 (1.71E+02)+ ≈ | 4.98E+02 (2.33E+02)+ ≈ | 1.19E+03 (1.13E+03)− − | 9.78E+02 (2.89E+02)≈ − | 1.06E+03 (4.35E+02)− − |
| 1.04E+01 (8.41E+00)++ | 6.37E+01 (2.05E+02)+− | 5.27E+01 (4.42E+01)≈ − | 1.18E+02 (2.62E+02)≈ − | 4.00E+01 (3.05E+01)+− |
| 2.71E+00 (7.91E-01)≈≈ | 2.57E+00 (5.45E-01)≈≈ | 2.68E+00 (8.11E-01)≈≈ | 2.63E+00 (7.59E-01)≈≈ | 2.92E+00 (6.34E-01)− ≈ |
| 9.19E+00 (4.63E+00)≈≈ | 8.32E+00 (3.15E+00)≈≈ | 1.02E+01 (4.92E+00)≈≈ | 1.02E+01 (4.92E+00)≈≈ | 9.87E+00 (3.89E+00)≈≈ |
| 9.43E+02 (2.30E+03)− + | 3.83E+03 (8.23E+03)≈ − | 9.48E+02 (2.29E+03)≈ + | 6.60E+02 (1.50E+03)≈ + | 3.84E+02 (1.04E+03)++ |
| 6.93E+01 (7.01E+01)+ ≈ | 7.75E+01 (6.43E+01)+ ≈ | 9.14E+01 (7.17E+01)≈≈ | 9.5E+01 (8.76E+01)≈≈ | 8.79E+01 (7.23E+01)≈≈ |
| 3.15E+02 (5.78E-14)≈≈ | 3.15E+02 (8.44E-14)≈≈ | 2.00E+02 (1.45E-13)++ | 2.00E+02 (1.45E-13)++ | 2.00E+02 (1.45E-13)++ |
| 2.00E+02 (2.47E-02)++ | 2.00E+02 (2.06E-02)++ | 2.00E+02 (1.04E-02)++ | 2.00E+02 (1.04E-02)++ | 2.00E+02 (1.57E-02)++ |
| 2.03E+02 (3.63E-02)++ | 2.02E+02 (9.50E-01)+ ≈ | 2.00E+02 (1.45E-13)++ | 2.00E+02 (1.45E-13)++ | 2.00E+02 (1.45E-13)++ |
| 1.03E+02 (1.82E+01)+− | 1.03E+02 (1.82E+01)+− | 1.00E+02 (2.54E-02)+− | 1.03E+02 (1.82E+01)+− | 1.00E+02 (1.94E-02)+− |
| 3.33E+02 (4.61E+01)≈ − | 3.31E+02 (4.17E+01)≈ − | 2.42E+02 (6.54E+01)++ | 2.26E+02 (5.97E+01)++ | 2.57E+02 (9.01E+01)++ |
| 7.20E+02 (2.81E+01)+− | 7.14E+02 (3.96E+01)+− | 7.32E+02 (2.44E+01)+− | 7.26E+02 (3.53E+01)+− | 6.77E+02 (1.65E+02)++ |
| 8.31E+02 (2.83E+02)− ≈ | 7.15E+02 (1.60E+02)+ ≈ | 7.17E+02 (4.43E+00)+ ≈ | 7.20E+02 (1.45E+02)+ ≈ | 6.91E+02 (2.31E+02)+ ≈ |
| 1.05E+03 (3.99E+02)+− | 1.38E+03 (4.66E+02)≈ − | 1.50E+03 (7.29E+02)≈ − | 1.42E+03 (5.38E+02)≈ − | 1.26E+03 (3.42E+02)≈ − |

Table 14: The results of the three versions of ETI-JADE for the CEC 2014 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 8.61E-13 (3.20E-12) | 3.53E-13 (3.69E-13)≈ | 3.15E-13 (5.18E-13)≈≈ | 4.59E-13 (8.79E-13)≈≈ |
| F2 | 9.47E-16 (5.19E-15) | 9.47E-16 (5.19E-15)≈ | 9.47E-16 (5.19E-15)≈≈ | 2.84E-15 (8.67E-15)≈≈ |
| F3 | 2.10E-13 (6.88E-13) | 0.00E+00 (0.00E+00)+ | 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ |
| F4 | 1.20E+00 (1.86E+00) | 1.46E+00 (1.95E+00)≈ | 1.46E+00 (1.95E+00)≈≈ | 1.73E+00 (2.01E+00)≈≈ |
| F5 | 2.00E+01 (8.00E-02) | 2.02E+01 (1.15E-01)− | 2.00E+01 (6.43E-04)++ | 2.00E+01 (8.29E-02)++ |
| F6 | 1.77E+00 (1.21E+00) | 3.79E-01 (6.69E-01)+ | 5.65E-01 (7.98E-01)+ ≈ | 7.43E-01 (8.03E-01)+ ≈ |
| F7 | 1.97E-03 (6.33E-03) | 8.21E-04 (3.12E-03)≈ | 1.48E-03 (3.4E-03)≈≈ | 1.48E-03 (4.90E-03)≈≈ |
| F8 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F9 | 2.77E+01 (6.12E+00) | 1.66E+01 (2.06E+00)+ | 1.46E+01 (2.59E+00)++ | 1.51E+01 (3.38E+00)++ |
| F10 | 4.79E-02 (3.55E-02) | 1.68E-02 (1.60E-02)+ | 0.00E+00 (0.00E+00)++ | 0.00E+00 (0.00E+00)++ |
| F11 | 2.19E+03 (4.38E+02) | 1.80E+03 (2.39E+02)+ | 1.56E+03 (2.97E+02)++ | 1.52E+03 (3.37E+02)++ |
| F12 | 1.15E-01 (6.45E-02) | 7.23E-02 (2.22E-02)+ | 5.64E-02 (2.47E-02)++ | 5.76E-02 (3.56E-02)++ |
| F13 | 2.12E-01 (4.31E-02) | 1.13E-01 (2.02E-02)+ | 1.19E-01 (2.15E-02)+ ≈ | 1.20E-01 (3.16E-02)+ ≈ |
| F14 | 2.14E-01 (4.52E-02) | 1.32E-01 (1.59E-02)+ | 1.16E-01 (1.60E-02)++ | 1.15E-01 (2.04E-02)++ |
| F15 | 2.91E+00 (4.90E-01) | 1.81E+00 (3.14E-01)+ | 2.28E+00 (5.79E-01)+− | 2.30E+00 (4.94E-01)+− |
| F16 | 9.92E+00 (6.29E-01) | 9.31E+00 (5.12E-01)+ | 8.46E+00 (6.44E-01)++ | 8.77E+00 (7.71E-01)++ |
| F17 | 3.66E+02 (2.70E+02) | 1.40E+02 (7.10E+01)+ | 3.58E+02 (2.50E+02)≈ − | 3.61E+02 (2.70E+02)≈ − |
| F18 | 7.66E+01 (1.03E+02) | 8.36E+00 (3.36E+00)+ | 7.69E+00 (2.81E+00)+ ≈ | 1.61E+01 (3.83E+01)+ ≈ |
| F19 | 3.81E+00 (1.33E+00) | 4.33E+00 (2.92E+00)≈ | 3.51E+00 (1.68E+00)≈≈ | 3.12E+00 (1.13E+00)+ ≈ |
| F20 | 7.00E+00 (2.90E+00) | 5.08E+00 (1.83E+00)+ | 4.83E+00 (1.93E+00)+ ≈ | 4.56E+00 (2.77E+00)+ ≈ |
| F21 | 1.29E+02 (1.32E+02) | 3.77E+01 (4.90E+01)+ | 1.36E+02 (1.44E+02)≈ − | 9.88E+01 (1.26E+02)≈≈ |
| F22 | 2.71E+01 (5.99E+00) | 2.49E+01 (3.41E+00)≈ | 2.44E+01 (3.51E+00)+ ≈ | 2.39E+01 (2.89E+00)+ ≈ |
| F23 | 3.30E+02 (3.00E-12) | 3.30E+02 (1.73E-13)≈ | 3.30E+02 (3.75E-13)≈≈ | 3.30E+02 (3.35E-13)≈≈ |
| F24 | 2.01E+02 (7.52E-02) | 2.01E+02 (3.63E-02)+ | 2.01E+02 (3.76E-02)++ | 2.01E+02 (4.11E-02)+ ≈ |
| F25 | 2.00E+02 (3.28E-03) | 2.00E+02 (2.09E-03)≈ | 2.00E+02 (2.47E-03)≈≈ | 2.00E+02 (3.20E-03)≈≈ |
| F26 | 1.00E+02 (3.29E-02) | 1.00E+02 (1.94E-02)+ | 1.00E+02 (1.68E-02)+ ≈ | 1.00E+02 (2.26E-02)+ ≈ |
| F27 | 3.34E+02 (2.96E+01) | 3.02E+02 (2.79E+00)+ | 3.31E+02 (2.95E+01)≈ − | 3.14E+02 (1.46E+01)+− |
| F28 | 3.95E+02 (2.13E+01) | 3.73E+02 (1.03E+00)+ | 3.83E+02 (5.30E+00)≈ − | 3.83E+02 (5.92E+00)≈ − |
| F29 | 2.09E+02 (1.47E+00) | 2.08E+02 (1.55E+00)≈ | 2.09E+02 (1.23E+00)≈ − | 2.09E+02 (1.25E+00)≈ − |
| F30 | 3.76E+02 (7.96E+01) | 2.43E+02 (1.30E+01)+ | 2.80E+02 (4.33E+01)+− | 2.72E+02 (3.93E+01)+− |

| | | Individuals redistribution | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 2.88E-13 (2.62E-13)≈≈ | 2.61E-12 (1.25E-11)≈≈ | 4.90E-09 (2.68E-08)≈≈ | 2.47E-13 (2.81E-13)≈≈ | 1.19E-11 (6.35E-11)≈≈ |
| 2.84E-15 (1.14E-14)≈≈ | 1.89E-15 (7.21E-15)≈≈ | 1.89E-15 (7.21E-15)≈≈ | 3.79E-15 (9.83E-15)≈≈ | 5.68E-15 (1.38E-14)≈≈ |
| 0.00E+00 (0.00E+00)+ ≈ | 0.00E+00 (0.00E+00)+ ≈ | 1.89E-15 (1.04E-14)+ ≈ | 5.68E-15 (1.73E-14)≈≈ | 5.68E-15 (1.73E-14)≈≈ |
| 1.59E+00 (1.99E+00)− | 1.86E+00 (2.02E+00)≈ − | 1.33E+00 (1.91E+00)≈≈ | 1.73E+00 (2.01E+00)≈ − | 1.33E+00 (1.91E+00)≈≈ |
| 2.00E+01 (8.67E-02)++ | 2.00E+01 (7.37E-02)++ | 2.00E+01 (5.42E-02)++ | 2.00E+01 (1.10E-02)+ | 2.00E+01 (7.37E-02)++ |
| 1.43E+00 (1.31E+00)≈ − | 1.64E+00 (1.32E+00)≈ − | 1.37E+00 (1.05E+00)≈ − | 2.05E+00 (1.57E+00)≈ − | 1.23E+00 (1.03E+00)≈ − |
| 2.22E-03 (4.45E-03)≈≈ | 1.56E-03 (4.36E-03)≈≈ | 1.14E-03 (6.27E-03)≈≈ | 1.15E-03 (3.02E-03)≈≈ | 1.23E-03 (3.76E-03)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.40E+01 (3.66E+00)++ | 2.34E+01 (6.05E+00)≈ − | 2.57E+01 (6.51E+00)≈ − | 2.79E+01 (7.33E+00)≈ − | 2.62E+01 (4.63E+00)≈ − |
| 0.00E+00 (0.00E+00)++ | 0.00E+00 (0.00E+00)++ | 1.94E-02 (2.62E-02)+ ≈ | 3.54E-02 (3.00E-02)≈ − | 4.30E-02 (2.78E-02)≈ − |
| 1.23E+03 (4.05E+02)++ | 1.87E+03 (4.60E+02)+ ≈ | 1.88E+03 (4.56E+02)+ ≈ | 2.02E+03 (3.84E+02)≈ − | 1.86E+03 (4.11E+02)+ ≈ |
| 5.45E-02 (3.18E-02)++ | 3.71E-02 (2.76E-02)++ | 3.66E-02 (1.74E-02)++ | 5.29E-02 (3.64E-02)++ | 7.57E-02 (4.63E-02)+ ≈ |
| 1.26E-01 (2.72E-02)+− | 1.12E-01 (2.49E-02)+ ≈ | 1.07E-01 (2.54E-02)+ ≈ | 1.08E-01 (1.76E-02)+ ≈ | 1.11E-01 (2.86E-02)+ ≈ |
| 1.02E-01 (1.69E-02)++ | 9.79E-02 (1.70E-02)++ | 8.68E-02 (1.66E-02)++ | 9.55E-02 (2.28E-02)++ | 9.60E-02 (1.65E-02)++ |
| 2.46E+00 (5.22E-01)+− | 2.44E+00 (5.30E-01)+− | 2.53E+00 (5.13E-01)+− | 2.70E+00 (6.52E-01)≈ − | 2.74E+00 (6.90E-01)≈ − |
| 8.73E+00 (8.58E-01)++ | 8.74E+00 (7.25E-01)++ | 8.80E+00 (6.11E-01)++ | 9.09E+00 (6.25E-01)+ ≈ | 9.12E+00 (5.79E-01)++ |
| 3.55E+02 (2.99E+02)≈ | 4.34E+02 (3.73E+02)≈ − | 4.00E+02 (3.47E+02)≈ − | 3.65E+02 (3.17E+02)≈ − | 2.54E+02 (1.74E+02)≈ − |
| 1.02E+01 (6.88E+00)+ ≈ | 1.46E+01 (1.44E+01)+ ≈ | 3.67E+01 (4.88E+01)≈ − | 3.42E+01 (4.80E+01)≈≈ | 3.83E+01 (3.51E+01)≈ − |
| 2.99E+00 (9.05E-01)+ ≈ | 3.14E+00 (1.29E+00)+ ≈ | 3.69E+00 (1.18E+00)≈≈ | 3.39E+00 (1.30E+00)≈≈ | 3.79E+00 (1.63E+00)≈≈ |
| 4.27E+00 (2.13E+00)+ ≈ | 4.29E+00 (1.25E+00)+ ≈ | 4.99E+00 (1.88E+00)+ ≈ | 6.11E+00 (4.65E+00)+ ≈ | 5.76E+00 (2.91E+00)+ ≈ |
| 1.52E+02 (1.64E+02)− | 1.53E+02 (2.03E+02)≈≈ | 1.58E+02 (1.45E+02)≈ − | 1.80E+02 (1.65E+02)≈ − | 1.52E+02 (1.95E+02)≈≈ |
| 2.42E+01 (3.76E+00)+ | 2.31E+01 (2.90E+00)++ | 2.47E+01 (4.79E+00)++ | 2.49E+01 (5.75E+00)+ ≈ | 2.47E+01 (3.90E+00)≈≈ |
| 3.30E+02 (3.47E-13)≈≈ | 3.30E+02 (3.07E-13)≈≈ | 3.30E+02 (2.83E-13)≈≈ | 3.30E+02 (4.04E-13)≈≈ | 3.30E+02 (3.36E-13)≈≈ |
| 2.01E+02 (4.80E-02)++ | 1.99E+02 (8.45E+00)+ ≈ | 2.01E+02 (3.39E-02)++ | 2.01E+02 (5.09E-02)++ | 2.01E+02 (4.26E-02)++ |
| 2.00E+02 (3.19E-03)≈≈ | 2.00E+02 (7.58E-03)≈≈ | 2.00E+02 (6.45E-01)≈≈ | 2.00E+02 (6.32E-01)≈≈ | 2.00E+02 (5.91E-01)≈≈ |
| 1.00E+02 (2.20E-02)++ | 1.00E+02 (2.13E-02)+ | 1.00E+02 (2.13E-02)++ | 1.00E+02 (1.76E-02)+ | 1.00E+02 (1.76E-02)++ |
| 3.29E+02 (2.77E+01)≈ − | 3.23E+02 (2.49E+01)≈ − | 3.43E+02 (3.78E+01)≈ − | 3.26E+02 (2.70E+01)≈ − | 3.44E+02 (3.63E+01)≈ − |
| 3.82E+02 (7.52E+00)+− | 3.83E+02 (5.70E+00)≈ − | 3.84E+02 (5.36E+00)≈ − | 3.85E+02 (8.59E+00)≈ − | 3.85E+02 (4.56E+00)≈ − |
| 2.10E+02 (1.31E+00)≈ − | 2.09E+02 (1.20E+00)≈ − | 2.09E+02 (1.32E+00)≈ − | 2.09E+02 (1.31E+00)≈ − | 2.09E+02 (1.24E+00)≈ − |
| 2.70E+02 (4.09E+01)+− | 2.57E+02 (1.93E+01)+− | 2.68E+02 (4.00E+01)+− | 2.63E+02 (3.20E+01)+− | 2.64E+02 (3.50E+01)+− |

Table 15: The results of the three versions of EDEV for the CEC 2014 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 7.23E-13 (5.89E-13) | 7.30E-04 (8.07E-04)− | 5.55E-03 (1.94E-02)− ≈ | 2.01E-03 (4.40E-03)− ≈ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 3.79E-14 (6.35E-14)−− | 2.56E-14 (2.28E-14)−− |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 1.42E-12 (5.99E-12)−− | 2.84E-13 (7.12E-13)−− |
| F4 | 5.50E-14 (3.50E-14) | 1.34E-09 (1.12E-09)− | 1.36E-12 (2.93E-12)−+ | 4.98E-13 (5.00E-13)−+ |
| F5 | 2.00E+01 (3.26E-04) | 2.02E+01 (4.94E-02)− | 2.02E+01 (2.10E-02)− ≈ | 2.02E+01 (4.38E-02)− ≈ |
| F6 | 6.11E-01 (1.73E+00) | 2.35E-13 (8.93E-13)≈ | 5.83E-02 (2.66E-01)+− | 6.42E-01 (1.24E+00)−− |
| F7 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F8 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F9 | 2.11E+01 (3.99E+00) | 2.23E+01 (2.96E+00)≈ | 2.87E+01 (2.96E+00)−− | 2.59E+01 (6.12E+00)−− |
| F10 | 2.78E-03 (9.04E-03) | 2.24E-01 (2.94E-01)− | 7.68E-02 (3.98E-02)−+ | 5.83E-02 (3.84E-02)−+ |
| F11 | 1.49E+03 (2.67E+02) | 1.23E+03 (2.61E+02)+ | 1.73E+03 (3.79E+02)−− | 1.64E+03 (4.19E+02)≈ − |
| F12 | 3.63E-02 (1.77E-02) | 2.28E-02 (8.78E-03)+ | 3.50E-02 (1.83E-02)≈ − | 3.07E-02 (1.31E-02)≈ − |
| F13 | 6.42E-01 (1.22E-02) | 1.17E-01 (1.61E-02)− | 1.19E-01 (2.01E-02)− ≈ | 1.12E-01 (1.53E-02)− ≈ |
| F14 | 1.23E-01 (2.29E-02) | 1.79E-01 (1.35E-02)− | 1.69E-01 (2.03E-02)−+ | 1.71E-01 (1.71E-02)− ≈ |
| F15 | 2.28E+00 (6.09E-01) | 1.98E+00 (2.86E-01)+ | 2.58E+00 (5.88E-01)−− | 2.56E+00 (6.40E-01)≈ − |
| F16 | 7.97E+00 (9.59E-01) | 7.21E+00 (6.01E-01)+ | 7.66E+00 (9.16E-01)≈ − | 8.07E+00 (5.54E-01)≈ − |
| F17 | 1.89E+02 (1.25E+02) | 8.54E+01 (5.31E+01)+ | 2.24E+02 (1.49E+02)−− | 1.88E+02 (1.18E+02)≈ − |
| F18 | 8.56E+00 (2.65E+00) | 6.28E+00 (1.57E+00)+ | 8.19E+00 (2.88E+00)≈ − | 9.94E+00 (3.32E+00)≈ − |
| F19 | 1.98E+00 (3.43E-01) | 1.76E+00 (3.68E-01)+ | 2.09E+00 (5.63E-01)≈ − | 2.05E+00 (4.26E-01)≈ − |
| F20 | 5.12E+00 (1.82E+00) | 3.52E+00 (9.94E-01)+ | 7.12E+00 (2.83E+00)−− | 6.45E+00 (2.12E+00)−− |
| F21 | 8.95E+01 (8.47E+01) | 2.41E+01 (4.09E+01)+ | 1.10E+02 (6.61E+01)≈ − | 1.00E+02 (7.89E+01)≈ − |
| F22 | 4.38E+01 (4.92E+01) | 1.82E+01 (2.57E+01)+ | 2.97E+01 (4.63E+01)≈≈ | 3.33E+01 (4.90E+01)+ ≈ |
| F23 | 3.15E+02 (1.98E-13) | 3.15E+02 (6.25E-12)≈ | 3.15E+02 (1.11E-13)≈≈ | 3.15E+02 (5.78E-14)≈≈ |
| F24 | 2.23E+02 (7.79E-01) | 2.22E+02 (1.59E-01)+ | 2.00E+02 (1.68E-05)++ | 2.00E+02 (4.84E-02)++ |
| F25 | 2.03E+02 (2.50E-01) | 2.03E+02 (2.85E-02)+ | 2.03E+02 (9.92E-01)− ≈ | 2.03E+02 (9.46E-01)≈ − |
| F26 | 1.00E+02 (1.02E-02) | 1.00E+02 (1.76E-02)≈ | 1.00E+02 (3.81E-02)− − | 1.00E+02 (4.42E-02)−− |
| F27 | 3.30E+02 (4.68E+01) | 3.00E+02 (3.54E-11)+ | 3.73E+02 (4.49E+01)−− | 3.22E+02 (4.12E+01)≈≈ |
| F28 | 7.93E+02 (3.12E+01) | 7.68E+02 (2.97E+01)+ | 7.93E+02 (5.80E+01)≈ − | 7.80E+02 (1.14E+02)≈ − |
| F29 | 7.18E+02 (7.17E+00) | 4.21E+02 (2.80E+02)+ | 6.27E+02 (2.12E+02)≈ − | 6.71E+02 (2.81E+02)≈ − |
| F30 | 4.51E+02 (6.90E+01) | 4.07E+02 (2.69E+01)+ | 5.34E+02 (1.42E+02)−− | 6.76E+02 (4.18E+02)−− |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 4.58E-04 (4.36E-04)− ≈ | 3.73E-04 (3.08E-04)− ≈ | 3.68E-04 (4.21E-04)−+ | 5.28E-04 (7.09E-04)− ≈ | 9.49E-04 (2.02E-03)− ≈ |
| 2.56E-14 (2.62E-14)−− | 2.08E-14 (1.66E-14)−− | 1.42E-14 (1.45E-14)−− | 1.61E-14 (1.43E-14)−− | 1.52E-14 (1.44E-14)−− |
| 3.30E-13 (8.18E-13)−− | 2.56E-13 (4.58E-13)−− | 5.50E-14 (3.16E-13)−− | 5.68E-14 (3.95E-14)−− | 4.74E-14 (2.62E-14)−− |
| 8.28E-13 (1.14E-12)−+ | 5.06E-13 (6.00E-13)−+ | 1.61E-12 (5.19E-12)−+ | 5.36E-13 (5.59E-13)−+ | 4.58E-13 (3.28E-13)−+ |
| 2.02E+01 (5.67E-02)− ≈ | 2.02E+01 (4.33E-02)− ≈ | 2.02E+01 (5.39E-02)− ≈ | 2.02E+01 (4.77E-02)− ≈ | 2.02E+01 (5.30E-02)− ≈ |
| 2.17E-01 (5.69E-01)+− | 2.16E-01 (5.88E-01)+− | 1.25E-01 (4.16E-01)+− | 5.33E-02 (2.00E-01)+− | 4.50E-02 (1.91E-01)+− |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 2.47E+01 (5.72E+00)− ≈ | 2.39E+01 (4.86E+00)≈ − | 2.31E+01 (5.68E+00)≈ − | 2.48E+01 (5.17E+00)−− | 2.16E+01 (4.34E+00)≈ − |
| 6.75E-02 (3.65E-02)−+ | 7.23E-02 (4.98E-02)−+ | 6.81E-02 (3.94E-02)−+ | 7.65E-02 (3.64E-02)−+ | 8.88E-02 (5.07E-02)−+ |
| 1.61E+03 (3.71E+02)≈ − | 1.47E+03 (3.23E+02)≈ − | 1.39E+03 (3.53E+02)≈ − | 1.31E+03 (2.14E+02)+ ≈ | 1.37E+03 (2.66E+02)≈ − |
| 3.25E-02 (1.57E-02)≈ − | 2.37E-02 (1.35E-02)+ ≈ | 2.56E-02 (9.63E-03)+ ≈ | 2.73E-02 (8.92E-03)+− | 2.60E-02 (1.14E-02)+ ≈ |
| 1.17E-01 (1.44E-02)− ≈ | 1.22E-01 (1.73E-02)− ≈ | 1.20E-01 (1.66E-02)− ≈ | 1.22E-01 (1.57E-02)− ≈ | 1.22E-01 (1.91E-02)− ≈ |
| 1.75E-01 (2.09E-02)− ≈ | 1.77E-01 (2.09E-02)− ≈ | 1.80E-01 (1.34E-02)− ≈ | 1.80E-01 (1.69E-02)− ≈ | 1.78E-01 (2.01E-02)− ≈ |
| 2.29E+00 (4.15E-01)≈ − | 2.31E+00 (3.52E-01)≈ − | 2.24E+00 (3.36E-01)≈ − | 2.10E+00 (3.29E-01)≈≈ | 2.11E+00 (3.47E-01)≈≈ |
| 8.11E+00 (4.47E-01)≈ − | 8.12E+00 (5.55E-01)≈ − | 7.94E+00 (6.53E-01)≈ − | 8.00E+00 (6.50E-01)≈ − | 8.09E+00 (6.76E-01)≈ − |
| 1.50E+02 (1.54E+02)+ ≈ | 1.26E+02 (1.03E+02)+ ≈ | 1.09E+02 (8.40E+01)+ ≈ | 1.06E+02 (8.58E+01)+ ≈ | 8.60E+01 (7.48E+01)+ ≈ |
| 7.48E+00 (2.16E+00)≈ − | 7.56E+00 (2.62E+00)≈ − | 6.81E+00 (1.62E+00)+ ≈ | 5.76E+00 (1.69E+00)+ ≈ | 5.99E+00 (1.41E+00)+ ≈ |
| 2.23E+00 (3.96E-01)−− | 1.91E+00 (5.81E-01)≈≈ | 1.92E+00 (4.08E-01)≈≈ | 1.90E+00 (3.87E-01)≈≈ | 1.65E+00 (4.89E-01)+ ≈ |
| 5.26E+00 (1.73E+00)− | 5.04E+00 (1.50E+00)≈ − | 4.39E+00 (1.55E+00)≈ − | 4.39E+00 (1.34E+00)≈ − | 4.31E+00 (1.11E+00)≈ − |
| 6.57E+01 (7.13E+01)≈ − | 3.25E+01 (4.27E+01)+ ≈ | 3.96E+01 (4.89E+01)≈ − | 4.06E+01 (5.15E+01)+ ≈ | 2.40E+01 (3.65E+01)+ ≈ |
| 2.26E+01 (2.02E+01)≈ − | 3.22E+01 (3.77E+01)≈ − | 2.50E+01 (3.78E+01)+ ≈ | 3.02E+01 (3.61E+01)≈ − | 2.85E+01 (3.01E+01)≈ − |
| 3.15E+02 (5.78E-14)≈≈ | 3.11E+02 (2.10E+01)≈≈ | 3.08E+02 (2.92E+01)≈≈ | 3.11E+02 (2.10E+01)≈≈ | 3.15E+02 (1.11E-13)≈≈ |
| 2.02E+02 (6.07E+00)++ | 2.00E+02 (9.20E-02)++ | 2.00E+02 (3.44E-06)++ | 2.00E+02 (6.07E-06)++ | 2.00E+02 (1.40E-06)++ |
| 2.03E+02 (2.14E-01)≈ − | 2.02E+02 (8.74E-01)≈ + | 2.03E+02 (5.70E-01)≈ − | 2.02E+02 (1.07E+00)++ | 2.03E+02 (7.56E-01)≈ − |
| 1.00E+02 (2.79E-02)−− | 1.00E+02 (2.60E-02)− | 1.00E+02 (3.00E-02)−− | 1.00E+02 (2.63E-02)− | 1.00E+02 (2.90E-02)−− |
| 3.14E+02 (2.92E+01)≈ − | 3.10E+02 (4.33E+01)≈≈ | 3.10E+02 (2.45E+01)≈ − | 3.07E+02 (1.59E+01)≈ − | 3.06E+02 (1.32E+01)≈≈ |
| 7.31E+02 (4.12E+01)++ | 7.23E+02 (3.34E+01)++ | 7.24E+02 (3.69E+01)++ | 7.38E+02 (4.32E+01)++ | 7.22E+02 (4.00E+01)++ |
| 7.10E+02 (1.12E+02)− | 6.84E+02 (1.95E+02)≈ − | 5.93E+02 (2.34E+02)≈ − | 6.64E+02 (1.66E+02)≈ − | 7.03E+02 (1.62E+02)≈ − |
| 5.78E+02 (2.45E+02)−− | 5.06E+02 (1.26E+02)≈ − | 5.53E+02 (2.22E+02)−− | 5.00E+02 (1.38E+02)≈ − | 4.65E+02 (7.99E+01)≈ − |

Table 16: The results of the three versions of MLCC-SI for the CEC 2014 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference

| Function | Original | Complete restart | Individuals redistribution | |
|---|---|---|---|---|
| | | | 1.00E-01 | 5.00E-02 |
| F1 | 0.00E+00 (0.00E+00) | 4.80E-01 (8.49E-01)− | 6.52E-02 (9.33E-02)−+ | 6.03E-02 (8.07E-02)−+ |
| F2 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F3 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F4 | 5.89E+01 (1.41E+00) | 5.47E+01 (1.49E+01)≈ | 5.08E+01 (2.02E+01)≈≈ | 4.49E+01 (2.52E+01)≈≈ |
| F5 | 2.01E+01 (1.04E-01) | 2.00E+01 (2.87E-02)+ | 2.00E+01 (2.82E-02)+≈ | 2.00E+01 (5.80E-03)++ |
| F6 | 1.68E+00 (1.86E+00) | 6.82E-01 (2.09E+00)+ | 7.08E-02 (2.71E-01)++ | 6.66E-01 (8.53E-01)+≈ |
| F7 | 0.00E+00 (0.00E+00) | 0.00E+00 (0.00E+00)≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| F8 | 5.74E+00 (2.76E+00) | 3.32E-01 (1.82E-01)+ | 1.09E+00 (1.96E+00)+≈ | 2.72E+00 (2.62E+00)+− |
| F9 | 4.66E+01 (1.63E+01) | 2.57E+01 (4.37E+00)+ | 2.50E+01 (6.08E+00)+≈ | 2.33E+01 (5.02E+00)+≈ |
| F10 | 6.05E+00 (2.15E+01) | 4.13E-01 (2.26E+00)+ | 1.32E-02 (3.02E-02)+≈ | 4.16E-03 (1.38E-02)+≈ |
| F11 | 2.70E+03 (6.59E+02) | 1.69E+03 (3.73E+02)+ | 1.75E+03 (2.85E+02)+≈ | 1.57E+03 (2.92E+02)+≈ |
| F12 | 3.05E-02 (1.99E-02) | 2.10E-02 (9.82E-03)≈ | 2.38E-02 (8.42E-03)≈≈ | 2.43E-02 (1.10E-02)≈≈ |
| F13 | 8.36E-02 (9.30E-02) | 1.42E-01 (2.45E-02)− | 1.51E-01 (3.20E-02)−≈ | 1.66E-01 (3.58E-02)−− |
| F14 | 1.45E-01 (5.60E-02) | 1.75E-01 (2.20E-02)− | 1.83E-01 (2.36E-02)−≈ | 1.76E-01 (2.57E-02)−≈ |
| F15 | 3.26E+00 (9.48E-01) | 2.18E+00 (3.84E-01)+ | 2.24E+00 (3.23E-01)+≈ | 2.32E+00 (4.71E-01)+≈ |
| F16 | 1.04E+01 (8.76E-01) | 9.32E+00 (7.38E-01)+ | 9.17E+00 (7.17E-01)+≈ | 9.38E+00 (4.92E-01)+≈ |
| F17 | 3.29E+02 (2.09E+02) | 9.40E+01 (7.76E+01)+ | 9.45E+01 (6.04E+01)+≈ | 8.91E+01 (6.95E+01)+≈ |
| F18 | 8.61E+00 (3.38E+00) | 9.42E+00 (3.06E+00)≈ | 1.05E+01 (3.32E+00)−≈ | 9.19E+00 (2.59E+00)≈≈ |
| F19 | 2.33E+00 (1.00E+00) | 3.12E+00 (6.28E-01)− | 2.39E+00 (4.53E-01)≈ + | 2.48E+00 (3.46E-01)≈ + |
| F20 | 6.24E+00 (2.72E+00) | 4.49E+00 (1.49E+00)+ | 4.53E+00 (1.21E+00)+≈ | 4.47E+00 (1.13E+00)+≈ |
| F21 | 1.16E+02 (1.09E+02) | 5.10E+01 (3.75E+00)+ | 2.00E+01 (4.13E+01)+≈ | 9.65E+00 (2.20E+01)+≈ |
| F22 | 6.17E+01 (5.18E+01) | 2.64E+01 (3.49E+00)+ | 2.55E+01 (4.08E+00)+≈ | 2.49E+01 (3.67E+00)++ |
| F23 | 3.36E+02 (0.00E+00) | 3.36E+02 (2.27E-13)≈ | 3.36E+02 (1.88E-13)≈≈ | 3.36E+02 (2.38E-13)≈≈ |
| F24 | 2.01E+02 (8.01E-02) | 2.01E+02 (5.13E-02)− | 2.01E+02 (5.97E-02)−≈ | 2.01E+02 (5.79E-02)−≈ |
| F25 | 2.00E+02 (8.33E-01) | 2.00E+02 (1.45E-13)≈ | 2.00E+02 (1.45E-13)≈≈ | 2.00E+02 (1.54E-13)≈≈ |
| F26 | 1.00E+02 (7.96E-02) | 1.00E+02 (3.12E-02)− | 1.00E+02 (2.84E-02)−≈ | 1.00E+02 (2.33E-02)−≈ |
| F27 | 3.57E+02 (4.58E+01) | 3.01E+02 (2.49E+00)+ | 3.36E+02 (4.39E+01)≈ − | 3.61E+02 (4.50E+01)≈ − |
| F28 | 4.19E+02 (2.93E+00) | 4.15E+02 (1.66E+00)+ | 4.15E+02 (1.79E+00)+≈ | 4.15E+02 (1.41E+00)+≈ |
| F29 | 4.27E+02 (3.05E+00) | 4.26E+02 (2.02E-01)≈ | 4.26E+02 (1.21E-01)≈≈ | 4.26E+02 (4.36E-01)≈≈ |
| F30 | 3.97E+02 (1.16E+01) | 3.94E+02 (9.37E+00)≈ | 4.02E+02 (9.21E+00)−− | 4.01E+02 (1.13E+01)−− |

| Individuals redistribution | | | | |
|---|---|---|---|---|
| 1.00E-02 | 5.00E-03 | 1.00E-03 | 5.00E-04 | 1.00E-04 |
| 4.59E-02 (1.05E-01)−+ | 2.89E-02 (5.68E-02)−+ | 6.09E-03 (7.92E-03)−+ | 2.36E-03 (3.99E-03)−+ | 1.19E-04 (2.05E-04)−+ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.61E+01 (2.60E+01)++ | 4.93E+01 (2.21E+01)≈≈ | 5.08E+01 (2.02E+01)≈≈ | 5.66E+01 (1.07E+01)≈≈ | 5.09E+01 (2.03E+01)≈≈ |
| 2.00E+01 (4.83E-02)++ | 2.00E+01 (1.23E-02)++ | 2.00E+01 (6.00E-03)++ | 2.00E+01 (3.55E-03)++ | 2.00E+01 (3.58E-05)++ |
| 1.79E+00 (1.80E+00)≈ − | 1.89E+00 (1.46E+00)≈ − | 1.95E+00 (1.71E+00)≈ − | 1.52E+00 (1.64E+00)≈ − | 1.82E+00 (1.48E+00)≈ − |
| 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ | 0.00E+00 (0.00E+00)≈≈ |
| 1.26E+00 (1.22E+00)+− | 4.31E-01 (6.75E-01)+− | 9.95E-02 (3.04E-01)+≈ | 3.32E-02 (1.82E-01)+≈ | 0.00E+00 (0.00E+00)+≈ |
| 3.12E+01 (7.47E+00)+− | 4.40E+01 (1.33E+01)≈ − | 4.28E+01 (1.74E+01)≈ − | 4.24E+01 (1.68E+01)≈ − | 4.42E+01 (1.33E+01)≈ − |
| 4.97E-01 (1.08E+00)≈ ≈ | 1.69E+00 (1.94E+00)≈ − | 2.50E+00 (2.84E+00)≈ − | 1.91E+00 (1.84E+00)≈ − | 7.81E-01 (6.43E-01)≈ − |
| 1.83E+03 (4.12E+02)+≈ | 2.12E+03 (5.51E+02)+− | 2.53E+03 (4.56E+02)−− | 2.48E+03 (5.25E+02)≈ − | 2.55E+03 (5.62E+02)≈ − |
| 1.94E-02 (8.74E-03)+≈ | 5.29E-03 (3.29E-03)++ | 2.59E-03 (3.28E-03)++ | 7.70E-03 (4.96E-03)++ | 3.22E-02 (2.18E-02)≈≈ |
| 1.51E-01 (2.97E-02)−≈ | 1.46E-01 (2.87E-02)−≈ | 1.33E-01 (2.47E-02)−≈ | 1.19E-01 (2.73E-02)−≈ | 1.29E-01 (3.19E-02)−≈ |
| 1.71E-01 (2.27E-02)−≈ | 1.64E-01 (2.34E-02)≈≈ | 1.65E-01 (2.20E-02)≈≈ | 1.63E-01 (2.24E-02)≈ + | 1.68E-01 (3.33E-02)≈ − |
| 2.29E+00 (4.30E-01)+≈ | 2.18E+00 (3.85E-01)+≈ | 2.45E+00 (7.40E-01)+≈ | 3.25E+00 (9.75E-01)≈ − | 3.37E+00 (1.03E+00)≈ − |
| 8.88E+00 (5.48E-01)++ | 8.81E+00 (8.96E-01)++ | 9.86E+00 (7.82E-01)+− | 1.00E+01 (7.17E-01)+− | 1.03E+01 (8.65E-01)≈ − |
| 7.96E+01 (5.84E+01)++ | 1.29E+02 (9.82E+01)+≈ | 2.71E+02 (1.83E+02)≈ − | 3.56E+02 (2.15E+02)≈ − | 3.29E+02 (2.03E+02)≈ − |
| 7.38E+00 (2.29E+00)≈ + | 6.50E+00 (2.49E+00)++ | 8.12E+00 (1.98E+00)≈ + | 8.67E+00 (3.03E+00)≈≈ | 1.22E+01 (5.10E+00)−− |
| 2.58E+00 (4.04E-01)≈ + | 2.73E+00 (6.26E-01)≈ + | 2.95E+00 (6.79E-01)−+ | 2.91E+00 (6.59E-01)− ≈ | 3.04E+00 (5.42E-01)− ≈ |
| 4.50E+00 (1.18E+00)+≈ | 4.87E+00 (1.25E+00)≈≈ | 5.81E+00 (2.21E+00)≈ − | 6.87E+00 (3.49E+00)≈ − | 8.17E+00 (3.25E+00)−− |
| 7.38E+01 (9.71E+01)− | 5.66E+01 (6.91E+01)≈ − | 1.12E+02 (9.14E+01)− | 1.28E+02 (1.04E+02)≈ − | 1.66E+02 (9.93E+01)≈ − |
| 3.31E+01 (2.37E+01)+ | 4.10E+01 (3.61E+01)≈ | 4.91E+01 (4.13E+01)≈ | 4.43E+01 (3.15E+01)≈ | 5.98E+01 (5.08E+01)≈ − |
| 3.36E+02 (1.39E-13)≈≈ | 3.36E+02 (1.18E-13)≈≈ | 3.36E+02 (1.46E-13)≈≈ | 3.36E+02 (1.46E-13)≈≈ | 3.36E+02 (1.19E-13)≈≈ |
| 2.01E+02 (4.47E-02)− | 1.97E+02 (1.36E+01)+≈ | 2.01E+02 (6.55E-02)−+ | 2.00E+02 (2.69E+00)++ | 2.01E+02 (5.02E-02)−+ |
| 2.00E+02 (9.26E-01)≈≈ | 2.00E+02 (1.03E+00)≈≈ | 2.00E+02 (9.38E-01)≈≈ | 2.00E+02 (1.01E+00)≈≈ | 2.00E+02 (8.78E-01)≈≈ |
| 1.00E+02 (2.96E-02)−+ | 1.00E+02 (2.73E-02)−+ | 1.00E+02 (2.79E-02)−+ | 1.00E+02 (2.24E-02)−+ | 1.00E+02 (2.96E-02)−+ |
| 3.53E+02 (4.57E+01)− | 3.56E+02 (4.63E+01)≈ − | 3.47E+02 (4.19E+01)− | 3.43E+02 (4.06E+01)≈ − | 3.37E+02 (3.84E+01)≈ − |
| 4.16E+02 (2.74E+00)+− | 4.18E+02 (3.24E+00)≈ − | 4.20E+02 (4.48E+00)≈ − | 4.20E+02 (4.02E+00)≈ − | 4.20E+02 (3.46E+00)≈ − |
| 4.26E+02 (5.92E-01)≈≈ | 4.26E+02 (3.00E-01)≈≈ | 4.29E+02 (7.01E+00)≈≈ | 4.28E+02 (3.67E+00)≈≈ | 4.29E+02 (4.13E+00)−− |
| 3.90E+02 (1.05E+01)≈≈ | 3.91E+02 (9.36E+00)+≈ | 4.14E+02 (3.01E+01)−− | 4.24E+02 (4.25E+01)−− | 4.31E+02 (4.19E+01)−− |

Table 17: The results of the three versions of NDE for the CEC 2014 benchmark test suite. The symbol behind the results based on complete restart shows the difference to the original results, while the two symbols behind the results with individuals redistribution show the difference to the original results and the results with complete restart, respectively. "+" and "−" denote significantly better and statistically worse than the peer in terms of Wilcoxon's rank sum test at a 0.05 significance level, respectively. Meanwhile, "≈" represents no significantly difference