Table 1: Results of experiments with different strategies

|  |  |  |  |
| --- | --- | --- | --- |
| Function | CSA | CSA+FPA (without Tent Chaos to the initial position) | CSA+FPA+ Cauchy Mutation (without Tent Chaos to the initial position) |
| *f1* | 1.43E-02 | 1.01E+03 | 2.90E-94 |
| *f2* | 1.40E+00 | 9.04E+00 | 5.31E-48 |
| *f3* | 2.62E+00 | 1.37E+01 | 1.04E-47 |
| *f4* | 8.61E+02 | 3.18E+03 | 9.65E-95 |
| *f5* | 2.17E-02 | 1.35E-01 | 3.43E-04 |
| *f6* | 1.47E+03 | 2.41E+03 | 2.30E-92 |
| *f7* | 2.54E+04 | 3.03E+05 | 1.39E-90 |
| *f8* | 2.18E+01 | 7.79E+01 | 0.00E+00 |
| *f9* | 3.29E+00 | 8.99E+00 | 8.88E-16 |
| *f10* | 9.90E-02 | 9.84E+00 | 0.00E+00 |
| *f11* | 2.15E-01 | 4.60E+00 | 1.37E-49 |
| *f12* | 6.01E-01 | 4.55E+01 | 1.21E-95 |
| *f13* | 7.77E-01 | 3.21E+00 | 1.26E-01 |
| *f14* | 2.04E+01 | 1.14E+04 | 1.30E+00 |
| *f15* | 9.72E-04 | 3.89E-03 | 0.00E+00 |
| *f16* | 4.01E-25 | 0.00E+00 | 1.52E-30 |
| *f17* | 0.00037 | 0.00034 | 0.00030 |
| *f18* | 2.35E-25 | 2.78E-163 | 2.90E-182 |
| *f19* | 0.398 | 0.398 | 0.398 |
| *f20* | 3.00E+00 | 3.00E+00 | 3.00E+00 |

Table 2: Results of high-dimensional unimodal benchmark functions

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Function | Index | BOA | SSA | GWO | CSA | MISCSA | IFCSA |
|  | Best | 1.53E-14 | 5.66E-09 | 1.40E-68 | 3.41E-03 | 7.59E-33 | **2.26E-102** |
| Worst | 1.85E-14 | 1.40E-08 | 1.26E-72 | 3.73E-02 | 7.83E-30 | 1.03E-89 |
| Mean | 1.69E-14 | 8.84E-09 | 9.11E-70 | 1.36E-02 | 7.98E-31 | 6.03E-91 |
| Std | 9.60E-16 | 1.74E-09 | 2.82E-69 | 7.20E-03 | 1.56E-30 | 2.03E-90 |
| Rank | 4 | 5 | 2 | 6 | 3 | 1 |
|  | Best | 2.02E-12 | 1.56E-04 | 3.43E-42 | 3.80E-01 | 3.85E-17 | **1.69E-50** |
| Worst | 1.17E-11 | 3.05E+00 | 4.46E-40 | 2.75E+00 | 2.02E-15 | 4.66E-43 |
| Mean | 9.19E-12 | 6.77E-01 | 6.50E-41 | 1.47E+00 | 4.55E-16 | 1.56E-44 |
| Std | 2.97E-12 | 7.52E-01 | 9.17E-41 | 6.29E-01 | 4.20E-16 | 8.51E-44 |
| Rank | 4 | 5 | 2 | 6 | 3 | 1 |
|  | Best | 1.01E-11 | 8.78E-01 | 1.46E-18 | 1.22E+00 | 5.80E-17 | **1.57E-50** |
| Worst | 1.27E-11 | 9.46E+00 | 6.98E-17 | 5.48E+00 | 2.28E-15 | 4.79E-44 |
| Mean | 1.15E-11 | 4.50E+00 | 1.25E-17 | 3.09E+00 | 5.24E-16 | 2.87E-45 |
| Std | 6.68E-13 | 2.38E+00 | 1.57E-17 | 1.02E+00 | 5.20E-16 | 1.06E-44 |
| Rank | 4 | 5 | 2 | 6 | 3 | 1 |
|  | Best | 1.48E-14 | 5.93E+00 | 4.57E-26 | 4.07E+02 | 1.06E-30 | **4.02E-100** |
| Worst | 1.89E-14 | 2.51E+02 | 4.53E-17 | 1.53E+03 | 1.33E-27 | 1.38E-88 |
| Mean | 1.70E-14 | 6.46E+01 | 1.55E-18 | 8.79E+02 | 2.52E-28 | 6.89E-90 |
| Std | 9.12E-16 | 5.98E+01 | 8.27E-18 | 3.26E+02 | 3.93E-28 | 2.59E-89 |
| Rank | 4 | 5 | 3 | 6 | 2 | 1 |
|  | Best | 8.80E-05 | 2.27E-02 | 9.33E-05 | 7.07E-03 | **6.38E-06** | 9.98E-06 |
| Worst | 1.18E-03 | 1.16E-01 | 1.35E-03 | 3.99E-02 | 3.53E-04 | 3.39E-04 |
| Mean | 5.96E-04 | 5.79E-02 | 5.17E-04 | 2.09E-02 | 5.35E-05 | 9.12E-05 |
| Std | 3.01E-04 | 2.28E-02 | 3.35E-04 | 7.87E-03 | 6.36E-05 | 7.17E-05 |
| Rank | 3 | 6 | 4 | 5 | 1 | 2 |
|  | Best | 1.34E-14 | 3.45E+03 | 7.91E-72 | 6.67E+02 | 5.90E-30 | **2.17E-97** |
| Worst | 1.81E-14 | 3.09E+04 | 1.18E-68 | 2.62E+03 | 6.76E-27 | 7.54E-88 |
| Mean | 1.61E-14 | 8.82E+03 | 1.08E-69 | 1.45E+03 | 9.79E-28 | 2.71E-89 |
| Std | 1.13E-15 | 5.69E+03 | 2.77E-69 | 5.15E+02 | 1.53E-27 | 1.38E-88 |
| Rank | 4 | 6 | 2 | 5 | 3 | 1 |
|  | Best | 1.49E-14 | 4.97E+04 | 1.44E-70 | 7.57E+03 | 6.03E-29 | **1.63E-95** |
| Worst | 1.90E-14 | 3.65E+05 | 2.08E-67 | 5.13E+04 | 1.23E-25 | 1.34E-87 |
| Mean | 1.74E-14 | 1.57E+05 | 2.30E-68 | 2.19E+04 | 8.07E-27 | 1.26E-88 |
| Std | 1.08E-15 | 8.29E+04 | 4.33E-68 | 9.20E+03 | 2.40E-26 | 2.94E-88 |
| Rank | 4 | 6 | 2 | 5 | 3 | 1 |

Table 3: Results of high-dimensional multimodal benchmark functions

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Function | Index | BOA | SSA | GWO | CSA | MISCSA | IFCSA |
|  | Best | **0.00E+00** | 2.49E+01 | **0.00E+00** | 1.09E+01 | **0.00E+00** | **0.00E+00** |
| Worst | 2.10E+02 | 7.46E+01 | 4.51E+00 | 4.08E+01 | 0.00E+00 | 0.00E+00 |
| Mean | 1.24E+01 | 4.60E+01 | 1.50E-01 | 2.27E+01 | 0.00E+00 | 0.00E+00 |
| Std | 4.76E+01 | 1.27E+01 | 8.24E-01 | 8.63E+00 | 0.00E+00 | 0.00E+00 |
| Rank | 1 | 6 | 1 | 5 | 1 | 1 |
|  | Best | 6.05E-12 | 1.78E+00 | 7.99E-15 | 1.91E+00 | **8.88E-16** | **8.88E-16** |
| Worst | 1.32E-11 | 3.63E+00 | 1.51E-14 | 4.70E+00 | 8.88E-16 | 8.88E-16 |
| Mean | 1.12E-11 | 1.78E+00 | 1.31E-14 | 3.30E+00 | 8.88E-16 | 8.88E-16 |
| Std | 1.39E-12 | 8.54E-01 | 2.59E-15 | 6.50E-01 | 0.00E+00 | 0.00E+00 |
| Rank | 4 | 5 | 3 | 6 | 1 | 1 |
|  | Best | **0.00E+00** | 2.27E-08 | **0.00E+00** | 3.11E-02 | **0.00E+00** | **0.00E+00** |
| Worst | 3.66E-15 | 4.91E-02 | 1.35E-02 | 2.58E-01 | 0.00E+00 | 0.00E+00 |
| Mean | 9.25E-16 | 1.01E-02 | 1.10E-03 | 1.05E-01 | 0.00E+00 | 0.00E+00 |
| Std | 1.05E-15 | 1.17E-02 | 3.43E-03 | 4.18E-02 | 0.00E+00 | 0.00E+00 |
| Rank | 1 | 6 | 1 | 5 | 1 | 1 |
|  | Best | 1.52E-15 | 5.72E-02 | 1.57E-41 | 6.60E-03 | 4.12E-18 | **1.88E-52** |
| Worst | 1.24E-12 | 4.92E+00 | 5.50E-04 | 5.17E-01 | 5.08E-17 | 1.08E-46 |
| Mean | 4.70E-14 | 1.73E+00 | 2.21E-05 | 1.04E-01 | 1.91E-16 | 7.20E-48 |
| Std | 2.25E-13 | 1.15E+00 | 1.00E-04 | 1.45E-01 | 3.83E-17 | 2.24E-47 |
| Rank | 4 | 5 | 2 | 6 | 3 | 1 |
|  | Best | 9.11E-15 | 9.43E-02 | 1.45E-07 | 2.82E-01 | 2.49E-34 | **1.79E-103** |
| Worst | 1.65E-14 | 1.17E+00 | 1.17E-05 | 1.94E+00 | 1.21E-30 | 5.87E-92 |
| Mean | 1.39E-14 | 4.51E-01 | 2.80E-06 | 6.99E-01 | 1.14E-31 | 2.86E-93 |
| Std | 1.70E-15 | 2.98E-01 | 2.77E-06 | 3.74E-01 | 2.24E-31 | 1.12E-92 |
| Rank | 3 | 5 | 4 | 6 | 2 | 1 |
|  | Best | 1.51E+00 | 2.69E-01 | 7.22E-01 | 2.70E-01 | 6.31E-01 | **1.37E-04** |
| Worst | 2.52E+00 | 1.27E+01 | 1.27E+00 | 3.21E+00 | 2.34E+00 | 8.21E-01 |
| Mean | 2.00E+00 | 6.61E+00 | 9.89E-01 | 1.06E+00 | 1.47E+00 | 5.99E-02 |
| Std | 2.47E-01 | 3.05E+00 | 1.52E-01 | 7.62E-01 | 3.94E-01 | 1.68E-01 |
| Rank | 6 | 2 | 5 | 3 | 4 | 1 |
|  | Best | 1.55E+00 | **2.91E-10** | 1.43E-05 | 4.90E+00 | 1.40E+00 | 1.60E-03 |
| Worst | 3.00E+00 | 1.10E-01 | 6.23E-01 | 3.95E+01 | 4.22E+00 | 2.90E+00 |
| Mean | 2.57E+00 | 7.93E-03 | 3.16E-01 | 2.03E+01 | 2.92E+00 | 7.19E-01 |
| Std | 3.50E-01 | 2.07E-02 | 1.52E-01 | 9.93E+00 | 7.59E-01 | 6.88E-01 |
| Rank | 5 | 1 | 2 | 6 | 4 | 3 |

Table 4: Results of fixed-dimensional multimodal benchmark functions

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Function | Index | BOA | SSA | GWO | CSA | MISCSA | IFCSA |
|  | Best | 3.33E-16 | 8.66E-15 | **0.00E+00** | **0.00E+00** | **0.00E+00** | **0.00E+00** |
| Worst | 1.02E-02 | 9.72E-03 | 9.72E-03 | 9.72E-03 | 0.00E+00 | 0.00E+00 |
| Mean | 8.15E-03 | 1.94E-03 | 2.27E-03 | 7.00E-04 | 0.00E+00 | 0.00E+00 |
| Std | 3.71E-03 | 3.95E-03 | 4.18E-03 | 2.46E-03 | 0.00E+00 | 0.00E+00 |
| Rank | 5 | 6 | 1 | 1 | 1 | 1 |
|  | Best | 1.55E-05 | 4.57E-18 | 1.29E-09 | 3.68E-27 | **0.00E+00** | **0.00E+00** |
| Worst | 3.98E-01 | 5.52E-15 | 2.37E-07 | 7.56E-24 | 1.40E-28 | 0.00E+00 |
| Mean | 8.38E-02 | 1.03E-15 | 3.28E-08 | 7.73E-25 | 5.56E-30 | 0.00E+00 |
| Std | 1.26E-01 | 1.34E-15 | 4.51E-08 | 1.54E-24 | 2.56E-29 | 0.00E+00 |
| Rank | 6 | 4 | 5 | 3 | 1 | 1 |
|  | Best | 0.00031 | 0.00031 | **0.00030** | **0.00030** | 0.00031 | **0.00030** |
| Worst | 0.00038 | 0.00124 | 0.02036 | 0.00122 | 0.00133 | 0.00122 |
| Mean | 0.00033 | 0.00081 | 0.00381 | 0.00034 | 0.00043 | 0.00037 |
| Std | 0.00002 | 0.00026 | 0.00754 | 0.00017 | 0.00020 | 0.00023 |
| Rank | 4 | 4 | 1 | 1 | 4 | 1 |
|  | Best | 2.29E-19 | 7.08E-18 | **0.00E+00** | 7.24E-28 | 1.22E-43 | 2.41E-177 |
| Worst | 2.61E-17 | 2.86E-15 | 0.00E+00 | 1.04E-24 | 7.79E-41 | 4.06E-166 |
| Mean | 6.01E-18 | 7.11E-16 | 0.00E+00 | 1.88E-25 | 1.19E-41 | 1.45E-167 |
| Std | 7.05E-18 | 7.43E-16 | 0.00E+00 | 2.45E-25 | 1.70E-41 | 0.00E+00 |
| Rank | 5 | 6 | 1 | 4 | 3 | 2 |
|  | Best | **0.398** | **0.398** | **0.398** | **0.398** | **0.398** | **0.398** |
| Worst | 1.212 | 0.398 | 0.398 | 0.398 | 0.398 | 0.398 |
| Mean | 0.441 | 0.398 | 0.398 | 0.398 | 0.398 | 0.398 |
| Std | 1.532E-01 | 2.410E-15 | 1.252E-07 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| Rank | 1 | 1 | 1 | 1 | 1 | 1 |
|  | Best | 3.0002 | **3.0000** | **3.0000** | **3.0000** | **3.0000** | **3.0000** |
| Worst | 3.2338 | 3.0000 | 3.0000 | 3.0000 | 3.0000 | 3.0000 |
| Mean | 3.0297 | 3.0000 | 3.0000 | 3.0000 | 3.0000 | 3.0000 |
| Std | 5.10E-02 | 7.55E-14 | 3.91E-06 | 1.47E-15 | 1.65E-15 | 1.37E-15 |
| Rank | 6 | 1 | 1 | 1 | 1 | 1 |

Table 5: Wilcoxon rank sum test and *p-value*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Function | IFCSA/BOA | IFCSA/SSA | IFCSA/GWO | IFCSA/CSA | IFCSA/MISCSA |
| *f1* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f2* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f3* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f4* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f5* | 1.33E-10 | 3.02E-11 | 3.82E-10 | 3.02E-11 | 5.57E-03 |
| *f6* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f7* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f8* | 2.16E-02 | 1.21E-12 | **8.15E-02** | 1.21E-12 | NA |
| *f9* | 1.21E-12 | 1.21E-12 | 5.47E-13 | 1.21E-12 | NA |
| *f10* | 1.93E-09 | 1.21E-12 | **8.15E-02** | 1.21E-12 | NA |
| *f11* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f12* | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 | 3.02E-11 |
| *f13* | 3.02E-11 | 3.69E-11 | 6.07E-11 | 1.61E-10 | 1.61E-10 |
| *f14* | 5.57E-10 | 2.44E-09 | 7.62E-03 | 3.02E-11 | 2.61E-10 |
| *f15* | 1.21E-12 | 1.21E-12 | 5.58E-03 | 1.37E-03 | NA |
| *f16* | 1.21E-12 | 1.21E-12 | 1.21E-12 | 1.21E-12 | 5.83E-09 |
| *f17* | 8.15E-09 | 2.34E-09 | 1.35E-09 | 6.76E-09 | 6.84E-09 |
| *f18* | 3.02E-11 | 3.02E-11 | 1.21E-12 | 1.21E-12 | 1.21E-12 |
| *f19* | 1.21E-12 | 3.09E-04 | 1.21E-12 | NA | NA |
| *f20* | 1.10E-11 | 1.10E-11 | 1.10E-11 | 1.35E-06 | 3.55E-06 |

Table 10: Test results of different algorithms for Speed Reducer Design

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | IFCSA | CSO [27] | Gandomi et al [28] | ABC [29] | Akhtar et al [30] | Montes and Coello [31] |
| Best | **2896.26** | 2996.60 | 3000.98 | 2997.06 | 3008.08 | 3025.01 |
|  | 3.500000 | 3.500000 | 3.501500 | 3.499999 | 3.506122 | 3.506163 |
|  | 0.700000 | 0.700000 | 0.700000 | 0.700000 | 0.700006 | 0.700831 |
|  | 17.00000 | 17.00000 | 17.00000 | 17.00000 | 17.00000 | 17.00000 |
|  | 7.300000 | 7.308000 | 7.605000 | 7.300000 | 7.549126 | 7.460181 |
|  | 7.800000 | 7.802000 | 7.818100 | 7.800000 | 7.859330 | 7.962143 |
|  | 2.900000 | 3.350000 | 3.352000 | 3.350215 | 3.365576 | 3.362900 |
|  | 5.286683 | 5.287000 | 5.287500 | 5.287800 | 5.289773 | 5.309000 |