

Supplementary Materials

Multi-strategy secretary bird optimization algorithm for threshold segmentation of cardiac CT images

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S1. Characteristics of the CEC2022 and CEC2017 Benchmarking Functions

1. Introduction

Table S1 and Table S2 provide information on the CEC2022 and CEC2017 benchmark functions used in the experiments, including function types, search space boundaries, and desired optimal solutions.

Table S1

Characteristics of the CEC2017 benchmark test functions.

	No.	Functions	Range	f_{opt}
Unimodal Functions	f_1	Shifted and Rotated Bent Cigar Function	[-100, 100]	100
	f_3	Shifted and Rotated Zakharov Function	[-100, 100]	200
Simple Multimodal Functions	f_4	Shifted and Rotated Rosenbrock's Function	[-100, 100]	300
	f_5	Shifted and Rotated Rastrigin's Function	[-100, 100]	400
	f_6	Shifted and Rotated Expanded Scaffer's F6 Function	[-100, 100]	500
	f_7	Shifted and Rotated Lunacek Bi_Rastrigin Function	[-100, 100]	600
	f_8	Shifted and Rotated Non-Continuous Rastrigin's Function	[-100, 100]	700
	f_9	Shifted and Rotated Levy Function	[-100, 100]	800
	f_{10}	Shifted and Rotated Schwefel's Function	[-100, 100]	900
	f_{11}	Hybrid Function 1 ($N = 3$)	[-100, 100]	1000
	f_{12}	Hybrid Function 2 ($N = 3$)	[-100, 100]	1100
	f_{13}	Hybrid Function 3 ($N = 3$)	[-100, 100]	1200
Hybrid Functions	f_{14}	Hybrid Function 4 ($N = 4$)	[-100, 100]	1300
	f_{15}	Hybrid Function 5 ($N = 4$)	[-100, 100]	1400
	f_{16}	Hybrid Function 6 ($N = 4$)	[-100, 100]	1500
	f_{17}	Hybrid Function 6 ($N = 5$)	[-100, 100]	1600
	f_{18}	Hybrid Function 6 ($N = 5$)	[-100, 100]	1700
	f_{19}	Hybrid Function 6 ($N = 5$)	[-100, 100]	1800
	f_{20}	Hybrid Function 6 ($N = 6$)	[-100, 100]	1900
	f_{21}	Composition Function 1($N = 3$)	[-100, 100]	2000
	f_{22}	Composition Function 2($N = 3$)	[-100, 100]	2100
	f_{23}	Composition Function 3($N = 4$)	[-100, 100]	2200
Composition Functions	f_{24}	Composition Function 4($N = 4$)	[-100, 100]	2300
	f_{25}	Composition Function 5($N = 5$)	[-100, 100]	2400
	f_{26}	Composition Function 6($N = 5$)	[-100, 100]	2500
	f_{27}	Composition Function 7($N = 6$)	[-100, 100]	2600
	f_{28}	Composition Function 8($N = 6$)	[-100, 100]	2700
	f_{29}	Composition Function 9($N = 3$)	[-100, 100]	2800
	f_{30}	Composition Function 10($N = 3$)	[-100, 100]	2900

*Dimensions: $D=10, 30, 50$ and 100 , f_{opt} : Optimal solution.

Table S2

Characteristics of the CEC2022 benchmark test functions.

	No.	Functions	Range	f_{opt}
Unimodal Function	f_1	Shifted and Rotated Bent Cigar Function	$[-100, 100]$	300
Basic Functions	f_2	Shifted and Rotated Zakharov Function	$[-100, 100]$	400
	f_3	Shifted and Rotated Rosenbrock's Function	$[-100, 100]$	600
	f_4	Shifted and full Rotated Non-Continuous Rastrigin's Function	$[-100, 100]$	800
	f_5	Shifted and full Rotated Levy Function	$[-100, 100]$	900
Hybrid Functions	f_6	Hybrid Function 1 ($N = 3$)	$[-100, 100]$	1800
	f_7	Hybrid Function 2 ($N = 6$)	$[-100, 100]$	2000
	f_8	Hybrid Function 3 ($N = 5$)	$[-100, 100]$	2200
Composition Functions	f_9	Composition Function 1($N = 5$)	$[-100, 100]$	2300
	f_{10}	Composition Function 2($N = 4$)	$[-100, 100]$	2400
	f_{11}	Composition Function 3($N = 5$)	$[-100, 100]$	2600
	f_{12}	Composition Function 4($N = 6$)	$[-100, 100]$	2700

*Dimensions: $D=10$ and 20 , f_{opt} : Optimal solution.

S2. Experimental results on the CEC2017 benchmark function

This section presents experimental results for the MAHSBOA algorithm and eight other algorithms on 29 functions within the CEC2017 benchmark suite, covering 10-dimensional, 30-dimensional, 50-dimensional, and 100-dimensional scenarios. The results are shown in Tables S3, S4, S5, and S6, respectively.

Table S3: Experimental results on the CEC2017 benchmark function with 10 dimensions (f_1, f_3-f_{30}).

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_1	Mean	6.8921E+02	3.8413E+03	9.6920E+05	3.8495E+09	6.5347E+07	2.0419E+03	6.8918E+09	3.3701E+03	1.9080E+03
	Std	9.6151E+02	2.7669E+03	2.5740E+05	1.8914E+09	2.1415E+08	2.4883E+03	2.0917E+09	3.5724E+03	2.4937E+03
	Best	1.0009E+02	1.2750E+02	3.8652E+05	1.0694E+09	3.7289E+03	1.0001E+02	2.3881E+09	1.0036E+02	1.0000E+02
	Rank	1	5	6	8	7	3	9	4	2
f_3	Mean	3.0000E+02	3.0000E+02	1.3981E+03	9.4726E+03	7.5177E+02	3.0000E+02	1.8026E+04	3.0000E+02	4.4394E+02
	Std	2.5856E-14	1.0556E-14	4.3834E+02	3.6160E+03	2.4270E+03	6.9670E-10	3.2509E+03	2.9095E-09	3.8061E+02
	Best	3.0000E+02	3.0000E+02	3.9476E+02	2.4975E+03	3.0016E+02	3.0000E+02	1.1973E+04	3.0000E+02	3.0000E+02
	Rank	1.5	1.5	7	8	6	3	9	4	5
f_4	Mean	4.0024E+02	4.0052E+02	4.0217E+02	6.4826E+02	4.1726E+02	4.0182E+02	9.4779E+02	4.0171E+02	4.0479E+02
	Std	1.2725E-01	3.5912E-01	6.5132E-01	1.9141E+02	2.6872E+01	8.3793E-01	1.2627E+02	1.2751E+00	2.2340E+00
	Best	4.0001E+02	4.0000E+02	4.0110E+02	4.7218E+02	4.0001E+02	4.0007E+02	6.7527E+02	4.0000E+02	4.0003E+02
	Rank	1	2	5	8	7	4	9	3	6
f_5	Mean	5.0649E+02	5.0752E+02	5.1857E+02	5.5692E+02	5.3681E+02	5.2831E+02	5.9482E+02	5.1712E+02	5.0509E+02
	Std	1.4625E+00	4.0965E+00	8.1468E+00	1.1182E+01	1.8686E+01	1.4248E+01	1.1422E+01	8.7169E+00	2.5860E+00
	Best	5.0293E+02	5.0199E+02	5.0456E+02	5.3709E+02	5.0611E+02	5.0696E+02	5.7519E+02	5.0497E+02	5.0099E+02
	Rank	2	3	5	8	7	6	9	4	1
f_6	Mean	6.0000E+02	6.0002E+02	6.0090E+02	6.2862E+02	6.1672E+02	6.0386E+02	6.5744E+02	6.0252E+02	6.0000E+02
	Std	0.0000E+00	1.1639E-01	1.4255E-01	7.6429E+00	9.0756E+00	5.6813E+00	5.8557E+00	2.4635E+00	2.8720E-06
	Best	6.0000E+02	6.0000E+02	6.0067E+02	6.1630E+02	6.0565E+02	6.0000E+02	6.4426E+02	6.0000E+02	6.0000E+02
	Rank	1	3	4	8	7	6	9	5	2
f_7	Mean	7.1755E+02	7.1854E+02	7.4173E+02	7.6670E+02	7.4115E+02	7.3910E+02	8.7827E+02	7.3229E+02	7.1412E+02
	Std	1.8371E+00	5.0019E+00	4.9401E+00	1.4079E+01	1.8938E+01	1.5117E+01	1.5982E+01	9.3673E+00	2.0195E+00
	Best	7.1435E+02	7.1172E+02	7.2173E+02	7.4352E+02	7.1547E+02	7.1338E+02	8.1187E+02	7.1721E+02	7.1079E+02
	Rank	2	3	7	8	6	5	9	4	1
f_8	Mean	8.0565E+02	8.0707E+02	8.2190E+02	8.3510E+02	8.2592E+02	8.2305E+02	8.8835E+02	8.2080E+02	8.0508E+02
	Std	1.3479E+00	3.6235E+00	5.4986E+00	7.8361E+00	1.0149E+01	1.1399E+01	5.6203E+00	8.6910E+00	2.1962E+00
	Best	8.0300E+02	8.0298E+02	8.1096E+02	8.1977E+02	8.0827E+02	8.0497E+02	8.7789E+02	8.0597E+02	8.0099E+02
	Rank	2	3	5	8	7	6	9	4	1
f_9	Mean	9.0000E+02	9.0000E+02	9.0053E+02	1.1368E+03	9.6622E+02	1.0385E+03	2.3492E+03	9.0163E+02	9.0006E+02
	Std	0.0000E+00	1.6346E-02	1.5360E-01	1.1997E+02	1.1222E+02	2.0273E+02	3.1674E+02	5.0169E+00	3.1530E-01
	Best	9.0000E+02	9.0000E+02	9.0031E+02	9.6044E+02	9.0845E+02	9.0045E+02	1.5763E+03	9.0000E+02	9.0000E+02
	Rank	1	2	4	8	6	7	9	5	3
f_{10}	Mean	1.1937E+03	1.3004E+03	1.7255E+03	2.3475E+03	2.1822E+03	2.0506E+03	2.9800E+03	1.6335E+03	1.4533E+03
	Std	1.3435E+02	2.1558E+02	3.8462E+02	2.3222E+02	3.1844E+02	3.1568E+02	2.1379E+02	2.6591E+02	2.4380E+02
	Best	1.0103E+03	1.0036E+03	1.1581E+03	1.9284E+03	1.6007E+03	1.4795E+03	2.2887E+03	1.1652E+03	1.0418E+03
	Rank	1	2	5	8	7	6	9	4	3
f_{11}	Mean	1.1029E+03	1.1033E+03	1.1109E+03	2.2332E+03	1.2675E+03	1.1456E+03	2.0785E+03	1.1290E+03	1.1039E+03

Table S3 (continued)

Table S3 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{12}	Std	8.4407E-01	1.5107E+00	2.6046E+00	1.2659E+03	1.9321E+02	3.2303E+01	4.8689E+02	1.6250E+01	2.0574E+00
	Best	1.1017E+03	1.1013E+03	1.1062E+03	1.1603E+03	1.1156E+03	1.1022E+03	1.3611E+03	1.1085E+03	1.1008E+03
	Rank	1	2	4	9	7	6	8	5	3
	Mean	2.2201E+04	1.8862E+04	5.6476E+04	1.2078E+07	1.4909E+06	1.1129E+04	3.2264E+08	1.5033E+05	7.0904E+03
	Std	1.9601E+04	1.5420E+04	2.5387E+04	2.0208E+07	4.4452E+06	1.0125E+04	1.5673E+08	1.6005E+05	9.7454E+03
f_{13}	Best	2.1465E+03	1.7118E+03	1.0373E+04	2.3439E+05	3.2151E+03	1.7367E+03	3.8577E+07	6.6670E+03	1.3352E+03
	Rank	4	3	5	8	7	2	9	6	1
	Mean	1.3756E+03	2.1320E+03	2.7267E+03	2.7325E+05	3.9309E+03	5.8160E+03	2.7977E+06	4.1500E+03	1.3076E+03
	Std	1.2185E+02	8.4954E+02	9.7621E+02	5.9662E+05	9.2364E+03	2.3681E+03	2.9218E+06	2.4736E+03	7.5073E+00
	Best	1.3120E+03	1.4158E+03	1.8563E+03	1.9559E+03	1.5661E+03	1.3823E+03	4.4562E+05	1.9406E+03	1.3000E+03
f_{14}	Rank	2	3	4	8	5	7	9	6	1
	Mean	1.4082E+03	1.4239E+03	1.4674E+03	5.7964E+03	1.5547E+03	1.1238E+04	4.8842E+03	1.4986E+03	1.8400E+03
	Std	4.0818E+00	1.2171E+01	1.8377E+01	2.4210E+03	3.6049E+02	7.0292E+03	4.2112E+03	2.9649E+01	2.2925E+03
	Best	1.4029E+03	1.4035E+03	1.4420E+03	2.0527E+03	1.4296E+03	2.2114E+03	1.9615E+03	1.4504E+03	1.4000E+03
	Rank	1	2	3	8	5	9	7	4	6
f_{15}	Mean	1.5052E+03	1.5174E+03	1.6343E+03	7.6039E+03	1.7550E+03	9.1011E+03	3.3267E+04	2.0427E+03	1.5015E+03
	Std	2.5187E+00	1.1921E+01	4.9081E+01	2.8250E+03	3.5457E+02	6.2444E+03	2.5355E+04	4.9491E+02	1.6651E+00
	Best	1.5020E+03	1.5030E+03	1.5695E+03	3.8484E+03	1.5198E+03	1.6596E+03	1.1353E+04	1.5717E+03	1.5002E+03
	Rank	2	3	4	7	5	8	9	6	1
	Mean	1.6009E+03	1.6112E+03	1.6311E+03	1.9698E+03	1.7985E+03	1.8295E+03	2.1800E+03	1.6563E+03	1.6372E+03
f_{16}	Std	2.4448E-01	3.0097E+01	3.4858E+01	9.6878E+01	1.8204E+02	1.1857E+02	1.5940E+02	4.4042E+01	5.6846E+01
	Best	1.6005E+03	1.6011E+03	1.6022E+03	1.7841E+03	1.6036E+03	1.6017E+03	1.7675E+03	1.6058E+03	1.6005E+03
	Rank	1	2	3	8	6	7	9	5	4
	Mean	1.7022E+03	1.7228E+03	1.7401E+03	1.7832E+03	1.7846E+03	1.7550E+03	1.9105E+03	1.7605E+03	1.7091E+03
	Std	3.7723E+00	8.0877E+00	7.9392E+00	1.7430E+01	4.4730E+01	3.6487E+01	5.7280E+01	1.5022E+01	1.1727E+01
f_{17}	Best	1.7003E+03	1.7027E+03	1.7256E+03	1.7549E+03	1.7464E+03	1.7045E+03	1.8010E+03	1.7291E+03	1.7003E+03
	Rank	1	3	4	7	8	5	9	6	2
	Mean	3.7397E+03	4.7333E+03	9.6647E+03	2.7068E+08	8.5559E+03	9.3212E+03	1.0282E+07	9.9017E+03	1.8589E+03
	Std	1.7735E+03	2.1762E+03	7.5299E+03	3.2570E+08	1.2441E+04	7.9294E+03	8.3740E+06	8.2235E+03	2.9210E+02
	Best	1.9304E+03	2.7019E+03	2.3265E+03	3.4323E+03	1.8349E+03	2.4772E+03	1.3670E+05	2.4846E+03	1.8000E+03
f_{18}	Rank	2	3	6	9	4	5	8	7	1
	Mean	1.9026E+03	1.9226E+03	1.9541E+03	1.8903E+05	3.0038E+03	5.4916E+03	5.0841E+04	2.0106E+03	1.9012E+03
	Std	1.9683E+00	1.5683E+01	2.8028E+01	3.1984E+05	5.6555E+03	4.0413E+03	5.3439E+04	2.4445E+02	1.2752E+00
	Best	1.9006E+03	1.9078E+03	1.9233E+03	1.9539E+03	1.9073E+03	1.9271E+03	6.9143E+03	1.9113E+03	1.9000E+03
	Rank	2	3	4	9	6	7	8	5	1
f_{19}	Mean	2.0000E+03	2.0053E+03	2.0444E+03	2.1865E+03	2.1653E+03	2.0990E+03	2.2288E+03	2.1023E+03	2.0110E+03
	Std	1.0793E-01	7.8169E+00	4.5182E+01	3.3642E+01	7.1258E+01	7.7282E+01	4.9486E+01	5.0731E+01	2.6787E+01
	Best	2.0000E+03	2.0000E+03	2.0105E+03	2.0809E+03	2.0307E+03	2.0210E+03	2.0655E+03	2.0408E+03	2.0000E+03

Table S3 (continued)

Table S3 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{21}	Rank	1	2	4	8	7	5	9	6	3
	Mean	2.2974E+03	2.2677E+03	2.3020E+03	2.3422E+03	2.3161E+03	2.3272E+03	2.3160E+03	2.2334E+03	2.2904E+03
	Std	3.3107E+01	5.2247E+01	4.0111E+01	3.6442E+01	4.0974E+01	1.2919E+01	3.9455E+01	5.3219E+01	4.0509E+01
	Best	2.2000E+03	2.2000E+03	2.2027E+03	2.2227E+03	2.2008E+03	2.3095E+03	2.2470E+03	2.2000E+03	2.2000E+03
f_{22}	Rank	4	2	5	9	7	8	6	1	3
	Mean	2.2969E+03	2.2945E+03	2.2832E+03	2.5083E+03	2.3115E+03	2.3052E+03	2.8074E+03	2.3030E+03	2.2978E+03
	Std	1.8296E+01	2.2546E+01	4.6027E+01	9.2073E+01	8.8156E+00	2.6804E+00	2.3510E+02	1.2841E+00	1.5537E+01
	Best	2.2000E+03	2.2116E+03	2.2007E+03	2.3426E+03	2.3028E+03	2.3010E+03	2.4281E+03	2.3016E+03	2.2156E+03
f_{23}	Rank	3	2	1	8	7	6	9	5	4
	Mean	2.6073E+03	2.6095E+03	2.6137E+03	2.7437E+03	2.6392E+03	2.6257E+03	2.7254E+03	2.6167E+03	2.6129E+03
	Std	2.7698E+00	4.2018E+00	4.8213E+00	2.6204E+01	2.8942E+01	8.5715E+00	1.6525E+01	5.3612E+00	6.3587E+00
	Best	2.6000E+03	2.6026E+03	2.6063E+03	2.6930E+03	2.6107E+03	2.6134E+03	2.6965E+03	2.6068E+03	2.6044E+03
f_{24}	Rank	1	2	4	9	7	6	8	5	3
	Mean	2.7127E+03	2.7215E+03	2.7438E+03	2.8290E+03	2.7796E+03	2.7578E+03	2.8284E+03	2.7462E+03	2.7399E+03
	Std	7.2162E+01	6.0477E+01	6.5140E+00	5.6843E+01	2.6735E+01	1.0204E+01	4.2837E+01	7.6576E+00	5.0324E+00
	Best	2.5000E+03	2.5000E+03	2.7340E+03	2.5610E+03	2.7417E+03	2.7382E+03	2.7204E+03	2.7346E+03	2.7342E+03
f_{25}	Rank	1	2	4	9	7	6	8	5	3
	Mean	2.9010E+03	2.9109E+03	2.9229E+03	3.0408E+03	2.9290E+03	2.9052E+03	3.4005E+03	2.9108E+03	2.9438E+03
	Std	1.1557E+01	2.1368E+01	2.5254E+01	4.7273E+01	2.9055E+01	1.8020E+01	1.4289E+02	2.0119E+01	4.6024E+01
	Best	2.8977E+03	2.8977E+03	2.8979E+03	2.9762E+03	2.8978E+03	2.8977E+03	3.1531E+03	2.8977E+03	2.8977E+03
f_{26}	Rank	1	4	5	8	6	2	9	3	7
	Mean	2.8900E+03	2.9314E+03	2.9728E+03	4.1171E+03	3.5305E+03	3.5430E+03	3.7031E+03	2.9934E+03	2.9978E+03
	Std	3.0513E+01	1.8282E+02	2.4264E+02	2.3659E+02	6.2404E+02	4.7549E+02	2.0637E+02	3.2212E+02	2.3385E+02
	Best	2.8000E+03	2.6000E+03	2.8283E+03	3.7554E+03	2.8267E+03	3.0672E+03	3.4634E+03	2.8000E+03	2.8000E+03
f_{27}	Rank	1	2	3	9	6	7	8	4	5
	Mean	3.0897E+03	3.0901E+03	3.0904E+03	3.2491E+03	3.1026E+03	3.1134E+03	3.1960E+03	3.0925E+03	3.0956E+03
	Std	2.0711E+00	1.6837E+00	1.7998E+00	3.6618E+01	1.2674E+01	1.2304E+01	2.6744E+01	2.5914E+00	4.6098E+00
	Best	3.0869E+03	3.0882E+03	3.0891E+03	3.1813E+03	3.0906E+03	3.0978E+03	3.1235E+03	3.0893E+03	3.0891E+03
f_{28}	Rank	1	2	3	9	6	7	8	4	5
	Mean	3.1312E+03	3.2455E+03	3.3481E+03	3.7897E+03	3.4351E+03	3.3811E+03	3.6134E+03	3.3467E+03	3.2815E+03
	Std	9.5146E+01	1.5822E+02	1.6549E+02	5.1351E+01	2.1656E+02	9.6011E+01	1.0882E+02	1.1298E+02	1.2251E+02
	Best	3.1000E+03	3.1000E+03	3.1026E+03	3.5949E+03	3.1686E+03	3.1000E+03	3.4215E+03	3.1000E+03	3.1000E+03
f_{29}	Rank	1	2	5	9	7	6	8	4	3
	Mean	3.1468E+03	3.1479E+03	3.1667E+03	3.2594E+03	3.2217E+03	3.2040E+03	3.4870E+03	3.1572E+03	3.1443E+03
	Std	8.0417E+00	1.0816E+01	2.6151E+01	4.0109E+01	4.6900E+01	3.6378E+01	5.8488E+01	1.3910E+01	1.8280E+01
	Best	3.1403E+03	3.1314E+03	3.1373E+03	3.1959E+03	3.1356E+03	3.1515E+03	3.3353E+03	3.1355E+03	3.1313E+03
f_{30}	Rank	2	3	5	8	7	6	9	4	1
	Mean	3.4530E+04	1.4296E+05	2.9658E+05	3.2610E+06	5.1292E+05	4.7065E+04	1.5914E+07	1.9198E+04	2.6756E+05

Table S3 (continued)

Table S3 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
Std		1.4849E+05	3.0823E+05	4.5898E+05	3.5070E+06	7.5628E+05	1.6589E+05	6.3772E+06	7.4255E+03	3.8428E+05
Best		4.1176E+03	3.7208E+03	4.4490E+03	3.3250E+05	3.5453E+03	4.8339E+03	3.5731E+06	7.5646E+03	3.5334E+03
Rank		2	4	6	8	7	3	9	1	5
Ave.Rank		1.6034	2.6034	4.4828	8.2414	6.4483	5.6552	8.5517	4.4483	2.9655
Total.Rank		1	2	5	8	7	6	9	4	3

Table S4: Experimental results on the CEC2017 benchmark function with 30 dimensions (f_1, f_3-f_{30}).

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_1	Mean	3.2799E+03	4.3408E+03	3.1278E+07	3.6116E+10	6.9944E+07	5.5000E+03	7.0148E+10	4.8494E+03	1.0668E+08
	Std	3.3000E+03	4.9890E+03	5.4643E+06	7.3352E+09	4.6969E+07	5.3854E+03	7.0517E+09	6.1206E+03	4.4854E+08
	Best	1.0002E+02	1.5822E+02	2.0730E+07	2.2161E+10	1.0909E+07	1.2967E+02	5.1521E+10	1.1310E+02	1.0089E+02
	Rank	1	2	5	8	6	4	9	3	7
f_3	Mean	4.5470E+02	3.3676E+02	3.8213E+04	7.3360E+04	2.3862E+04	9.4217E+02	9.4229E+04	4.0530E+02	5.0486E+02
	Std	1.1995E+02	5.0767E+01	6.3935E+03	7.5960E+03	4.4083E+04	8.0818E+02	2.6252E-03	3.8902E+02	4.4834E+02
	Best	3.0899E+02	3.0039E+02	2.2895E+04	5.8094E+04	8.3094E+02	3.0014E+02	9.4229E+04	3.0000E+02	3.0000E+02
	Rank	3	1	7	8	6	5	9	2	4
f_4	Mean	4.2553E+02	4.5408E+02	4.9360E+02	6.7005E+03	5.5152E+02	4.3770E+02	1.7555E+04	4.7328E+02	4.8999E+02
	Std	3.2380E+01	3.2488E+01	1.9254E+01	1.7396E+03	6.4727E+01	3.7230E+01	3.1350E+03	2.2777E+01	3.5112E+01
	Best	4.0000E+02	4.0000E+02	4.4765E+02	2.8244E+03	4.5758E+02	4.0000E+02	1.2041E+04	4.0421E+02	4.2246E+02
	Rank	1	3	6	8	7	2	9	4	5
f_5	Mean	5.6077E+02	5.6305E+02	6.4922E+02	8.2528E+02	7.1544E+02	6.2002E+02	9.9041E+02	6.2148E+02	5.2781E+02
	Std	1.2850E+01	2.2451E+01	4.0613E+01	3.2856E+01	4.4088E+01	3.0859E+01	2.5116E+01	3.4826E+01	7.7831E+00
	Best	5.4021E+02	5.3383E+02	5.8017E+02	7.6222E+02	6.5283E+02	5.6467E+02	9.0708E+02	5.5472E+02	5.1336E+02
	Rank	2	3	6	8	7	4	9	5	1
f_6	Mean	6.0001E+02	6.0148E+02	6.0456E+02	6.6735E+02	6.5121E+02	6.1418E+02	7.0305E+02	6.2051E+02	6.0016E+02
	Std	4.7736E-02	1.3658E+00	1.4917E+00	7.5597E+00	1.2576E+01	7.5840E+00	6.9452E+00	9.2355E+00	1.9567E-01
	Best	6.0000E+02	6.0001E+02	6.0288E+02	6.4923E+02	6.0956E+02	6.0175E+02	6.8751E+02	6.0560E+02	6.0000E+02
	Rank	1	3	4	8	7	5	9	6	2
f_7	Mean	8.1342E+02	8.2722E+02	9.4870E+02	1.2300E+03	1.1025E+03	9.3742E+02	1.5656E+03	8.3621E+02	7.5682E+02
	Std	2.0963E+01	4.5333E+01	1.5023E+01	7.1734E+01	1.0888E+02	6.6368E+01	3.4494E+01	3.3113E+01	8.1971E+00
	Best	7.8328E+02	7.5853E+02	9.1463E+02	1.0791E+03	8.9305E+02	8.3494E+02	1.4622E+03	7.8191E+02	7.4716E+02
	Rank	2	3	6	8	7	5	9	4	1
f_8	Mean	8.6023E+02	8.6003E+02	9.0218E+02	1.0709E+03	9.7630E+02	9.2082E+02	1.2249E+03	9.0837E+02	8.2769E+02
	Std	8.5660E+00	1.7587E+01	3.5915E+01	2.8452E+01	3.8679E+01	3.0021E+01	2.3644E+01	2.5961E+01	8.4493E+00
	Best	8.4312E+02	8.2288E+02	8.5021E+02	1.0191E+03	9.0197E+02	8.6766E+02	1.1389E+03	8.5174E+02	8.1492E+02
	Rank	3	2	4	8	7	6	9	5	1
f_9	Mean	9.0240E+02	9.9403E+02	9.9498E+02	6.2838E+03	3.7299E+03	3.2706E+03	1.6771E+04	1.8199E+03	9.6306E+02
	Std	5.5345E+00	1.6653E+02	5.0111E+01	1.0186E+03	1.7046E+03	1.3166E+03	1.2242E+03	8.5138E+02	9.9563E+01
	Best	9.0000E+02	9.0063E+02	9.3432E+02	4.4587E+03	1.4995E+03	1.5631E+03	1.4208E+04	9.6179E+02	9.0154E+02
	Rank	1	3	4	8	7	6	9	5	2
f_{10}	Mean	4.4201E+03	3.8159E+03	6.0443E+03	7.4190E+03	6.5067E+03	4.7830E+03	9.1793E+03	4.2883E+03	3.1993E+03
	Std	2.5660E+02	7.4431E+02	1.6252E+03	5.1493E+02	9.5344E+02	6.9194E+02	4.9807E+02	6.6035E+02	1.2774E+03
	Best	3.8147E+03	2.0144E+03	3.0290E+03	6.1006E+03	4.7519E+03	3.7337E+03	7.7226E+03	3.2891E+03	1.5442E+03
	Rank	4	2	6	8	7	5	9	3	1
f_{11}	Mean	1.1695E+03	1.1823E+03	1.5064E+03	6.3383E+03	1.3916E+03	1.2440E+03	1.2881E+04	1.2284E+03	1.1592E+03

Table S4 (continued)

Table S4 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{12}	Std	3.0026E+01	3.9743E+01	5.2491E+01	1.5106E+03	9.3951E+01	5.0338E+01	1.8407E+03	3.9064E+01	4.1412E+01
	Best	1.1229E+03	1.1227E+03	1.4048E+03	3.2275E+03	1.2395E+03	1.1789E+03	9.6126E+03	1.1735E+03	1.1125E+03
	Rank	2	3	7	8	6	5	9	4	1
	Mean	7.0264E+04	4.2310E+04	4.1487E+06	6.8401E+09	3.1016E+07	2.0053E+05	1.0650E+10	1.3125E+06	1.4822E+05
	Std	1.0515E+05	2.0969E+04	2.1552E+06	2.1137E+09	3.7231E+07	1.2480E+05	1.4888E+09	7.7027E+05	2.0645E+05
	Best	1.3916E+04	8.4921E+03	1.5495E+06	3.1014E+09	1.8594E+06	4.1951E+04	6.4606E+09	1.1245E+05	3.4750E+03
	Rank	2	1	6	8	7	4	9	5	3
	Mean	5.6606E+03	1.7900E+04	4.5006E+05	1.7818E+09	1.1993E+05	1.0791E+04	5.3310E+09	1.0649E+05	1.3119E+04
	Std	6.9831E+03	1.4553E+04	1.7821E+05	9.5421E+08	1.3318E+05	9.5360E+03	1.4066E+09	3.6258E+04	1.2068E+04
f_{13}	Best	1.3542E+03	1.5528E+03	1.8733E+05	4.8519E+08	2.2785E+04	1.6082E+03	2.0170E+09	3.5048E+04	1.3966E+03
	Rank	1	4	7	8	6	2	9	5	3
	Mean	4.3056E+03	9.9096E+03	1.3925E+04	1.8015E+06	2.4545E+04	3.2021E+04	3.0222E+06	8.5956E+03	5.9933E+03
	Std	1.8075E+03	7.2499E+03	9.3003E+03	4.2681E+05	2.8498E+04	1.6793E+04	1.4797E+06	5.2296E+03	1.0291E+04
	Best	1.8154E+03	2.1887E+03	2.8575E+03	9.2290E+05	1.6379E+03	7.5046E+03	7.6753E+05	3.5361E+03	1.4230E+03
	Rank	1	4	5	8	6	7	9	3	2
	Mean	3.8160E+03	6.8232E+03	1.0791E+05	1.9500E+08	3.1378E+04	1.0414E+04	7.5813E+08	4.2155E+04	3.3974E+03
	Std	3.5903E+03	6.9957E+03	4.5036E+04	1.3495E+08	3.9715E+04	7.2791E+03	3.2524E+08	1.8232E+04	4.7031E+03
	Best	1.6289E+03	1.6293E+03	4.7034E+04	1.9350E+06	2.9953E+03	1.8117E+03	2.2357E+08	9.7241E+03	1.5159E+03
f_{14}	Rank	2	3	7	8	5	4	9	6	1
	Mean	2.0052E+03	2.0222E+03	2.3177E+03	4.4406E+03	3.1595E+03	2.8006E+03	5.3204E+03	2.4866E+03	1.8906E+03
	Std	2.7206E+02	2.8239E+02	3.6079E+02	3.7406E+02	4.6859E+02	2.6858E+02	3.5506E+02	2.2268E+02	1.8288E+02
	Best	1.6382E+03	1.6072E+03	1.7298E+03	3.7608E+03	2.2027E+03	2.1479E+03	4.7820E+03	2.0844E+03	1.6141E+03
	Rank	2	3	4	8	7	6	9	5	1
	Mean	1.7646E+03	1.8719E+03	1.9752E+03	3.2127E+03	2.4692E+03	2.3174E+03	3.8528E+03	1.9844E+03	1.7769E+03
	Std	1.5999E+01	7.0080E+01	1.7717E+02	7.2312E+02	2.8893E+02	2.2527E+02	2.5126E+02	1.8647E+02	7.6455E+01
	Best	1.7452E+03	1.7675E+03	1.7999E+03	2.1238E+03	2.0715E+03	1.8780E+03	3.3504E+03	1.7753E+03	1.7154E+03
	Rank	1	3	4	8	7	6	9	5	2
f_{15}	Mean	1.6619E+05	1.9204E+05	3.1906E+05	2.6086E+07	3.8934E+05	2.1335E+05	3.8160E+07	6.2443E+04	4.8863E+04
	Std	6.7539E+04	1.5172E+05	2.5514E+05	1.2624E+07	4.5000E+05	1.3807E+05	2.0689E+07	4.5216E+04	3.5714E+04
	Best	5.5407E+04	3.5975E+04	8.1129E+04	1.5053E+06	5.2340E+03	2.2396E+04	6.7182E+06	1.7816E+04	7.8048E+03
	Rank	3	4	6	8	7	5	9	2	1
	Mean	3.7262E+03	1.3733E+04	1.3094E+05	2.6007E+07	2.2189E+06	8.5089E+03	8.5120E+08	1.8466E+05	6.5715E+03
	Std	2.8063E+03	1.3364E+04	7.6100E+04	2.5823E+07	1.1996E+07	8.4441E+03	3.4040E+08	5.2991E+04	9.7776E+03
	Best	1.9397E+03	2.0298E+03	3.6545E+04	2.1647E+06	2.1270E+03	1.9801E+03	1.3066E+08	6.2657E+04	1.9099E+03
	Rank	1	4	5	8	7	3	9	6	2
	Mean	2.1076E+03	2.1843E+03	2.3224E+03	2.6658E+03	2.8772E+03	2.7239E+03	3.0765E+03	2.3737E+03	2.1710E+03
f_{20}	Std	6.4849E+01	9.5765E+01	1.4774E+02	1.4602E+02	3.5558E+02	2.6824E+02	1.4166E+02	1.1208E+02	1.7122E+02
	Best	2.0252E+03	2.0551E+03	2.1133E+03	2.3515E+03	2.3625E+03	2.3002E+03	2.7433E+03	2.2157E+03	2.0094E+03

Table S4 (continued)

Table S4 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{21}	Rank	1	3	4	6	8	7	9	5	2
	Mean	2.3617E+03	2.3555E+03	2.3829E+03	2.6071E+03	2.5117E+03	2.4316E+03	2.7541E+03	2.4010E+03	2.3368E+03
	Std	6.1893E+00	2.2710E+01	2.7957E+01	2.9435E+01	5.2270E+01	3.2531E+01	2.0864E+01	1.5945E+01	1.0959E+01
	Best	2.3512E+03	2.3252E+03	2.3455E+03	2.5460E+03	2.4464E+03	2.3836E+03	2.6877E+03	2.3649E+03	2.3168E+03
f_{22}	Rank	3	2	4	8	7	6	9	5	1
	Mean	2.3001E+03	2.3007E+03	2.3285E+03	6.3807E+03	2.3676E+03	2.3019E+03	9.2237E+03	2.3004E+03	2.3177E+03
	Std	4.4909E-01	1.4431E+00	1.9013E+00	6.3850E+02	5.2497E+01	2.1402E+00	8.0672E+02	1.0034E+00	4.3023E+01
	Best	2.3000E+03	2.3000E+03	2.3237E+03	4.9748E+03	2.3252E+03	2.3000E+03	7.7326E+03	2.3000E+03	2.3000E+03
f_{23}	Rank	1	3	6	8	7	4	9	2	5
	Mean	2.7037E+03	2.7042E+03	2.7551E+03	3.4484E+03	3.0247E+03	2.8505E+03	3.4247E+03	2.7709E+03	2.6973E+03
	Std	1.2282E+01	2.6314E+01	4.5379E+01	7.3346E+01	8.6802E+01	6.5497E+01	5.2907E+01	3.7365E+01	1.8218E+01
	Best	2.6847E+03	2.6733E+03	2.7075E+03	3.2891E+03	2.8193E+03	2.7478E+03	3.3315E+03	2.6757E+03	2.6791E+03
f_{24}	Rank	2	3	4	9	7	6	8	5	1
	Mean	2.8821E+03	2.8895E+03	2.9010E+03	3.9400E+03	3.2730E+03	3.0317E+03	3.6402E+03	2.9371E+03	2.8622E+03
	Std	8.7942E+00	4.1192E+01	2.7126E+01	1.2239E+02	1.3499E+02	7.8341E+01	8.8186E+01	3.1629E+01	1.6849E+01
	Best	2.8577E+03	2.8433E+03	2.8762E+03	3.7650E+03	3.0940E+03	2.9073E+03	3.4614E+03	2.8748E+03	2.8397E+03
f_{25}	Rank	2	3	4	9	7	6	8	5	1
	Mean	2.8891E+03	2.8971E+03	2.8900E+03	3.9692E+03	2.9689E+03	2.9184E+03	7.3094E+03	2.8915E+03	2.9059E+03
	Std	1.0184E+01	1.5520E+01	3.2463E+00	2.5923E+02	4.0195E+01	2.4497E+01	2.5059E+02	8.7808E+00	2.3245E+01
	Best	2.8834E+03	2.8836E+03	2.8856E+03	3.5773E+03	2.9210E+03	2.8835E+03	6.6323E+03	2.8835E+03	2.8843E+03
f_{26}	Rank	1	4	2	8	7	6	9	3	5
	Mean	4.0796E+03	3.9716E+03	4.5670E+03	9.5133E+03	7.0631E+03	5.5394E+03	1.1218E+04	3.9118E+03	4.1486E+03
	Std	5.2238E+02	6.8314E+02	2.6402E+02	6.9691E+02	1.4650E+03	1.3333E+03	6.7776E+02	1.0807E+03	1.9559E+02
	Best	2.8000E+03	2.8000E+03	4.0214E+03	8.0956E+03	2.9718E+03	2.8000E+03	9.6930E+03	2.8000E+03	3.8695E+03
f_{27}	Rank	3	2	5	8	7	6	9	1	4
	Mean	3.2090E+03	3.2107E+03	3.2180E+03	4.2896E+03	3.3027E+03	3.2678E+03	4.1975E+03	3.2376E+03	3.2162E+03
	Std	6.9331E+00	8.4783E+00	9.9866E+00	1.5545E+02	8.0367E+01	2.9116E+01	1.2649E+02	2.6067E+01	1.5469E+01
	Best	3.1875E+03	3.1886E+03	3.1930E+03	3.9344E+03	3.2206E+03	3.2192E+03	3.8535E+03	3.2023E+03	3.1987E+03
f_{28}	Rank	1	2	4	9	7	6	8	5	3
	Mean	3.1518E+03	3.1387E+03	3.2240E+03	5.6009E+03	3.2991E+03	3.1472E+03	7.9586E+03	3.1505E+03	3.1979E+03
	Std	5.7225E+01	5.6658E+01	9.4432E+00	3.6417E+02	3.2199E+01	5.5437E+01	6.4833E+02	5.2003E+01	3.8281E+01
	Best	3.1000E+03	3.1000E+03	3.2081E+03	4.9469E+03	3.2589E+03	3.1000E+03	6.6714E+03	3.1000E+03	3.1000E+03
f_{29}	Rank	4	1	6	8	7	2	9	3	5
	Mean	3.4020E+03	3.5132E+03	3.6472E+03	5.6209E+03	4.4752E+03	3.9066E+03	6.3764E+03	3.8691E+03	3.4687E+03
	Std	5.2408E+01	8.6694E+01	1.4111E+02	3.4922E+02	3.0438E+02	2.5618E+02	4.1107E+02	1.4494E+02	1.3278E+02
	Best	3.2769E+03	3.3813E+03	3.4649E+03	5.0490E+03	4.0317E+03	3.4702E+03	5.5378E+03	3.5617E+03	3.3122E+03
f_{30}	Rank	1	3	4	8	7	6	9	5	2
	Mean	9.5016E+03	7.9603E+03	2.4627E+05	9.6812E+07	4.3192E+05	9.4816E+03	7.2066E+08	3.5794E+05	9.0924E+03

Table S4 (continued)

Table S4 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
Std		2.8712E+03	2.4237E+03	8.7954E+04	5.4678E+07	9.3034E+05	1.6468E+03	1.8553E+08	1.9414E+05	2.7254E+03
Best		6.2681E+03	5.3783E+03	8.4062E+04	1.8728E+07	3.3785E+04	6.6647E+03	5.3109E+08	9.6924E+04	5.3951E+03
Rank		4	1	5	8	7	3	9	6	2
Ave.Rank		1.9310	2.6897	5.0690	8.0345	6.7931	4.8966	8.8966	4.2414	2.4483
Total.Rank		1	3	6	8	7	5	9	4	2

Table S5: Experimental results on the CEC2017 benchmark function with 50 dimensions (f_1, f_3-f_{30}).

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_1	Mean	4.3358E+03	3.2131E+03	1.4089E+08	8.3955E+10	3.3124E+08	3.1166E+03	1.3075E+11	2.9526E+03	7.8610E+07
	Std	5.5121E+03	3.3851E+03	2.2523E+07	8.1314E+09	1.3957E+08	3.9587E+03	5.4669E+09	2.7569E+03	1.2656E+08
	Best	1.0685E+02	1.0032E+02	1.0504E+08	6.7891E+10	1.2960E+08	1.0031E+02	1.1800E+11	1.3658E+02	2.5645E+03
	Rank	4	3	6	8	7	2	9	1	5
f_3	Mean	1.1434E+04	8.9548E+03	9.5397E+04	1.5352E+05	4.4016E+04	5.9434E+03	3.1856E+05	5.1814E+02	1.0009E+05
	Std	3.2151E+03	3.1333E+03	1.5925E+04	1.3341E+04	7.2112E+04	3.9773E+03	3.9234E+04	8.8697E+02	5.1587E+04
	Best	5.4521E+03	3.4302E+03	7.0291E+04	1.3046E+05	3.2878E+03	7.6920E+02	2.3745E+05	3.0000E+02	2.0166E+04
	Rank	4	3	6	8	5	2	9	1	7
f_4	Mean	4.7823E+02	5.0020E+02	6.0445E+02	2.1701E+04	7.5781E+02	4.7969E+02	4.6388E+04	5.3713E+02	4.9264E+02
	Std	3.9253E+01	4.2559E+01	4.0405E+01	3.7154E+03	8.1994E+01	5.0292E+01	4.8438E+03	4.5417E+01	4.9361E+01
	Best	4.2372E+02	4.2851E+02	4.5867E+02	1.1459E+04	6.3224E+02	4.0039E+02	3.5132E+04	4.3250E+02	4.0212E+02
	Rank	1	4	6	8	7	2	9	5	3
f_5	Mean	6.6235E+02	6.7864E+02	7.8428E+02	1.0769E+03	9.0620E+02	7.6417E+02	1.3038E+03	7.6185E+02	5.8046E+02
	Std	1.9996E+01	5.0824E+01	7.0397E+01	3.8305E+01	7.1747E+01	6.0988E+01	1.9899E+01	4.4495E+01	2.6064E+01
	Best	6.2659E+02	5.8994E+02	6.8774E+02	1.0074E+03	7.9283E+02	6.8009E+02	1.2357E+03	6.8208E+02	5.3054E+02
	Rank	2	3	6	8	7	5	9	4	1
f_6	Mean	6.0032E+02	6.1255E+02	6.1047E+02	6.8203E+02	6.6914E+02	6.1651E+02	7.1706E+02	6.2998E+02	6.0213E+02
	Std	3.6773E-01	4.6701E+00	2.6366E+00	5.8886E+00	9.5114E+00	7.6359E+00	4.6749E+00	7.6452E+00	1.2071E+00
	Best	6.0002E+02	6.0264E+02	6.0677E+02	6.7025E+02	6.5120E+02	6.0283E+02	7.0751E+02	6.1429E+02	6.0028E+02
	Rank	1	4	3	8	7	5	9	6	2
f_7	Mean	9.9527E+02	1.0385E+03	1.2290E+03	1.7826E+03	1.6899E+03	1.2346E+03	2.1804E+03	9.8850E+02	8.4624E+02
	Std	3.8713E+01	8.7834E+01	3.3548E+01	6.7337E+01	1.4293E+02	7.3295E+01	2.5948E+01	6.7378E+01	3.5789E+01
	Best	9.3774E+02	8.8080E+02	1.1557E+03	1.6476E+03	1.4525E+03	1.1071E+03	2.0855E+03	8.5868E+02	8.0132E+02
	Rank	3	4	5	8	7	6	9	2	1
f_8	Mean	9.5405E+02	9.6060E+02	1.0735E+03	1.4181E+03	1.2311E+03	1.0769E+03	1.6599E+03	1.0438E+03	8.8113E+02
	Std	1.9343E+01	3.9524E+01	5.9702E+01	2.8614E+01	6.8261E+01	6.2745E+01	4.9959E+01	4.6710E+01	2.7045E+01
	Best	9.1420E+02	8.8955E+02	9.8938E+02	1.3575E+03	1.0531E+03	9.8705E+02	1.5325E+03	9.2238E+02	8.2985E+02
	Rank	2	3	5	8	7	6	9	4	1
f_9	Mean	2.3427E+03	3.0036E+03	2.9238E+03	2.5031E+04	1.2170E+04	9.2549E+03	5.4316E+04	5.6899E+03	1.2809E+03
	Std	1.0642E+03	1.9188E+03	9.5645E+02	3.3659E+03	3.4144E+03	2.4726E+03	3.9937E+03	2.0460E+03	2.2520E+02
	Best	1.0955E+03	1.1568E+03	1.7435E+03	1.8928E+04	6.6232E+03	5.4976E+03	4.0589E+04	1.7300E+03	9.3639E+02
	Rank	2	4	3	8	7	6	9	5	1
f_{10}	Mean	7.5043E+03	6.5940E+03	1.2013E+04	1.2724E+04	1.0750E+04	7.8671E+03	1.5663E+04	6.9550E+03	9.1119E+03
	Std	3.5983E+02	9.2718E+02	2.7957E+03	6.3058E+02	1.5964E+03	7.7954E+02	3.5557E+02	8.7035E+02	2.9758E+03
	Best	6.7090E+03	4.5409E+03	6.7846E+03	1.1677E+04	8.1837E+03	6.2176E+03	1.4810E+04	5.8009E+03	3.8876E+03
	Rank	3	1	7	8	6	4	9	2	5
f_{11}	Mean	1.2591E+03	1.2524E+03	2.4392E+03	1.8768E+04	1.7362E+03	1.3478E+03	3.2562E+04	1.2932E+03	1.4260E+03

Table S5 (continued)

Table S5 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{12}	Std	3.3340E+01	4.6507E+01	2.5736E+02	2.4051E+03	3.0738E+02	6.1882E+01	6.4040E+03	3.8186E+01	3.2024E+02
	Best	1.1949E+03	1.1908E+03	2.0575E+03	1.3403E+04	1.3458E+03	1.1700E+03	1.8450E+04	1.2370E+03	1.1530E+03
	Rank	2	1	7	8	6	4	9	3	5
	Mean	6.3052E+05	3.2446E+05	4.2127E+07	5.2256E+10	2.0746E+08	8.9704E+05	6.4736E+10	3.6029E+06	1.8287E+06
	Std	3.3048E+05	2.0300E+05	1.5269E+07	9.8403E+09	2.2116E+08	5.6389E+05	7.3925E+09	1.9715E+06	3.0526E+06
f_{13}	Best	1.4704E+05	1.3793E+05	1.9454E+07	3.1421E+10	1.5540E+07	1.0118E+05	4.9182E+10	8.7527E+05	1.3725E+05
	Rank	2	1	6	8	7	3	9	5	4
	Mean	8.4078E+03	1.4352E+04	2.5601E+06	2.5711E+10	5.4097E+07	3.7877E+03	2.6557E+10	8.9034E+04	4.1564E+06
	Std	6.0070E+03	8.8053E+03	7.3408E+05	6.0007E+09	1.8139E+08	2.0792E+03	4.7591E+09	5.2956E+04	1.5941E+07
	Best	1.5599E+03	1.7919E+03	1.5973E+06	1.5348E+10	4.6382E+04	1.5797E+03	1.8226E+10	2.8862E+04	1.4504E+03
f_{14}	Rank	2	3	5	8	7	1	9	4	6
	Mean	6.2455E+04	6.6469E+04	1.3227E+05	6.7838E+07	6.6503E+05	3.5448E+04	2.4502E+07	5.4946E+04	5.8278E+04
	Std	3.3145E+04	3.3500E+04	6.8281E+04	2.6240E+07	6.1008E+05	1.6846E+04	1.2860E+07	3.2560E+04	4.5162E+04
	Best	1.1803E+04	6.7643E+03	1.4074E+04	2.4748E+07	7.3213E+03	2.1135E+03	8.3456E+06	1.0905E+04	2.0178E+03
	Rank	4	5	6	9	7	1	8	2	3
f_{15}	Mean	5.6478E+03	1.0508E+04	5.3062E+05	4.6946E+09	7.8214E+04	1.4240E+04	7.6967E+09	4.8651E+04	1.2567E+05
	Std	3.1840E+03	5.9622E+03	1.3316E+05	2.3636E+09	1.0648E+05	5.7280E+03	2.1192E+09	1.5762E+04	2.3416E+05
	Best	1.6110E+03	1.9876E+03	3.4095E+05	1.0884E+09	3.4087E+03	1.8641E+03	3.1697E+09	2.7304E+04	1.6758E+03
	Rank	1	2	7	8	5	3	9	4	6
	Mean	2.5071E+03	2.7042E+03	3.1143E+03	6.6743E+03	4.0891E+03	3.4225E+03	8.6609E+03	3.1393E+03	2.3451E+03
f_{16}	Std	2.1240E+02	4.6600E+02	3.7146E+02	7.8764E+02	4.9817E+02	4.3080E+02	3.8583E+02	5.0414E+02	3.3950E+02
	Best	2.0451E+03	1.9207E+03	2.5341E+03	5.1508E+03	3.1200E+03	2.5475E+03	7.5603E+03	2.3201E+03	1.8460E+03
	Rank	2	3	4	8	7	6	9	5	1
	Mean	2.2727E+03	2.5218E+03	2.9506E+03	4.4792E+03	3.9001E+03	3.5213E+03	1.3908E+04	3.1686E+03	2.1669E+03
	Std	1.6565E+02	1.7638E+02	3.7252E+02	5.5508E+02	4.0241E+02	3.3630E+02	5.6446E+03	3.0039E+02	2.3243E+02
f_{17}	Best	1.9420E+03	2.0962E+03	2.2835E+03	3.2612E+03	3.0631E+03	2.8907E+03	7.5983E+03	2.4554E+03	1.8045E+03
	Rank	2	3	4	8	7	6	9	5	1
	Mean	6.0463E+05	7.3399E+05	1.0689E+06	9.8948E+07	1.9187E+06	1.8792E+05	1.4388E+08	1.4618E+05	6.7999E+04
	Std	4.3041E+05	3.1601E+05	8.3062E+05	4.0544E+07	3.5944E+06	7.2239E+04	5.7613E+07	6.5054E+04	4.0988E+04
	Best	1.7703E+05	2.0215E+05	2.9025E+05	5.0357E+07	7.1036E+04	6.5677E+04	3.6088E+07	5.6763E+04	2.1793E+04
f_{18}	Rank	4	5	6	8	7	3	9	2	1
	Mean	1.0574E+04	1.3537E+04	4.8875E+05	1.3675E+09	3.0736E+05	1.8409E+04	3.2071E+09	2.0376E+05	1.9950E+04
	Std	7.8965E+03	1.0350E+04	2.5899E+05	7.7543E+08	6.8613E+05	6.5575E+03	1.0253E+09	7.7623E+04	1.1734E+04
	Best	1.9804E+03	2.0611E+03	1.1368E+05	1.7352E+08	5.3210E+03	5.1143E+03	1.1007E+09	4.3390E+04	1.9464E+03
	Rank	1	2	7	8	6	3	9	5	4
f_{20}	Mean	2.2901E+03	2.5661E+03	3.5897E+03	3.5270E+03	3.5389E+03	3.3475E+03	4.4129E+03	2.8229E+03	2.4451E+03
	Std	1.6614E+02	2.3212E+02	2.1634E+02	2.7981E+02	3.2651E+02	2.8732E+02	2.0453E+02	2.5781E+02	3.8384E+02
	Best	2.0760E+03	2.1690E+03	2.9471E+03	2.8893E+03	2.8580E+03	2.9449E+03	4.1246E+03	2.4435E+03	2.0356E+03

Table S5 (continued)

Table S5 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{21}	Rank	1	3	8	6	7	5	9	4	2
	Mean	2.4502E+03	2.4468E+03	2.5441E+03	3.0037E+03	2.8208E+03	2.5749E+03	3.2433E+03	2.5232E+03	2.3782E+03
	Std	1.9065E+01	4.7952E+01	5.5045E+01	5.1222E+01	1.0380E+02	5.2845E+01	4.3244E+01	6.2827E+01	1.9812E+01
	Best	2.4164E+03	2.3964E+03	2.4600E+03	2.8719E+03	2.5747E+03	2.4710E+03	3.1182E+03	2.4393E+03	2.3505E+03
f_{22}	Rank	3	2	5	8	7	6	9	4	1
	Mean	7.9019E+03	7.4035E+03	1.4985E+04	1.4533E+04	1.2896E+04	9.6388E+03	1.7151E+04	9.1036E+03	8.6474E+03
	Std	2.8593E+03	1.9540E+03	1.0180E+03	7.7228E+02	1.4036E+03	9.9112E+02	5.3528E+02	1.2905E+03	3.6087E+03
	Best	2.3000E+03	2.3000E+03	1.1053E+04	1.3294E+04	1.0026E+04	7.9283E+03	1.5494E+04	6.6928E+03	2.3066E+03
f_{23}	Rank	2	1	8	7	6	5	9	4	3
	Mean	2.8849E+03	2.9131E+03	2.9579E+03	4.6130E+03	3.6316E+03	3.1063E+03	4.2925E+03	2.9968E+03	2.8766E+03
	Std	2.3141E+01	6.2202E+01	4.3687E+01	1.6784E+02	2.3620E+02	1.0700E+02	9.9572E+01	7.1358E+01	6.0296E+01
	Best	2.8462E+03	2.8197E+03	2.9033E+03	4.2963E+03	3.2276E+03	2.9773E+03	4.1117E+03	2.8529E+03	2.7864E+03
f_{24}	Rank	2	3	4	9	7	6	8	5	1
	Mean	3.0555E+03	3.0763E+03	3.0937E+03	4.8806E+03	3.7024E+03	3.2690E+03	4.5751E+03	3.1484E+03	2.9837E+03
	Std	2.5776E+01	8.0358E+01	3.1538E+01	1.5012E+02	1.9429E+02	8.4800E+01	1.3705E+02	5.4959E+01	3.5143E+01
	Best	2.9880E+03	2.9873E+03	3.0416E+03	4.5277E+03	3.4586E+03	3.1469E+03	4.2480E+03	3.0499E+03	2.9409E+03
f_{25}	Rank	2	3	4	9	7	6	8	5	1
	Mean	3.0492E+03	3.0533E+03	3.0758E+03	1.0627E+04	3.1922E+03	3.0416E+03	1.9182E+04	3.0559E+03	3.0385E+03
	Std	4.5173E+01	4.0003E+01	2.7801E+01	1.3500E+03	4.9718E+01	5.0622E+01	1.6367E+02	4.0192E+01	4.1528E+01
	Best	2.9608E+03	2.9582E+03	2.9906E+03	5.8949E+03	3.1244E+03	2.9603E+03	1.8941E+04	2.9599E+03	2.9633E+03
f_{26}	Rank	3	4	6	8	7	2	9	5	1
	Mean	5.3379E+03	6.0902E+03	6.2871E+03	1.5125E+04	1.1939E+04	7.5481E+03	1.8409E+04	5.8456E+03	5.2403E+03
	Std	5.9592E+02	1.0714E+03	5.3579E+02	6.6248E+02	2.1115E+03	6.0724E+02	8.0758E+02	2.2016E+03	3.8700E+02
	Best	2.9000E+03	2.9000E+03	5.6964E+03	1.4072E+04	8.0162E+03	6.0895E+03	1.6670E+04	2.9000E+03	4.4081E+03
f_{27}	Rank	2	4	5	8	7	6	9	3	1
	Mean	3.2706E+03	3.4107E+03	3.4147E+03	7.4832E+03	4.0458E+03	3.7034E+03	6.2356E+03	3.5094E+03	3.5018E+03
	Std	2.5634E+01	1.1491E+02	1.2245E+02	5.0293E+02	2.2756E+02	1.0127E+02	2.6418E+02	1.6794E+02	1.6611E+02
	Best	3.2248E+03	3.2537E+03	3.2437E+03	6.3296E+03	3.5845E+03	3.5089E+03	5.5996E+03	3.3384E+03	3.2642E+03
f_{28}	Rank	1	2	3	9	7	6	8	5	4
	Mean	3.2960E+03	3.2972E+03	3.3276E+03	9.7141E+03	3.4641E+03	3.3062E+03	1.4881E+04	3.3081E+03	3.3064E+03
	Std	3.3382E+01	3.1509E+01	3.2508E+01	7.8376E+02	8.6171E+01	3.5717E+01	9.9356E+02	1.1703E+01	1.1329E+01
	Best	3.2588E+03	3.2588E+03	3.2716E+03	8.6550E+03	3.3291E+03	3.2699E+03	1.2994E+04	3.2618E+03	3.2791E+03
f_{29}	Rank	1	2	6	8	7	3	9	5	4
	Mean	3.6400E+03	3.9707E+03	4.2505E+03	3.2834E+04	6.3762E+03	4.6170E+03	2.3537E+04	4.6253E+03	3.7336E+03
	Std	1.2212E+02	2.4067E+02	3.1420E+02	1.4912E+04	1.0015E+03	3.5137E+02	6.0288E+03	3.0715E+02	2.4968E+02
	Best	3.3464E+03	3.5030E+03	3.7499E+03	1.2449E+04	4.5448E+03	3.9027E+03	1.3249E+04	3.7360E+03	3.3106E+03
f_{30}	Rank	1	3	4	9	7	5	8	6	2
	Mean	7.6704E+05	8.6877E+05	5.2670E+06	2.5743E+09	1.4295E+07	8.8216E+05	5.0739E+09	9.6243E+06	9.9470E+05

Table S5 (continued)

Table S5 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
Std		9.6617E+04	9.8413E+04	1.7694E+06	9.8890E+08	1.4764E+07	9.1784E+04	1.1446E+09	1.8273E+06	1.9204E+05
Best		6.3680E+05	6.8841E+05	3.2487E+06	6.1785E+08	1.2951E+06	7.6145E+05	3.0025E+09	5.7452E+06	6.2113E+05
Rank		1	2	5	8	7	3	9	6	4
Ave.Rank		2.1034	2.8621	5.4138	8.0690	6.7241	4.1724	8.8276	4.0345	2.7931
Total.Rank		1	3	6	8	7	5	9	4	2

Table S6: Experimental results on the CEC2017 benchmark function with 100 dimensions (f_1, f_3-f_{30}).

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_1	Mean	5.5393E+03	3.9663E+03	7.8706E+08	2.2714E+11	1.3992E+09	1.0282E+04	2.9221E+11	8.8689E+03	2.3988E+09
	Std	8.8354E+03	5.6024E+03	7.5570E+07	1.2819E+10	6.7806E+08	1.1404E+04	4.8811E+09	1.2431E+04	2.4092E+09
	Best	1.0006E+02	1.0001E+02	6.7014E+08	1.8910E+11	2.7862E+08	1.5452E+02	2.8213E+11	1.8567E+02	1.3723E+08
	Rank	2	1	5	8	6	4	9	3	7
f_3	Mean	9.7875E+04	9.4794E+04	3.2893E+05	3.1257E+05	9.3324E+04	8.7146E+04	3.7125E+05	6.9738E+03	4.0454E+05
	Std	1.2851E+04	1.3766E+04	3.8392E+04	1.1530E+04	1.2514E+05	2.4332E+04	1.1635E+04	3.9742E+03	6.1999E+04
	Best	7.0949E+04	5.9929E+04	2.5472E+05	2.9329E+05	1.7431E+04	4.4197E+04	3.6577E+05	2.1438E+03	2.9724E+05
	Rank	5	4	7	6	3	2	8	1	9
f_4	Mean	5.9892E+02	6.2740E+02	7.7092E+02	6.6502E+04	1.2597E+03	6.0418E+02	1.4282E+05	6.3790E+02	6.5717E+02
	Std	4.8352E+01	4.8617E+01	5.8469E+01	9.3787E+03	1.9135E+02	4.8246E+01	1.3794E+04	4.0113E+01	8.1635E+01
	Best	4.7964E+02	5.5368E+02	6.9819E+02	5.0850E+04	1.0115E+03	4.6507E+02	1.1076E+05	5.4851E+02	5.5455E+02
	Rank	1	3	6	8	7	2	9	4	5
f_5	Mean	1.0206E+03	1.0105E+03	1.3300E+03	1.8965E+03	1.5568E+03	1.1808E+03	2.2990E+03	1.1511E+03	8.4406E+02
	Std	4.0444E+01	8.6921E+01	9.5934E+01	6.5151E+01	1.0628E+02	1.1214E+02	2.0023E+01	8.9021E+01	5.6673E+01
	Best	9.5125E+02	8.6117E+02	1.1702E+03	1.7819E+03	1.3167E+03	1.0233E+03	2.2191E+03	9.9250E+02	7.3383E+02
	Rank	3	2	6	8	7	5	9	4	1
f_6	Mean	6.0992E+02	6.3345E+02	6.3137E+02	6.9667E+02	6.8207E+02	6.1427E+02	7.2230E+02	6.4525E+02	6.1318E+02
	Std	4.5074E+00	3.9426E+00	5.1632E+00	5.0028E+00	7.5393E+00	4.4527E+00	2.8442E+00	6.4746E+00	4.1775E+00
	Best	6.0276E+02	6.2574E+02	6.2382E+02	6.8179E+02	6.6693E+02	6.0776E+02	7.1664E+02	6.3355E+02	6.0625E+02
	Rank	1	5	4	8	7	3	9	6	2
f_7	Mean	1.8727E+03	1.9927E+03	2.1035E+03	3.5840E+03	3.3483E+03	2.4591E+03	4.2148E+03	1.4581E+03	1.4154E+03
	Std	1.5128E+02	2.3786E+02	6.9812E+01	1.1031E+02	2.4701E+02	2.1323E+02	3.8103E+01	1.2906E+02	2.1066E+02
	Best	1.4977E+03	1.7125E+03	1.9654E+03	3.3814E+03	2.8295E+03	2.0900E+03	4.0787E+03	1.2242E+03	1.1043E+03
	Rank	3	4	5	8	7	6	9	2	1
f_8	Mean	1.3195E+03	1.3218E+03	1.6183E+03	2.3863E+03	2.0371E+03	1.5444E+03	2.7265E+03	1.5036E+03	1.1577E+03
	Std	4.5921E+01	6.6902E+01	1.0657E+02	5.9116E+01	1.5070E+02	1.0036E+02	2.0517E+01	1.1544E+02	6.3321E+01
	Best	1.2283E+03	1.2179E+03	1.4793E+03	2.2876E+03	1.6535E+03	1.2861E+03	2.6638E+03	1.2656E+03	1.0757E+03
	Rank	2	3	6	8	7	5	9	4	1
f_9	Mean	1.8955E+04	2.9023E+04	1.7817E+04	5.8100E+04	3.9367E+04	2.2687E+04	1.0208E+05	1.8331E+04	3.1520E+03
	Std	2.7297E+03	7.9940E+03	5.5446E+03	5.0077E+03	6.1869E+03	4.4175E+03	3.8211E+03	5.6243E+03	1.0123E+03
	Best	1.4450E+04	9.4232E+03	1.1618E+04	4.6414E+04	2.9607E+04	1.6234E+04	8.6229E+04	1.0024E+04	1.9478E+03
	Rank	4	6	2	8	7	5	9	3	1
f_{10}	Mean	1.7180E+04	1.4134E+04	3.0064E+04	2.8914E+04	2.1741E+04	1.5822E+04	3.2799E+04	1.4327E+04	2.2842E+04
	Std	5.7003E+02	1.3921E+03	2.7330E+03	1.0931E+03	2.7132E+03	1.5303E+03	4.1760E+02	1.6060E+03	3.2417E+03
	Best	1.6088E+04	1.1677E+04	1.7095E+04	2.6236E+04	1.7620E+04	1.2947E+04	3.2280E+04	1.2214E+04	1.6224E+04
	Rank	4	1	8	7	5	3	9	2	6
f_{11}	Mean	1.9723E+03	1.7642E+03	4.2053E+04	1.6605E+05	1.3728E+04	2.4693E+03	3.0958E+05	2.0995E+03	3.8309E+03

Table S6 (continued)

Table S6 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{12}	Std	1.2897E+02	1.8961E+02	8.8706E+03	3.1091E+04	1.4888E+04	2.3149E+02	4.2629E+04	1.3775E+02	2.9286E+03
	Best	1.7130E+03	1.4809E+03	2.8814E+04	8.5787E+04	3.1377E+03	1.9113E+03	1.7978E+05	1.8943E+03	1.6847E+03
	Rank	2	1	7	8	6	4	9	3	5
	Mean	7.1662E+05	1.1193E+06	2.5233E+08	1.4067E+11	8.4100E+08	1.4380E+06	2.1747E+11	8.7221E+06	1.1801E+08
	Std	3.3788E+05	5.0876E+05	8.5189E+07	1.8734E+10	4.4833E+08	5.1342E+05	1.2019E+10	4.3350E+06	3.9683E+08
	Best	3.0328E+05	3.7033E+05	1.2938E+08	1.0242E+11	3.3101E+08	5.8420E+05	1.9109E+11	3.0430E+06	8.3703E+05
f_{13}	Rank	1	2	6	8	7	3	9	4	5
	Mean	7.9545E+03	5.8725E+03	1.0927E+07	3.2339E+10	5.5108E+06	6.2611E+03	5.1025E+10	4.9248E+04	1.4152E+06
	Std	6.0438E+03	2.4442E+03	1.4896E+06	5.9684E+09	7.3829E+06	3.6543E+03	3.9909E+09	1.3940E+04	7.5138E+06
	Best	1.9495E+03	2.9251E+03	7.9274E+06	2.3436E+10	2.6526E+04	2.5549E+03	4.3108E+10	2.4864E+04	2.3556E+03
f_{14}	Rank	3	1	7	8	6	2	9	4	5
	Mean	1.1174E+06	6.1489E+05	2.3610E+06	3.2936E+07	2.1783E+06	1.2999E+05	1.3434E+08	6.7338E+04	8.7775E+04
	Std	4.6793E+05	3.2867E+05	9.4730E+05	1.3686E+07	4.5650E+06	4.1264E+04	3.0708E+07	2.8958E+04	3.1675E+04
	Best	2.2318E+05	1.0640E+05	5.2633E+05	1.8836E+07	2.3160E+05	6.1347E+04	5.6733E+07	1.4473E+04	1.5200E+04
f_{15}	Rank	5	4	7	8	6	3	9	1	2
	Mean	4.5790E+03	4.6219E+03	2.8878E+06	1.1748E+10	3.0977E+05	4.5003E+03	1.7978E+10	5.5026E+04	1.5009E+07
	Std	2.6766E+03	2.2144E+03	4.9578E+05	3.1233E+09	4.8080E+05	2.5111E+03	4.2537E+09	2.6044E+04	8.1311E+07
	Best	1.8690E+03	1.9315E+03	1.3182E+06	5.1438E+09	3.9869E+04	1.7898E+03	1.1912E+10	3.0227E+04	1.8546E+03
f_{16}	Rank	2	3	6	8	5	1	9	4	7
	Mean	5.0361E+03	4.8378E+03	5.4785E+03	1.7827E+04	8.3893E+03	5.9296E+03	2.2454E+04	5.6004E+03	3.6362E+03
	Std	2.4254E+02	9.5514E+02	6.0769E+02	2.0364E+03	1.1477E+03	6.7400E+02	1.3461E+03	5.6445E+02	6.0797E+02
	Best	4.4518E+03	3.5923E+03	4.4306E+03	1.4283E+04	5.9939E+03	4.0580E+03	1.9896E+04	4.6991E+03	2.6832E+03
f_{17}	Rank	3	2	4	8	7	6	9	5	1
	Mean	4.2621E+03	4.6077E+03	5.7420E+03	1.7146E+06	6.7554E+03	5.7413E+03	2.0707E+06	5.0977E+03	3.2758E+03
	Std	3.1421E+02	1.0560E+03	7.6497E+02	1.5798E+06	8.6206E+02	5.9891E+02	9.0645E+05	5.6080E+02	3.7070E+02
	Best	3.5884E+03	3.2932E+03	4.3391E+03	2.6970E+05	4.3835E+03	4.6083E+03	4.2912E+05	3.7248E+03	2.4134E+03
f_{18}	Rank	2	3	6	8	7	5	9	4	1
	Mean	1.8357E+06	1.6974E+06	3.4421E+06	5.4527E+07	1.9596E+06	3.3449E+05	2.4543E+08	1.7383E+05	1.8321E+05
	Std	7.5434E+05	8.6240E+05	1.3107E+06	2.6198E+07	1.5742E+06	9.9755E+04	8.8178E+07	4.6942E+04	9.5256E+04
	Best	5.2971E+05	4.3855E+05	1.2337E+06	1.4773E+07	5.4782E+05	1.6597E+05	1.1270E+08	1.1849E+05	5.7894E+04
f_{19}	Rank	5	4	7	8	6	3	9	1	2
	Mean	5.0291E+03	6.0002E+03	5.7559E+06	1.4973E+10	2.2289E+06	5.2138E+03	2.1539E+10	3.6915E+05	1.0618E+05
	Std	2.3492E+03	3.8486E+03	1.0435E+06	2.5408E+09	4.1825E+06	3.0082E+03	2.4762E+09	1.3384E+05	5.4990E+05
	Best	2.0771E+03	2.1440E+03	3.3370E+06	9.5348E+09	1.2724E+05	2.3899E+03	1.5523E+10	1.0976E+05	2.0688E+03
f_{20}	Rank	1	3	7	8	6	2	9	5	4
	Mean	4.0655E+03	4.2072E+03	6.9415E+03	6.4526E+03	5.7189E+03	5.3370E+03	8.0764E+03	4.6294E+03	2.8435E+03
	Std	2.0089E+02	5.4115E+02	2.8515E+02	4.5813E+02	5.4637E+02	5.4906E+02	2.2281E+02	4.8144E+02	3.7672E+02
	Best	3.6529E+03	3.5196E+03	6.3511E+03	5.4405E+03	4.6680E+03	4.3878E+03	7.5182E+03	3.5914E+03	2.1982E+03

Table S6 (continued)

Table S6 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
f_{21}	Rank	2	3	8	7	6	5	9	4	1
	Mean	2.7763E+03	2.7676E+03	3.1135E+03	4.2598E+03	3.7784E+03	3.0867E+03	4.7713E+03	3.0111E+03	2.6771E+03
	Std	5.1081E+01	1.0717E+02	5.9761E+01	1.3174E+02	1.9564E+02	8.8175E+01	1.1722E+02	1.2545E+02	4.7902E+01
	Best	2.6553E+03	2.6508E+03	2.9965E+03	4.0539E+03	3.3721E+03	2.9127E+03	4.3932E+03	2.7728E+03	2.5951E+03
f_{22}	Rank	3	2	6	8	7	5	9	4	1
	Mean	1.9196E+04	1.5769E+04	3.2800E+04	3.0948E+04	2.2586E+04	1.7690E+04	3.5042E+04	1.6441E+04	1.4489E+04
	Std	5.4193E+02	1.3059E+03	7.4134E+02	1.0277E+03	2.5345E+03	7.2703E+02	4.1111E+02	1.2265E+03	4.3997E+03
	Best	1.8163E+04	1.2458E+04	3.0624E+04	2.8201E+04	1.9650E+04	1.6029E+04	3.4146E+04	1.4626E+04	7.4754E+03
f_{23}	Rank	5	2	8	7	6	4	9	3	1
	Mean	3.1456E+03	3.2922E+03	3.5435E+03	7.1310E+03	5.1559E+03	3.4166E+03	6.3758E+03	3.6527E+03	3.3786E+03
	Std	3.5766E+01	8.8619E+01	5.9133E+01	1.7185E+02	4.7980E+02	9.3492E+01	2.0913E+02	1.4606E+02	1.3555E+02
	Best	3.0941E+03	3.1673E+03	3.4372E+03	6.7053E+03	4.3338E+03	3.2997E+03	5.9971E+03	3.4343E+03	3.2093E+03
f_{24}	Rank	1	2	5	9	7	4	8	6	3
	Mean	3.8037E+03	3.8729E+03	4.1648E+03	1.2068E+04	6.5089E+03	4.2629E+03	1.0121E+04	4.1918E+03	4.1235E+03
	Std	5.9561E+01	9.0410E+01	9.5199E+01	4.4535E+02	6.7679E+02	1.1928E+02	4.8060E+02	1.6720E+02	4.5568E+02
	Best	3.7101E+03	3.7162E+03	3.9921E+03	1.0827E+04	5.3067E+03	4.0557E+03	9.0165E+03	3.8523E+03	3.7114E+03
f_{25}	Rank	1	2	4	9	7	6	8	5	3
	Mean	3.2810E+03	3.2807E+03	3.4760E+03	2.3185E+04	3.9081E+03	3.3011E+03	3.5034E+04	3.2879E+03	3.2984E+03
	Std	6.3885E+01	7.0002E+01	7.0146E+01	2.1299E+03	1.5488E+02	4.3838E+01	5.2945E+01	8.2632E+01	6.5788E+01
	Best	3.1392E+03	3.1442E+03	3.3757E+03	1.6856E+04	3.6256E+03	3.2237E+03	3.4913E+04	3.1381E+03	3.1719E+03
f_{26}	Rank	2	1	6	8	7	5	9	3	4
	Mean	1.2488E+04	1.4860E+04	1.4746E+04	4.9209E+04	3.2578E+04	1.7393E+04	5.9023E+04	1.5150E+04	1.1683E+04
	Std	1.1535E+03	3.1138E+03	8.0889E+02	2.7045E+03	4.8329E+03	2.5664E+03	1.4044E+03	3.6064E+03	1.4191E+03
	Best	1.0415E+04	1.1264E+04	1.3404E+04	4.3743E+04	2.1734E+04	1.4055E+04	5.4096E+04	2.9000E+03	9.6240E+03
f_{27}	Rank	2	4	3	8	7	6	9	5	1
	Mean	3.4827E+03	3.7020E+03	3.5104E+03	1.3121E+04	4.3560E+03	3.9547E+03	1.1548E+04	3.8636E+03	3.6319E+03
	Std	6.6681E+01	1.0240E+02	8.0228E+01	8.2674E+02	3.9859E+02	1.5130E+02	6.0120E+02	2.0716E+02	8.9262E+01
	Best	3.3714E+03	3.5022E+03	3.4084E+03	1.1415E+04	3.8686E+03	3.6506E+03	1.0253E+04	3.4925E+03	3.4775E+03
f_{28}	Rank	1	4	2	9	7	6	8	5	3
	Mean	3.3623E+03	3.3804E+03	3.5163E+03	2.9789E+04	3.8931E+03	3.3431E+03	3.4522E+04	3.3640E+03	3.4196E+03
	Std	2.7630E+01	4.1051E+01	3.1281E+01	1.4873E+03	1.2041E+02	3.1113E+01	6.2834E+02	3.9914E+01	1.7632E+02
	Best	3.3269E+03	3.2979E+03	3.4650E+03	2.7306E+04	3.6883E+03	3.2953E+03	3.3561E+04	3.3106E+03	3.3434E+03
f_{29}	Rank	2	4	6	8	7	1	9	3	5
	Mean	6.1591E+03	6.4949E+03	7.1135E+03	1.0842E+05	1.1093E+04	7.7019E+03	5.5159E+05	8.2557E+03	5.6737E+03
	Std	2.7842E+02	9.2482E+02	5.2754E+02	5.4767E+04	1.0685E+03	5.0429E+02	2.8953E+05	4.5302E+02	3.5283E+02
	Best	5.7146E+03	5.4183E+03	6.1466E+03	5.3592E+04	8.4017E+03	6.6600E+03	1.6947E+05	7.1868E+03	5.1733E+03
f_{30}	Rank	2	3	4	8	7	5	9	6	1
	Mean	8.2507E+03	9.3956E+03	1.8226E+07	2.7811E+10	4.0590E+07	7.3498E+03	3.2470E+10	3.3007E+06	1.0140E+06

Table S6 (continued)

Table S6 (continued)

Functions	Quality	MAHSBOA	SBOA	MISBOA	HOA	TOC	MSO	DRA	VPPSO	TRADE
Std		2.1670E+03	3.3831E+03	4.6331E+06	3.9475E+09	3.5505E+07	1.0796E+03	4.3783E+09	9.8338E+05	4.6770E+06
Best		5.9671E+03	6.1934E+03	1.1235E+07	1.8794E+10	5.3491E+06	6.3935E+03	2.1886E+10	1.1049E+06	6.2946E+03
Rank		2	3	6	8	7	1	9	5	4
Ave.Rank		2.4828	2.8276	5.6552	7.9310	6.4483	3.8621	8.8621	3.7586	3.1724
Total.Rank		1	2	6	8	7	5	9	4	3

S2. Comparison of SBOA and its variants on CEC2022

In this section, Table S7 presents experimental results of the MAHSBOA algorithm and its variants on 12 functions within the 10-dimensional CEC2022 benchmark suite.

Table S7: Comparison of SBOA and its variants on CEC2022 in 10 dimensions (f_1-f_{12}).

Functions	Quality	MAHSBOA	SBOA	SBOA1	SBOA2	SBOA3
f_1	Mean	3.0000E+02	3.0000E+02	3.0000E+02	3.0000E+02	3.0000E+02
	Std	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	Best	3.0000E+02	3.0000E+02	3.0000E+02	3.0000E+02	3.0000E+02
	Rank	3	3	3	3	3
f_2	Mean	4.0125E+02	4.0499E+02	4.0153E+02	4.0221E+02	4.0164E+02
	Std	2.3597E+00	3.6469E+00	2.7519E+00	2.9202E+00	3.1410E+00
	Best	4.0000E+02	4.0001E+02	4.0000E+02	4.0000E+02	4.0000E+02
	Rank	1	5	2	4	3
f_3	Mean	6.0000E+02	6.0000E+02	6.0000E+02	6.0000E+02	6.0000E+02
	Std	0.0000E+00	1.7084E-05	1.7257E-04	9.7012E-05	2.0764E-06
	Best	6.0000E+02	6.0000E+02	6.0000E+02	6.0000E+02	6.0000E+02
	Rank	1	3	5	4	2
f_4	Mean	8.0559E+02	8.0919E+02	8.0706E+02	8.0783E+02	8.0473E+02
	Std	1.7251E+00	3.5891E+00	2.0466E+00	3.2291E+00	1.5868E+00
	Best	8.0298E+02	8.0398E+02	8.0298E+02	8.0298E+02	8.0100E+02
	Rank	2	5	3	4	1
f_5	Mean	9.0000E+02	9.0001E+02	9.0000E+02	9.0003E+02	9.0000E+02
	Std	0.0000E+00	2.2714E-02	0.0000E+00	5.3356E-02	0.0000E+00
	Best	9.0000E+02	9.0000E+02	9.0000E+02	9.0000E+02	9.0000E+02
	Rank	2	4	2	5	2
f_6	Mean	2.0657E+03	2.4975E+03	2.4031E+03	2.3278E+03	2.1547E+03
	Std	2.4755E+02	6.0032E+02	5.5840E+02	3.4735E+02	2.8847E+02
	Best	1.8057E+03	1.9605E+03	1.9258E+03	1.8608E+03	1.8808E+03
	Rank	1	5	4	3	2
f_7	Mean	2.0001E+03	2.0118E+03	2.0028E+03	2.0040E+03	2.0016E+03
	Std	2.1098E-01	2.2960E+01	5.1571E+00	6.9495E+00	3.5231E+00
	Best	2.0000E+03	2.0000E+03	2.0000E+03	2.0000E+03	2.0000E+03
	Rank	1	5	3	4	2
f_8	Mean	2.2012E+03	2.2085E+03	2.2069E+03	2.2114E+03	2.2071E+03
	Std	3.7613E+00	9.8344E+00	1.0050E+01	1.1290E+01	9.7685E+00
	Best	2.2000E+03	2.2001E+03	2.2001E+03	2.2001E+03	2.2003E+03
	Rank	1	4	2	5	3
f_9	Mean	2.5293E+03	2.5293E+03	2.5293E+03	2.5293E+03	2.5293E+03
	Std	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
	Best	2.5293E+03	2.5293E+03	2.5293E+03	2.5293E+03	2.5293E+03
	Rank	3	3	3	3	3
f_{10}	Mean	2.5506E+03	2.5609E+03	2.5433E+03	2.5464E+03	2.5393E+03
	Std	5.4834E+01	5.3915E+01	5.3633E+01	5.3695E+01	5.2264E+01
	Best	2.5002E+03	2.5001E+03	2.5002E+03	2.5001E+03	2.5002E+03
	Rank	4	5	2	3	1
f_{11}	Mean	2.6100E+03	2.6967E+03	2.7267E+03	2.7034E+03	2.6350E+03
	Std	5.4772E+01	1.4141E+02	1.6751E+02	1.5311E+02	9.3927E+01
	Best	2.6000E+03	2.6000E+03	2.6000E+03	2.6000E+03	2.6000E+03
	Rank	1	3	5	4	2

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Table S7 (Cont.): Comparison of SBOA and its variants on CEC2022 in 10 dimensions

Functions	Quality	MAHSBOA	SBOA	SBOA1	SBOA2	SBOA3
f_{12}	Mean	2.8618E+03	2.8621E+03	2.8637E+03	2.8645E+03	2.8630E+03
	Std	2.2427E+00	1.8433E+00	1.6938E+00	8.7396E-01	1.8674E+00
	Best	2.8586E+03	2.8586E+03	2.8594E+03	2.8624E+03	2.8594E+03
	Rank	1	2	4	5	3
Ave.Rank		1.7500	3.9167	3.1667	3.9167	2.2500
Total.Rank		1	4	3	5	2

S3. Comparison of objective function values for different image segmentation algorithms

In this section, Table S8 presents a comparison of objective function values for seven different segmentation algorithms across various threshold values in each image.

Table S8

Comparison of objective function values for different image segmentation algorithms.

Image	Threshold	MAHSBOA	SBOA	MISBOA	TOC	VPPSO	HOA	DRA
IE1-120	k = 2	1.657179E+08	1.657179E+08	1.657179E+08	1.657179E+08	1.657179E+08	1.657179E+08	1.655247E+08
	k = 4	1.797341E+08	1.797341E+08	1.791832E+08	1.797319E+08	1.797297E+08	1.797311E+08	1.781962E+08
	k = 6	1.829303E+08	1.829293E+08	1.824324E+08	1.828517E+08	1.825054E+08	1.826131E+08	1.811740E+08
	k = 8	1.841135E+08	1.840939E+08	1.833722E+08	1.839934E+08	1.840214E+08	1.840065E+08	1.829512E+08
	k = 10	1.847641E+08	1.847460E+08	1.839769E+08	1.846376E+08	1.846562E+08	1.845208E+08	1.837100E+08
	k = 12	1.850690E+08	1.850985E+08	1.843327E+08	1.849855E+08	1.849768E+08	1.847798E+08	1.842783E+08
IE2-120	k = 2	1.851157E+08	1.851157E+08	1.851155E+08	1.851157E+08	1.851157E+08	1.851155E+08	1.849635E+08
	k = 4	1.994759E+08	1.994759E+08	1.993078E+08	1.994706E+08	1.994759E+08	1.993825E+08	1.972004E+08
	k = 6	2.027677E+08	2.027646E+08	2.022312E+08	2.027370E+08	2.023298E+08	2.024283E+08	2.017611E+08
	k = 8	2.042034E+08	2.042117E+08	2.034690E+08	2.041921E+08	2.040920E+08	2.037293E+08	2.032131E+08
	k = 10	2.048538E+08	2.048240E+08	2.039104E+08	2.047252E+08	2.046324E+08	2.046889E+08	2.033595E+08
	k = 12	2.052715E+08	2.052393E+08	2.045003E+08	2.050983E+08	2.051101E+08	2.049348E+08	2.043767E+08
IE3-122	k = 2	1.574057E+08	1.574057E+08	1.573951E+08	1.574057E+08	1.574057E+08	1.574057E+08	1.571819E+08
	k = 4	1.660834E+08	1.660834E+08	1.659108E+08	1.660806E+08	1.660822E+08	1.660218E+08	1.651347E+08
	k = 6	1.685326E+08	1.685303E+08	1.678242E+08	1.685286E+08	1.685055E+08	1.683609E+08	1.673681E+08
	k = 8	1.695074E+08	1.694913E+08	1.689623E+08	1.694745E+08	1.695141E+08	1.693302E+08	1.686423E+08
	k = 10	1.700792E+08	1.700680E+08	1.696309E+08	1.700036E+08	1.698313E+08	1.698261E+08	1.695998E+08
	k = 12	1.703941E+08	1.703844E+08	1.699235E+08	1.702341E+08	1.702839E+08	1.701324E+08	1.695449E+08
IE4-100	k = 2	1.701160E+08	1.701160E+08	1.701132E+08	1.701160E+08	1.701160E+08	1.701160E+08	1.698148E+08
	k = 4	1.815439E+08	1.815415E+08	1.812057E+08	1.815423E+08	1.815439E+08	1.814419E+08	1.795779E+08
	k = 6	1.843872E+08	1.843873E+08	1.836412E+08	1.843583E+08	1.843865E+08	1.842435E+08	1.831488E+08
	k = 8	1.854833E+08	1.854771E+08	1.846267E+08	1.853606E+08	1.854464E+08	1.852917E+08	1.844707E+08
	k = 10	1.860452E+08	1.859591E+08	1.852463E+08	1.858955E+08	1.859356E+08	1.857071E+08	1.851441E+08
	k = 12	1.863361E+08	1.862967E+08	1.857528E+08	1.862409E+08	1.862579E+08	1.862150E+08	1.853988E+08
IE5-110	k = 2	1.500572E+08	1.500572E+08	1.500514E+08	1.500572E+08	1.500572E+08	1.500572E+08	1.498884E+08
	k = 4	1.592721E+08	1.592725E+08	1.590503E+08	1.592676E+08	1.592630E+08	1.592555E+08	1.585867E+08
	k = 6	1.619562E+08	1.619543E+08	1.615563E+08	1.619374E+08	1.616033E+08	1.618534E+08	1.608625E+08
	k = 8	1.629521E+08	1.629592E+08	1.622449E+08	1.629099E+08	1.629223E+08	1.628680E+08	1.621391E+08
	k = 10	1.634902E+08	1.634735E+08	1.630446E+08	1.634202E+08	1.634623E+08	1.631774E+08	1.627202E+08
	k = 12	1.638316E+08	1.638214E+08	1.631837E+08	1.637133E+08	1.637371E+08	1.634807E+08	1.631169E+08
IE6-110	k = 2	1.222744E+08	1.222744E+08	1.222683E+08	1.222744E+08	1.222744E+08	1.222744E+08	1.218984E+08
	k = 4	1.334196E+08	1.334196E+08	1.330688E+08	1.334110E+08	1.334196E+08	1.334180E+08	1.324088E+08
	k = 6	1.354538E+08	1.354538E+08	1.348993E+08	1.353832E+08	1.354275E+08	1.353803E+08	1.346325E+08
	k = 8	1.362213E+08	1.362175E+08	1.356794E+08	1.361594E+08	1.360816E+08	1.361096E+08	1.352205E+08
	k = 10	1.366155E+08	1.366218E+08	1.361206E+08	1.365262E+08	1.364866E+08	1.364130E+08	1.361275E+08
	k = 12	1.368743E+08	1.368588E+08	1.364065E+08	1.367301E+08	1.367965E+08	1.366832E+08	1.362321E+08