

Supplementary materials for

Lixin MIAO, Zhenxue HE, Xiaojun ZHAO, Yijin WANG, Xiaodan ZHANG, Kui YU, Limin XIAO, Zhisheng HUO, 2025. An adaptive dung beetle optimizer based on an elastic annealing mechanism and its application to numerical problems and optimization of Reed–Muller logic circuits. *Front Inform Technol Electron Eng*, 26(9):1577-1595. <https://doi.org/10.1631/FITEE.2400967>

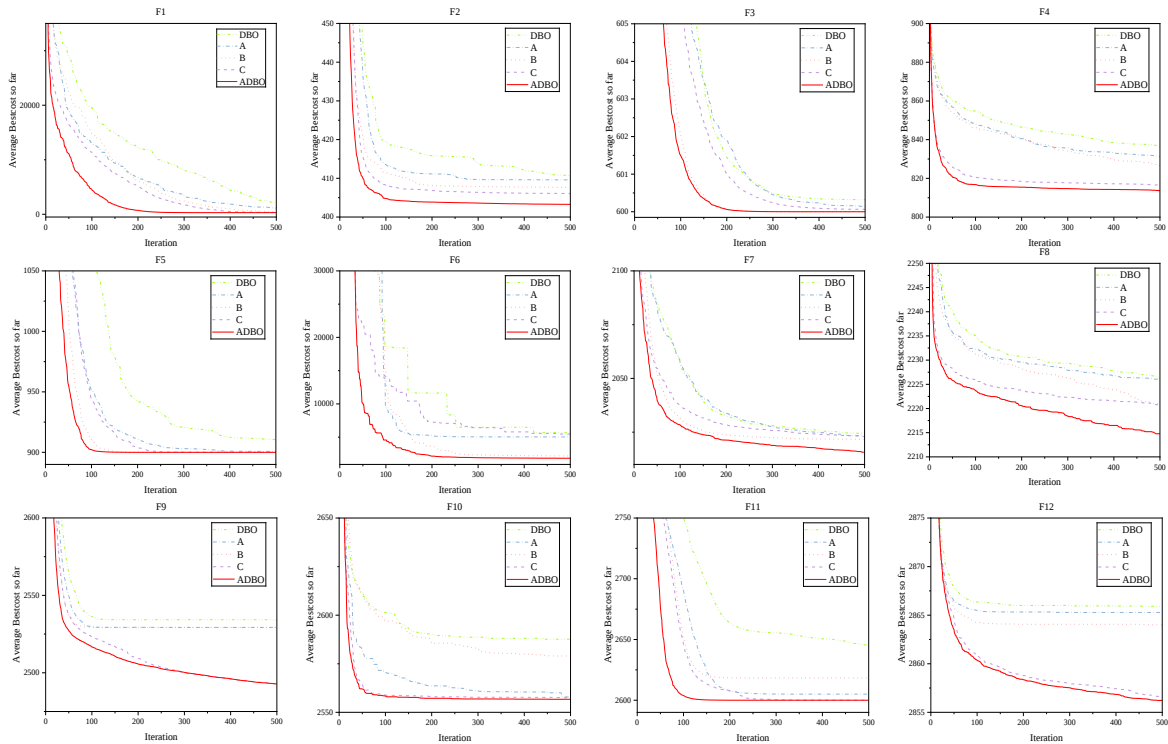


Fig. S1 Ablation experimental results

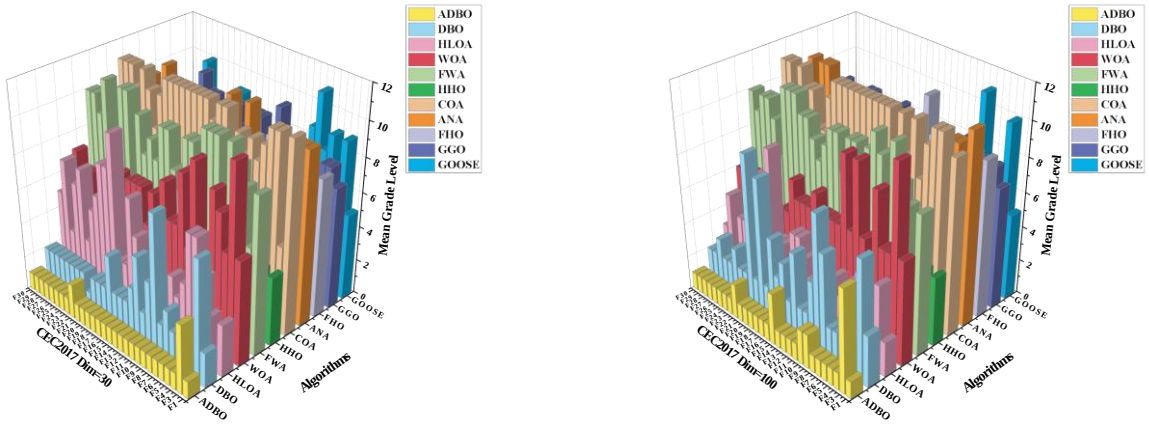


Fig. S2 Average rank of all algorithms on 30D and 100D CEC 2017 test sets

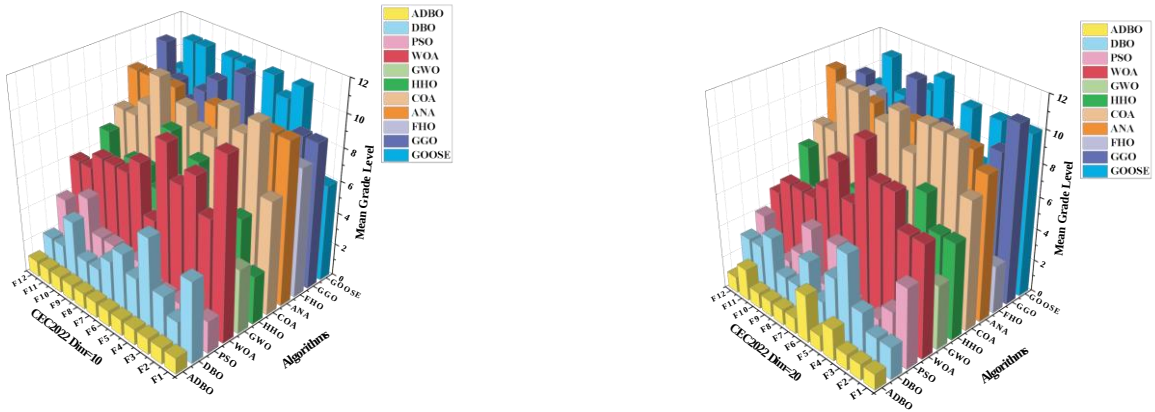


Fig. S3 Average rank of all algorithms on 10D and 20D CEC 2022 test sets

Table S1 10D CEC 2017 test set results

Function	Metric	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
F1	mean	2.29E+05	5.72E+07	5.16E+09	1.43E+06	1.04E+10	5.25E+09	2.66E+08	4.87E+09	2.42E+07	4.92E+03	2.30E+03
	rank	3	6	9	4	11	10	7	8	5	2	1
	Std	8.49E+05	7.46E+07	2.16E+09	2.18E+06	3.73E+09	3.00E+09	9.11E+07	2.50E+09	1.13E+08	3.96E+03	2.88E+03
F3	mean	3.29E+02	6.15E+03	8.19E+03	7.00E+02	1.06E+04	1.77E+04	3.22E+03	1.64E+04	5.22E+03	9.14E+02	3.00E+02
	rank	2	7	8	3	9	11	5	10	6	4	1
	Std	3.11E+01	4.94E+03	2.17E+03	3.71E+02	3.04E+03	1.10E+04	1.70E+03	9.22E+03	6.02E+03	5.89E+02	4.05E-04
F4	mean	4.19E+02	4.67E+02	6.66E+02	4.36E+02	1.20E+03	7.91E+02	4.37E+02	7.78E+02	4.34E+02	4.07E+02	4.02E+02
	rank	3	7	8	5	11	10	6	9	4	2	1
	Std	2.75E+01	5.72E+01	1.62E+02	4.42E+01	4.08E+02	2.45E+02	2.93E+01	2.37E+02	3.90E+01	1.43E+01	1.10E+00
F5	mean	5.73E+02	5.56E+02	5.81E+02	5.59E+02	5.97E+02	5.61E+02	5.37E+02	5.59E+02	5.84E+02	5.31E+02	5.13E+02
	rank	8	4	9	6	11	7	3	5	10	2	1
	Std	2.71E+01	2.18E+01	1.25E+01	2.04E+01	1.73E+01	1.78E+01	4.90E+00	1.73E+01	2.84E+01	1.18E+01	3.74E+00
F6	mean	6.50E+02	6.40E+02	6.44E+02	6.40E+02	6.49E+02	6.29E+02	6.12E+02	6.31E+02	6.59E+02	6.00E+02	6.00E+02
	rank	10	7	8	6	9	4	3	5	11	2	1
	Std	1.29E+01	1.17E+01	7.21E+00	1.12E+01	9.32E+00	8.69E+00	1.83E+00	9.50E+00	1.16E+01	3.62E-01	2.48E-02
F7	mean	7.96E+02	7.88E+02	8.23E+02	7.91E+02	8.00E+02	7.85E+02	7.55E+02	7.72E+02	1.00E+03	7.53E+02	7.33E+02
	rank	8	6	10	7	9	5	3	4	11	2	1
	Std	2.41E+01	2.53E+01	1.42E+01	2.00E+01	2.05E+01	2.54E+01	1.02E+01	2.15E+01	1.63E+02	1.24E+01	5.13E+00
F8	mean	8.42E+02	8.47E+02	8.61E+02	8.30E+02	8.55E+02	8.40E+02	8.32E+02	8.39E+02	8.62E+02	8.29E+02	8.15E+02
	rank	7	8	10	3	9	6	4	5	11	2	1
	Std	1.53E+01	1.82E+01	8.85E+00	9.14E+00	9.35E+00	1.21E+01	4.97E+00	1.26E+01	2.29E+01	8.95E+00	4.32E+00
F9	mean	1.62E+03	1.56E+03	1.35E+03	1.48E+03	1.56E+03	1.32E+03	1.01E+03	1.26E+03	2.27E+03	9.08E+02	9.00E+02
	rank	10	9	6	7	8	5	3	4	11	2	1
	Std	3.07E+02	3.93E+02	2.03E+02	2.55E+02	1.93E+02	2.38E+02	1.03E+02	2.51E+02	5.75E+02	3.65E+01	8.18E-01
F10	mean	2.38E+03	2.17E+03	2.89E+03	2.08E+03	2.64E+03	2.37E+03	2.51E+03	2.32E+03	2.47E+03	1.84E+03	1.55E+03
	rank	7	4	11	3	10	6	9	5	8	2	1
	Std	3.67E+02	3.62E+02	1.84E+02	2.89E+02	2.12E+02	3.39E+02	2.21E+02	2.74E+02	3.62E+02	4.13E+02	1.95E+02
F11	mean	1.19E+03	1.25E+03	1.78E+03	1.18E+03	2.61E+03	3.38E+03	1.59E+03	2.96E+03	1.38E+03	1.14E+03	1.10E+03
	rank	4	5	8	3	9	11	7	10	6	2	1
	Std	6.12E+01	8.99E+01	9.27E+02	7.25E+01	1.96E+03	3.05E+03	2.73E+02	2.28E+03	8.53E+02	5.92E+01	1.94E+00
F12	mean	1.08E+06	5.45E+06	1.02E+08	4.19E+06	2.97E+08	6.38E+07	8.08E+06	4.80E+07	1.33E+06	1.59E+05	3.20E+03
	rank	3	6	10	5	11	9	7	8	4	2	1
	Std	2.89E+06	5.68E+06	1.06E+08	4.23E+06	2.26E+08	1.33E+08	3.57E+06	8.74E+07	1.50E+06	9.43E+05	2.53E+03
F13	mean	6.32E+03	1.83E+04	1.15E+06	1.84E+04	8.75E+05	4.26E+06	1.60E+04	1.47E+06	1.79E+04	1.25E+04	1.33E+03
	rank	2	6	9	7	8	11	4	10	5	3	1
	Std	6.75E+03	1.53E+04	1.86E+06	1.51E+04	2.62E+06	3.13E+07	1.36E+04	5.28E+06	1.25E+04	1.09E+04	5.74E+00
F14	mean	1.93E+03	3.04E+03	6.16E+03	2.05E+03	1.57E+03	7.10E+03	1.82E+03	7.07E+03	7.60E+03	1.82E+03	1.43E+03
	rank	5	7	8	6	2	10	3	9	11	4	1
	Std	2.73E+03	1.78E+03	2.69E+03	1.01E+03	6.44E+01	5.88E+03	5.43E+02	5.61E+03	6.38E+03	5.89E+02	2.62E+00
F15	mean	2.71E+03	9.45E+03	1.29E+04	7.50E+03	8.59E+03	2.26E+04	3.31E+03	2.28E+04	3.10E+04	3.37E+03	1.51E+03
	rank	2	7	8	5	6	9	3	10	11	4	1
	Std	2.06E+03	7.87E+03	6.61E+03	3.23E+03	3.73E+03	1.98E+04	1.68E+03	1.98E+04	3.73E+04	2.47E+03	2.57E+00
F16	mean	2.08E+03	1.95E+03	2.04E+03	1.94E+03	2.09E+03	2.01E+03	1.92E+03	1.98E+03	2.21E+03	1.69E+03	1.61E+03
	rank	9	5	8	4	10	7	3	6	11	2	1
	Std	1.90E+02	1.57E+02	1.17E+02	1.53E+02	1.10E+02	1.44E+02	1.16E+02	1.61E+02	2.20E+02	8.35E+01	3.85E+01
F17	mean	1.91E+03	1.83E+03	1.83E+03	1.79E+03	1.81E+03	1.83E+03	1.77E+03	1.85E+03	2.06E+03	1.78E+03	1.73E+03
	rank	10	6	8	4	5	7	2	9	11	3	1
	Std	1.30E+02	6.77E+01	2.90E+01	4.93E+01	3.64E+01	9.03E+01	1.10E+01	9.39E+01	2.02E+02	3.51E+01	9.00E+00
F18	mean	1.29E+04	1.70E+04	4.99E+06	1.43E+04	9.21E+06	3.44E+07	2.46E+06	3.91E+07	2.16E+04	2.20E+04	1.83E+03
	rank	2	4	8	3	9	10	7	11	5	6	1
	Std	1.32E+04	1.16E+04	5.64E+06	1.09E+04	2.33E+07	8.45E+07	2.37E+07	1.14E+08	1.38E+04	1.41E+04	2.44E+00
F19	mean	8.66E+03	1.04E+05	1.91E+05	1.94E+04	1.48E+04	2.25E+05	5.69E+03	2.95E+05	1.18E+04	7.61E+03	1.90E+03
	rank	4	8	9	7	6	10	2	11	5	3	1
	Std	1.99E+04	2.03E+05	2.79E+05	2.27E+04	2.81E+04	8.84E+05	4.49E+03	9.31E+05	8.17E+03	7.17E+03	1.24E+00
F20	mean	2.25E+03	2.20E+03	2.23E+03	2.20E+03	2.24E+03	2.18E+03	2.10E+03	2.17E+03	2.31E+03	2.06E+03	2.01E+03
	rank	10	6	8	7	9	5	3	4	11	2	1
	Std	1.18E+02	8.00E+01	4.78E+01	7.22E+01	5.72E+01	7.39E+01	3.16E+01	7.77E+01	1.22E+02	5.13E+01	1.05E+01
F21	mean	2.36E+03	2.33E+03	2.30E+03	2.33E+03	2.37E+03	2.35E+03	2.33E+03	2.34E+03	2.35E+03	2.30E+03	2.28E+03
	rank	10	5	2	6	11	8	4	7	9	3	1
	Std	3.71E+01	4.85E+01	5.28E+01	6.21E+01	5.00E+01	3.04E+01	3.25E+01	2.95E+01	6.30E+01	5.63E+01	5.44E+01
F22	mean	2.49E+03	2.40E+03	2.70E+03	2.39E+03	3.06E+03	2.65E+03	2.36E+03	2.68E+03	2.59E+03	2.30E+03	2.30E+03
	rank	6	5	10	4	11	8	3	9	7	2	1
	Std	4.88E+02	3.23E+02	1.31E+02	3.16E+02	3.44E+02	3.43E+02	3.34E+01	3.57E+02	5.71E+02	1.12E+01	1.65E+01
F23	mean	2.70E+03	2.66E+03	2.75E+03	2.68E+03	2.72E+03	2.72E+03	2.66E+03	2.73E+03	2.77E+03	2.63E+03	2.61E+03
	rank	6	4	10	5	7	8	3	9	11	2	1
	Std	4.63E+01	2.57E+01	2.81E+01	3.49E+01	3.45E+01	4.25E+01	1.50E+01	4.04E+01	7.64E+01	1.18E+01	3.60E+00
F24	mean	2.82E+03	2.78E+03	2.74E+03	2.81E+03	2.87E+03	2.85E+03	2.76E+03	2.84E+03	2.90E+03	2.74E+03	2.73E+03
	rank	7	5	2	6	10	9	4	8	11	3	1
	Std	8.91E+01	6.60E+01	8.82E+01	7.98E+01	7.37E+01	7.35E+01	4.22E+01	7.20E+01	1.12E+02	7.39E+01	6.25E+01
F25	mean	2.94E+03	2.97E+03	3.15E+03	2.94E+03	3.44E+03	3.17E+03	2.96E+03	3.10E+03	2.96E+03	2.94E+03	2.92E+03
	rank	3	7	9	2	11	10	5	8	6	4	1
	Std	4.57E+01	3.38E+01	9.40E+01	2.84E+01	2.31E+02	1.60E+02	2.54E+01	1.44E+02	1.29E+02	2.93E+01	2.32E+01
F26	mean	3.93E+03	3.60E+03	3.64E+03	3.63E+03	4.20E+03	3.83E+03	3.11E+03	3.74E+03	4.10E+03	3.09E+03	2.90E+03
	rank	9	4	6	5	11	8	3	7	10	2	1
	Std	6.17E+02	5.91E+02	2.40E+02	5.79E+02	3.32E+02	4.26E+02	3.19E+02	4.15E+02	6.20E+02	3.76E+02	1.08E+02
F27	mean	3.17E+03	3.15E+03	3.23E+03	3.17E+03	3.20E+03	3.26E+03	3.15E+03	3.27E+03	3.23E+03	3.10E+03	3.09E+03
	rank	5	4	9	6	7	10	3	11	8	2	1
	Std	5.71E+01	4.75E+01	4.05E+01	5.30E+01	4.58E+01	5.44E+01	3.81E+01	7.30E+01	6.38E+01	1.74E+01	6.41E+00
F28	mean	3.38E+03	3.48E+03	3.68E+03	3.41E+03	3.76E+03	3.71E+03	3.57E+03	3.67E+03	3.44E+03	3.41E+03	3.25E+03
	rank	2	6	9	3	11	10	7	8	5	4	1
	Std	1.85E+02	1.53E+02	1.16E+02	1.22E+02	1.14E+02	1.48E+02	1.70E+02	1.73E+02	1.51E+02	1.54E+02	8.30E+01
F29	mean	3.51E+03	3.40E+03	3.42E+03	3.35E+03	3.43E+03	3.35E+03	3.25E+03	3.34E+03	3.56E+03	3.23E+03	3.16E+03
	rank	10	7	8	5	9	6	3	4	11	2	1
	Std	1.59E+02	1.06E+02	7.61E+01	1.02E+02	9.87E+01	1.22E+02	5.59E+01	8.53E+01	1.97E+02	5.66E+01	

Table S2 30D CEC 2017 test set results

Function	Metric	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
F1	mean	1.52E+08	5.31E+09	4.04E+10	4.55E+08	5.88E+10	4.39E+10	3.84E+10	3.57E+10	1.73E+09	3.79E+06	2.17E+04
	rank	3	6	9	4	11	10	8	7	5	2	1
	std	9.01E+07	1.73E+09	5.59E+09	2.86E+08	7.32E+09	9.75E+09	1.06E+10	8.68E+09	2.65E+09	4.19E+06	1.81E+04
F3	mean	3.60E+04	2.60E+05	8.58E+04	5.77E+04	8.45E+04	1.48E+05	6.35E+04	1.39E+05	1.46E+05	9.08E+04	6.68E+04
	rank	1	11	6	2	5	10	3	8	9	7	4
	std	9.57E+03	6.09E+04	7.69E+03	7.27E+03	6.37E+03	4.14E+04	1.08E+04	3.39E+04	4.29E+04	1.88E+04	1.27E+04
F4	mean	5.93E+02	1.33E+03	1.03E+04	7.06E+02	1.56E+04	1.25E+04	6.10E+03	9.94E+03	7.62E+02	5.25E+02	4.66E+02
	rank	3	6	9	4	11	10	7	8	5	2	1
	std	5.77E+01	4.20E+02	2.41E+03	1.05E+02	2.93E+03	3.56E+03	3.53E+03	2.82E+03	3.44E+02	2.87E+01	2.67E+01
F5	mean	8.05E+02	8.67E+02	9.11E+02	7.69E+02	9.26E+02	8.41E+02	7.95E+02	8.23E+02	8.79E+02	7.56E+02	6.46E+02
	rank	5	8	10	3	11	7	4	6	9	2	1
	std	3.73E+01	5.42E+01	2.67E+01	3.21E+01	2.53E+01	4.83E+01	3.79E+01	3.93E+01	8.06E+01	4.69E+01	2.45E+01
F6	mean	6.76E+02	6.83E+02	6.90E+02	6.69E+02	6.90E+02	6.70E+02	6.47E+02	6.68E+02	6.77E+02	6.21E+02	6.05E+02
	rank	7	9	11	5	10	6	3	4	8	2	1
	std	9.46E+00	1.25E+01	7.08E+00	6.74E+00	6.87E+00	9.71E+00	7.69E+00	9.39E+00	9.81E+00	9.80E+00	3.04E+00
F7	mean	1.35E+03	1.32E+03	1.38E+03	1.32E+03	1.42E+03	1.53E+03	1.31E+03	1.30E+03	2.36E+03	1.07E+03	9.46E+02
	rank	7	5	8	6	9	10	4	3	11	2	1
	std	6.71E+01	8.81E+01	4.91E+01	5.80E+01	5.85E+01	1.39E+02	7.46E+01	1.15E+02	8.77E+02	5.41E+01	1.82E+01
F8	mean	1.03E+03	1.07E+03	1.14E+03	9.89E+02	1.14E+03	1.09E+03	1.06E+03	1.07E+03	1.09E+03	1.02E+03	9.36E+02
	rank	4	6	11	2	10	8	5	7	9	3	1
	std	3.43E+01	4.77E+01	2.07E+01	2.57E+01	2.47E+01	4.26E+01	2.31E+01	3.16E+01	8.40E+01	5.59E+01	2.07E+01
F9	mean	7.17E+03	1.14E+04	1.14E+04	8.97E+03	1.09E+04	7.71E+03	7.32E+03	7.35E+03	8.51E+03	6.83E+03	1.76E+03
	rank	3	10	11	8	9	6	4	5	7	2	1
	std	1.28E+03	3.11E+03	1.48E+03	1.00E+03	1.39E+03	1.88E+03	1.63E+03	2.11E+03	2.77E+03	1.84E+03	8.66E+02
F10	mean	6.98E+03	7.45E+03	8.94E+03	6.22E+03	8.90E+03	7.49E+03	8.65E+03	7.48E+03	5.81E+03	8.47E+03	5.07E+03
	rank	4	5	11	3	10	7	9	6	2	8	1
	std	8.26E+02	6.90E+02	3.68E+02	6.76E+02	4.74E+02	6.26E+02	4.50E+02	6.08E+02	7.45E+02	4.90E+02	3.28E+02
F11	mean	1.47E+03	1.01E+04	7.40E+03	1.61E+03	8.77E+03	1.06E+04	5.15E+03	1.01E+04	1.74E+03	1.69E+03	1.23E+03
	rank	2	9	7	3	8	11	6	10	5	4	1
	std	1.08E+02	4.46E+03	1.28E+03	2.27E+02	1.86E+03	5.09E+03	4.20E+03	4.32E+03	6.73E+02	2.43E+02	2.70E+01
F12	mean	3.98E+07	4.72E+08	1.09E+10	8.37E+07	1.42E+10	8.91E+09	1.36E+09	7.71E+09	6.70E+07	3.73E+06	2.91E+06
	rank	3	6	10	5	11	9	7	8	4	2	1
	std	2.89E+07	3.22E+08	2.39E+09	7.50E+07	3.54E+09	3.20E+09	8.55E+08	2.52E+09	1.54E+08	3.57E+06	1.60E+06
F13	mean	1.03E+06	1.02E+07	7.71E+09	1.19E+06	1.04E+10	7.45E+09	3.10E+08	5.68E+09	1.36E+05	2.20E+06	7.54E+04
	rank	3	6	10	4	11	9	7	8	2	5	1
	std	2.14E+06	9.06E+06	3.22E+09	7.31E+05	4.47E+09	4.27E+09	1.50E+08	3.40E+09	9.25E+04	1.23E+07	9.20E+04
F14	mean	2.23E+05	2.82E+06	2.48E+06	1.30E+06	3.60E+06	4.05E+06	9.28E+05	3.29E+06	2.00E+05	2.05E+05	1.66E+03
	rank	4	8	7	6	10	11	5	9	2	3	1
	std	2.61E+05	2.62E+06	1.22E+06	1.22E+06	2.99E+06	5.07E+06	7.09E+05	3.11E+06	3.50E+05	2.37E+05	5.01E+01
F15	mean	4.73E+04	6.92E+06	1.59E+08	1.17E+05	8.51E+08	2.91E+08	2.35E+07	1.71E+08	6.54E+04	1.23E+04	5.56E+03
	rank	3	6	8	5	11	10	7	9	4	2	1
	std	4.89E+04	8.63E+06	1.38E+08	6.97E+04	5.88E+08	4.03E+08	8.42E+07	2.63E+08	6.85E+04	1.29E+04	1.92E+03
F16	mean	3.88E+03	4.41E+03	5.39E+03	3.71E+03	6.02E+03	4.76E+03	3.85E+03	4.69E+03	3.95E+03	3.15E+03	2.70E+03
	rank	5	7	10	3	11	9	4	8	6	2	1
	std	6.48E+02	6.92E+02	6.46E+02	5.01E+02	9.78E+02	9.06E+02	3.12E+02	8.40E+02	5.81E+02	5.12E+02	2.39E+02
F17	mean	2.95E+03	2.80E+03	3.50E+03	2.68E+03	5.27E+03	3.23E+03	2.49E+03	3.09E+03	2.91E+03	2.31E+03	2.04E+03
	rank	7	5	10	4	11	9	3	8	6	2	1
	std	3.49E+02	2.91E+02	3.81E+02	2.93E+02	3.40E+03	1.45E+03	1.45E+02	8.38E+02	3.48E+02	2.15E+02	1.12E+02
F18	mean	1.76E+06	1.41E+07	2.47E+07	4.05E+06	6.20E+07	3.26E+07	9.88E+06	2.95E+07	1.05E+06	2.64E+06	9.68E+04
	rank	3	7	8	5	11	10	6	9	2	4	1
	std	2.04E+06	1.73E+07	1.60E+07	5.79E+06	4.84E+07	4.40E+07	1.17E+07	3.16E+07	9.94E+05	3.39E+06	4.01E+04
F19	mean	4.44E+05	2.53E+07	3.79E+08	1.48E+06	7.42E+08	3.85E+08	2.41E+07	2.31E+08	1.38E+06	5.90E+04	6.88E+03
	rank	3	7	9	5	11	10	6	8	4	2	1
	std	8.61E+05	2.35E+07	2.34E+08	1.05E+06	4.63E+08	5.38E+08	9.24E+06	2.80E+08	7.72E+05	1.85E+05	4.35E+03
F20	mean	3.05E+03	2.92E+03	3.00E+03	2.83E+03	3.07E+03	2.88E+03	2.84E+03	2.90E+03	3.01E+03	2.70E+03	2.42E+03
	rank	10	7	8	3	11	5	4	6	9	2	1
	std	2.63E+02	2.08E+02	1.30E+02	2.23E+02	2.02E+02	2.07E+02	1.93E+02	2.28E+02	2.58E+02	1.87E+02	1.26E+02
F21	mean	2.66E+03	2.64E+03	2.71E+03	2.59E+03	2.75E+03	2.65E+03	2.55E+03	2.63E+03	2.70E+03	2.53E+03	2.43E+03
	rank	8	6	10	4	11	7	3	5	9	2	1
	std	6.81E+01	4.90E+01	3.98E+01	6.19E+01	5.09E+01	4.90E+01	2.43E+01	4.20E+01	6.81E+01	5.07E+01	2.16E+01
F22	mean	8.25E+03	7.89E+03	7.70E+03	7.06E+03	9.55E+03	8.70E+03	7.79E+03	8.42E+03	7.39E+03	2.55E+03	3.43E+03
	rank	8	7	5	3	11	10	6	9	4	1	2
	std	1.09E+03	1.91E+03	7.99E+02	1.48E+03	7.74E+02	1.07E+03	1.47E+03	1.40E+03	1.34E+03	1.27E+03	1.88E+03
F23	mean	3.37E+03	3.16E+03	3.66E+03	3.26E+03	3.65E+03	3.51E+03	3.05E+03	3.51E+03	3.49E+03	2.86E+03	2.78E+03
	rank	6	4	11	5	10	8	3	9	7	2	1
	std	1.84E+02	9.64E+01	1.59E+02	1.27E+02	1.59E+02	1.53E+02	1.19E+02	1.30E+02	1.96E+02	7.12E+01	2.69E+01
F24	mean	3.48E+03	3.26E+03	3.95E+03	3.50E+03	3.80E+03	3.85E+03	3.35E+03	3.88E+03	3.73E+03	3.05E+03	2.93E+03
	rank	5	3	11	6	8	9	4	10	7	2	1
	std	1.76E+02	1.03E+02	1.75E+02	1.66E+02	1.68E+02	1.98E+02	1.31E+02	1.74E+02	1.19E+02	5.47E+01	2.46E+01
F25	mean	3.00E+03	3.23E+03	4.42E+03	3.01E+03	5.10E+03	5.22E+03	4.43E+03	4.37E+03	3.02E+03	2.90E+03	2.89E+03
	rank	3	6	8	4	10	11	9	7	5	2	1
	std	3.45E+01	7.95E+01	3.86E+02	3.58E+01	4.72E+02	7.97E+02	5.70E+02	5.02E+02	1.09E+02	1.52E+01	4.95E+00
F26	mean	9.76E+03	8.52E+03	9.91E+03	8.00E+03	1.18E+04	1.01E+04	7.35E+03	9.64E+03	1.07E+04	4.98E+03	4.50E+03
	rank	7	5	8	4	11	9	3	6	10	2	1
	std	1.75E+03	1.08E+03	6.71E+02	1.46E+03	8.77E+02	9.45E+02	6.64E+02	8.31E+02	2.58E+03	1.47E+03	1.02E+03
F27	mean	3.72E+03	3.49E+03	4.60E+03	3.57E+03	4.56E+03	4.46E+03	3.64E+03	4.45E+03	4.23E+03	3.26E+03	3.21E+03
	rank	6	3	11	4	10	9	5	8	7	2	1
	std	4.01E+02	1.32E+02	2.92E+02	1.90E+02	4.24E+02	3.21E+02	1.82E+02	2.57E+02	4.76E+02	4.62E+01	1.13E+01
F28	mean	3.35E+03	3.89E+03	6.02E+03	3.49E+03	7.54E+03	6.56E+03	5.45E+03	5.99E+03	3.63E+03	3.28E+03	3.23E+03
	rank	3	6	9	4	11	10	7	8	5	2	1
	std	4.54E+01	2.81E+02	5.01E+02	9.40E+01	6.38E+02	1.03E+03	8.70E+02	7.41E+02			

Table S3 50D CEC 2017 test set results

Function	Metric	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
F1	mean	9.71E+08	2.11E+10	9.53E+10	5.26E+09	1.13E+11	1.06E+11	9.55E+10	8.46E+10	9.83E+09	1.27E+09	6.69E+06
	rank	2	6	8	4	11	10	9	7	5	3	1
	std	3.75E+08	4.64E+09	6.92E+09	1.90E+09	7.93E+09	1.50E+10	1.24E+10	1.24E+10	1.18E+10	1.12E+09	4.93E+06
F3	mean	2.38E+05	3.00E+05	1.90E+05	1.71E+05	1.98E+05	2.82E+05	3.25E+05	2.61E+05	3.33E+05	2.08E+05	1.81E+05
	rank	6	9	3	1	4	8	10	7	11	5	2
	std	6.28E+04	1.00E+05	2.12E+04	1.82E+04	2.62E+04	6.24E+04	8.74E+04	5.18E+04	7.44E+04	3.23E+04	3.05E+04
F4	mean	9.22E+02	5.00E+03	2.58E+04	1.79E+03	3.94E+04	3.20E+04	2.54E+04	2.45E+04	2.59E+03	7.87E+02	5.98E+02
	rank	3	6	9	4	11	10	8	7	5	2	1
	std	1.17E+02	1.56E+03	3.53E+03	3.47E+02	5.41E+03	8.26E+03	9.35E+03	5.16E+03	1.87E+03	1.25E+02	3.76E+01
F5	mean	1.00E+03	1.12E+03	1.19E+03	9.31E+02	1.21E+03	1.16E+03	1.10E+03	1.11E+03	1.11E+03	9.88E+02	8.54E+02
	rank	4	8	10	2	11	9	5	7	6	3	1
	std	5.71E+01	8.46E+01	2.97E+01	2.93E+01	2.38E+01	5.67E+01	3.62E+01	5.90E+01	1.82E+02	8.55E+01	3.32E+01
F6	mean	6.86E+02	6.98E+02	7.04E+02	6.80E+02	7.03E+02	6.87E+02	6.75E+02	6.85E+02	6.81E+02	6.53E+02	6.31E+02
	rank	7	9	11	4	10	8	3	6	5	2	1
	std	8.76E+00	1.18E+01	4.87E+00	4.47E+00	4.37E+00	8.65E+00	8.37E+00	9.02E+00	9.93E+00	1.38E+01	1.34E+01
F7	mean	1.90E+03	1.91E+03	1.98E+03	1.89E+03	2.06E+03	2.57E+03	1.93E+03	1.98E+03	3.66E+03	1.55E+03	1.24E+03
	rank	4	5	7	3	9	10	6	8	11	2	1
	std	7.75E+01	1.16E+02	6.24E+01	8.29E+01	5.40E+01	2.58E+02	7.92E+01	1.93E+02	1.74E+03	1.17E+02	3.65E+01
F8	mean	1.33E+03	1.40E+03	1.52E+03	1.23E+03	1.50E+03	1.46E+03	1.39E+03	1.42E+03	1.44E+03	1.33E+03	1.16E+03
	rank	3	6	11	2	10	9	5	7	8	4	1
	std	5.20E+01	7.73E+01	2.53E+01	3.42E+01	3.14E+01	6.33E+01	4.12E+01	5.33E+01	1.71E+02	8.18E+01	4.23E+01
F9	mean	2.41E+04	3.83E+04	4.08E+04	3.20E+04	3.78E+04	2.78E+04	2.80E+04	2.63E+04	2.08E+04	2.76E+04	1.12E+04
	rank	3	10	11	8	9	6	7	4	2	5	1
	std	3.50E+03	1.11E+04	2.95E+03	3.11E+03	3.49E+03	6.19E+03	4.91E+03	6.18E+03	6.53E+03	5.96E+03	4.88E+03
F10	mean	1.19E+04	1.32E+04	1.54E+04	1.06E+04	1.54E+04	1.31E+04	1.48E+04	1.31E+04	9.09E+03	1.48E+04	8.94E+03
	rank	4	7	10	3	11	5	8	6	2	9	1
	std	1.14E+03	9.08E+02	4.75E+02	1.31E+03	5.22E+02	7.55E+02	7.69E+02	6.27E+02	9.25E+02	6.98E+02	5.48E+02
F11	mean	2.42E+03	8.72E+03	2.01E+04	3.05E+03	2.63E+04	3.36E+04	1.09E+04	2.97E+04	5.77E+03	4.54E+03	1.53E+03
	rank	2	6	8	3	9	11	7	10	5	4	1
	std	4.96E+02	2.27E+03	2.15E+03	7.39E+02	2.21E+03	1.12E+04	3.25E+03	9.51E+03	4.22E+03	1.73E+03	6.57E+01
F12	mean	4.27E+08	4.51E+09	6.09E+10	9.35E+08	8.87E+10	5.87E+10	1.97E+10	5.38E+10	7.19E+08	6.74E+07	3.24E+07
	rank	3	6	10	5	11	9	7	8	4	2	1
	std	2.59E+08	2.08E+09	9.92E+09	5.92E+08	1.52E+10	1.48E+10	1.54E+10	1.29E+10	1.03E+09	5.99E+07	1.82E+07
F13	mean	1.68E+07	5.50E+08	3.20E+10	2.52E+07	5.30E+10	2.84E+10	2.39E+09	2.58E+10	1.79E+05	1.03E+05	1.18E+05
	rank	4	6	10	5	11	9	7	8	3	1	2
	std	3.99E+07	3.14E+08	9.35E+09	2.13E+07	1.24E+10	9.92E+09	2.08E+09	9.61E+09	1.52E+05	8.03E+04	5.22E+05
F14	mean	1.69E+06	7.30E+06	4.68E+07	5.16E+06	9.79E+07	7.47E+07	1.26E+07	7.38E+07	6.49E+05	1.52E+06	3.68E+04
	rank	4	6	8	5	11	10	7	9	2	3	1
	std	2.45E+06	5.69E+06	2.61E+07	3.91E+06	6.61E+07	5.45E+07	1.44E+07	5.19E+07	8.98E+05	1.60E+06	2.46E+04
F15	mean	2.05E+06	6.13E+07	4.38E+09	1.47E+06	9.40E+09	4.94E+09	6.06E+08	3.75E+09	5.17E+04	4.32E+04	5.93E+04
	rank	5	6	9	4	11	10	7	8	2	1	3
	std	1.04E+07	6.31E+07	1.30E+09	7.69E+05	3.50E+09	3.13E+09	6.11E+08	2.11E+09	4.66E+04	4.18E+04	1.23E+05
F16	mean	5.72E+03	6.37E+03	8.19E+03	4.71E+03	1.04E+04	7.38E+03	5.72E+03	7.33E+03	4.96E+03	4.53E+03	3.74E+03
	rank	5	7	10	3	11	9	6	8	4	2	1
	std	1.04E+03	9.33E+02	8.20E+02	6.33E+02	1.77E+03	1.01E+03	6.19E+02	1.21E+03	7.48E+02	9.47E+02	2.83E+02
F17	mean	4.37E+03	4.48E+03	7.00E+03	3.84E+03	1.41E+04	7.76E+03	4.36E+03	5.10E+03	4.00E+03	3.97E+03	3.18E+03
	rank	6	7	9	2	11	10	5	8	4	3	1
	std	5.26E+02	6.87E+02	1.65E+03	4.03E+02	8.87E+03	9.12E+03	6.09E+02	1.41E+03	4.49E+02	5.48E+02	2.33E+02
F18	mean	5.35E+06	6.72E+07	1.08E+08	1.04E+07	2.06E+08	1.22E+08	1.90E+07	1.20E+08	3.26E+06	1.04E+07	1.05E+06
	rank	3	7	8	5	11	10	6	9	2	4	1
	std	5.48E+06	4.75E+07	5.26E+07	8.70E+06	9.48E+07	8.31E+07	1.32E+07	7.59E+07	3.07E+06	8.15E+06	6.91E+05
F19	mean	1.31E+06	2.34E+07	2.69E+09	2.50E+06	4.04E+09	2.29E+09	2.65E+08	1.95E+09	2.62E+06	8.19E+04	5.43E+04
	rank	3	6	10	4	11	9	7	8	5	2	1
	std	1.38E+06	2.63E+07	1.21E+09	2.53E+06	1.67E+09	1.48E+09	3.08E+08	1.48E+09	1.94E+06	2.42E+05	7.02E+04
F20	mean	4.08E+03	3.91E+03	4.30E+03	3.56E+03	4.25E+03	3.92E+03	3.80E+03	3.91E+03	4.05E+03	4.01E+03	3.25E+03
	rank	9	4	11	2	10	6	3	5	8	7	1
	std	3.95E+02	3.41E+02	2.03E+02	3.21E+02	2.29E+02	3.62E+02	1.93E+02	3.40E+02	4.05E+02	2.79E+02	2.11E+02
F21	mean	3.12E+03	3.07E+03	3.15E+03	2.93E+03	3.24E+03	3.05E+03	2.90E+03	3.02E+03	3.08E+03	2.81E+03	2.62E+03
	rank	9	7	10	4	11	6	3	5	8	2	1
	std	1.20E+02	1.07E+02	5.49E+01	9.02E+01	1.04E+02	7.89E+01	5.61E+01	7.53E+01	1.18E+02	8.06E+01	4.18E+01
F22	mean	1.39E+04	1.49E+04	1.74E+04	1.24E+04	1.71E+04	1.51E+04	1.63E+04	1.52E+04	1.08E+04	1.58E+04	1.04E+04
	rank	4	5	11	3	10	6	9	7	2	8	1
	std	1.38E+03	9.48E+02	4.74E+02	9.72E+02	5.32E+02	9.06E+02	1.19E+03	8.53E+02	9.76E+02	2.93E+03	4.54E+02
F23	mean	4.28E+03	3.87E+03	4.81E+03	4.01E+03	4.62E+03	4.53E+03	3.58E+03	4.56E+03	4.34E+03	3.26E+03	3.08E+03
	rank	6	4	11	5	10	8	3	9	7	2	1
	std	3.05E+02	1.85E+02	2.27E+02	2.17E+02	1.98E+02	2.55E+02	1.97E+02	2.56E+02	2.67E+02	1.06E+02	5.01E+01
F24	mean	4.41E+03	3.91E+03	5.21E+03	4.38E+03	4.91E+03	5.07E+03	4.10E+03	5.03E+03	4.44E+03	3.43E+03	3.20E+03
	rank	6	3	11	5	8	10	4	9	7	2	1
	std	3.61E+02	1.49E+02	2.89E+02	2.75E+02	2.73E+02	3.02E+02	2.03E+02	3.08E+02	1.63E+02	6.28E+01	5.29E+01
F25	mean	3.38E+03	5.21E+03	1.28E+04	3.81E+03	1.60E+04	1.66E+04	1.40E+04	1.23E+04	4.30E+03	3.29E+03	3.08E+03
	rank	3	6	8	4	10	11	9	7	5	2	1
	std	1.14E+02	5.65E+02	1.04E+03	1.93E+02	1.07E+03	3.16E+03	1.99E+03	1.92E+03	1.17E+03	1.34E+02	3.27E+01
F26	mean	1.38E+04	1.54E+04	1.59E+04	1.19E+04	1.75E+04	1.81E+04	1.37E+04	1.61E+04	1.54E+04	7.00E+03	5.11E+03
	rank	5	6	8	3	10	11	4	9	7	2	1
	std	1.69E+03	1.52E+03	8.69E+02	1.19E+03	7.35E+02	1.82E+03	2.16E+03	1.22E+03	4.41E+03	2.83E+03	2.38E+03
F27	mean	5.07E+03	4.81E+03	7.57E+03	4.95E+03	7.07E+03	7.01E+03	4.93E+03	7.00E+03	6.03E+03	3.65E+03	3.39E+03
	rank	6	3	11	5	10	9	4	8	7	2	1
	std	7.74E+02	6.31E+02	5.64E+02	5.01E+02	8.43E+02	6.73E+02	4.57E+02	6.07E+02	8.45E+02	1.74E+02	6.21E+01
F28	mean	3.91E+03	6.10E+03	1.12E+04	4.86E+03	1.38E+04	1.20E+04	1.05E+04	1.08E+04	5.42E+03	3.66E+03	3.34E+03
	rank	3	6	9	4	11	10	7	8	5	2	1
	std	1.21E+03	5.41E+02	8.45E+02	4.05E+02	1.39E+03	1.58E+03	1.57E+03	1.16E+03	1.23E+03	1.45E+02	2.83E+01
F29	mean	8.62E+03	9.78E+03	2.44E+04	7.07E+03	1.82E+05	3.21E+04	9.27E+03	3.13E+04	7.48E+03	5.04E+03	4.88E+03
	rank	5	7	8	3	11	10	6	9	4	2	1
	std	1.39E+03	1.92E+03	9.13E+03	9.15E+02	2.04E+05	2.81E+04	3.39E+03	2.79E+04	1.30E+03	6.10E+02	3.53E+02 </

Table S4 100D CEC 2017 test set results

Function	Metric	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
F1	mean	1.07E+10	1.08E+11	2.48E+11	5.03E+10	2.71E+11	3.00E+11	2.55E+11	2.39E+11	8.35E+10	3.98E+10	5.52E+08
	rank	2	6	8	4	10	11	9	7	5	3	1
	std	2.85E+09	1.06E+10	8.52E+09	6.96E+09	1.07E+10	2.84E+10	1.63E+10	2.74E+10	6.04E+10	9.81E+09	1.38E+08
F3	mean	4.64E+05	9.45E+05	3.95E+05	3.71E+05	3.61E+05	5.84E+05	3.99E+05	5.48E+05	8.09E+05	5.12E+05	4.57E+05
	rank	6	11	3	2	1	9	4	8	10	7	5
	std	1.09E+05	1.37E+05	2.97E+04	1.11E+05	2.11E+04	1.04E+05	2.86E+04	8.20E+04	1.19E+05	1.56E+05	8.30E+04
F4	mean	2.66E+03	2.13E+04	7.97E+04	9.06E+03	1.11E+05	9.48E+04	8.50E+04	7.29E+04	1.60E+04	4.31E+03	9.80E+02
	rank	2	6	8	4	11	10	9	7	5	3	1
	std	5.34E+02	3.56E+03	7.86E+03	1.94E+03	1.30E+04	1.93E+04	1.82E+04	1.49E+04	1.00E+04	1.29E+03	6.31E+01
F5	mean	1.80E+03	1.97E+03	2.10E+03	1.67E+03	2.13E+03	2.12E+03	1.99E+03	1.99E+03	1.82E+03	1.72E+03	1.52E+03
	rank	4	6	9	2	11	10	7	8	5	3	1
	std	7.25E+01	1.19E+02	4.41E+01	5.72E+01	4.01E+01	1.01E+02	6.27E+01	9.37E+01	4.30E+02	1.42E+02	6.75E+01
F6	mean	6.96E+02	7.07E+02	7.13E+02	6.90E+02	7.12E+02	7.03E+02	7.01E+02	6.99E+02	6.79E+02	6.90E+02	6.76E+02
	rank	5	9	11	4	10	8	7	6	2	3	1
	std	5.48E+00	9.71E+00	3.50E+00	3.87E+00	3.87E+00	6.66E+00	5.41E+00	6.99E+00	1.21E+01	9.00E+00	9.05E+00
F7	mean	3.77E+03	3.78E+03	4.00E+03	3.78E+03	4.01E+03	6.04E+03	3.86E+03	4.22E+03	7.42E+03	3.12E+03	2.21E+03
	rank	3	5	7	4	8	10	6	9	11	2	1
	std	1.15E+02	1.57E+02	9.72E+01	1.15E+02	6.45E+01	4.37E+02	9.53E+01	3.43E+02	3.84E+03	1.90E+02	1.07E+02
F8	mean	2.27E+03	2.42E+03	2.56E+03	2.14E+03	2.60E+03	2.54E+03	2.42E+03	2.42E+03	2.39E+03	2.14E+03	1.90E+03
	rank	4	6	10	3	11	9	8	7	5	2	1
	std	7.18E+01	1.31E+02	4.82E+01	6.21E+01	5.48E+01	9.40E+01	8.38E+01	1.00E+02	3.85E+02	1.70E+02	8.34E+01
F9	mean	5.82E+04	8.14E+04	8.96E+04	6.79E+04	7.94E+04	7.75E+04	7.38E+04	7.05E+04	4.69E+04	7.36E+04	5.72E+04
	rank	3	10	11	4	9	8	7	5	1	6	2
	std	5.77E+03	2.16E+04	4.07E+03	4.73E+03	4.24E+03	1.10E+04	5.60E+03	1.24E+04	1.82E+04	4.90E+03	8.74E+03
F10	mean	2.75E+04	2.92E+04	3.27E+04	2.44E+04	3.28E+04	2.93E+04	3.19E+04	2.89E+04	1.71E+04	3.19E+04	2.13E+04
	rank	4	6	10	3	11	7	9	5	1	8	2
	std	2.01E+03	1.55E+03	6.94E+02	1.81E+03	7.55E+02	1.31E+03	8.31E+02	1.29E+03	1.45E+03	8.33E+02	7.46E+02
F11	mean	1.14E+05	3.13E+05	2.17E+05	1.45E+05	2.67E+05	2.83E+05	4.79E+05	2.67E+05	1.80E+05	1.79E+05	8.57E+04
	rank	2	10	6	3	8	9	11	7	5	4	1
	std	3.83E+04	1.23E+05	4.07E+04	3.50E+04	6.27E+04	7.91E+04	1.34E+05	9.15E+04	4.87E+04	4.06E+04	1.61E+04
F12	mean	2.63E+09	3.09E+10	1.71E+11	1.08E+10	2.07E+11	1.68E+11	1.52E+11	1.48E+11	1.28E+10	2.32E+09	2.94E+08
	rank	3	6	10	4	11	9	8	7	5	2	1
	std	8.29E+08	7.29E+09	1.36E+10	3.10E+09	1.93E+10	2.65E+10	3.45E+10	1.99E+10	1.04E+10	1.12E+09	1.14E+08
F13	mean	6.82E+07	3.14E+09	3.86E+10	2.64E+08	4.76E+10	3.73E+10	3.02E+10	3.12E+10	1.75E+07	1.85E+06	4.46E+05
	rank	4	6	10	5	11	9	7	8	3	2	1
	std	3.73E+07	1.24E+09	4.41E+09	1.45E+08	5.84E+09	6.97E+09	1.05E+10	5.97E+09	9.58E+07	1.79E+06	2.02E+06
F14	mean	9.86E+06	1.90E+07	6.43E+07	1.11E+07	9.83E+07	9.39E+07	2.62E+07	7.45E+07	3.99E+06	1.41E+07	2.90E+06
	rank	3	6	8	4	11	10	7	9	2	5	1
	std	4.02E+06	8.73E+06	2.31E+07	3.28E+06	4.08E+07	5.84E+07	1.14E+07	4.25E+07	2.48E+06	6.16E+06	1.11E+06
F15	mean	1.12E+07	4.95E+08	1.84E+10	1.60E+07	2.49E+10	1.69E+10	1.02E+10	1.45E+10	6.84E+04	1.03E+05	1.59E+05
	rank	4	6	10	5	11	9	7	8	1	2	3
	std	1.06E+07	3.00E+08	3.12E+09	9.24E+06	5.15E+09	5.11E+09	6.21E+09	4.37E+09	4.09E+04	4.79E+04	7.75E+05
F16	mean	1.30E+04	1.70E+04	2.04E+04	1.01E+04	2.52E+04	1.87E+04	1.40E+04	1.80E+04	9.08E+03	1.05E+04	7.77E+03
	rank	5	7	10	3	11	9	6	8	2	4	1
	std	1.93E+03	2.65E+03	1.65E+03	1.17E+03	2.84E+03	2.78E+03	2.50E+03	2.10E+03	1.04E+03	2.18E+03	5.46E+02
F17	mean	8.93E+03	3.13E+04	3.11E+06	8.34E+03	1.22E+07	4.38E+06	9.82E+04	1.68E+06	6.44E+03	7.83E+03	5.82E+03
	rank	5	6	9	4	11	10	7	8	2	3	1
	std	1.47E+03	3.37E+04	2.12E+06	1.69E+03	9.25E+06	9.01E+06	2.10E+05	2.06E+06	7.23E+02	1.11E+03	3.92E+02
F18	mean	7.83E+06	2.00E+07	1.19E+08	9.93E+06	2.91E+08	1.42E+08	2.76E+07	1.21E+08	3.82E+06	1.85E+07	3.70E+06
	rank	3	6	8	4	11	10	7	9	2	5	1
	std	3.54E+06	1.13E+07	4.35E+07	4.51E+06	1.33E+08	9.76E+07	9.59E+06	8.57E+07	2.64E+06	1.16E+07	1.34E+06
F19	mean	3.12E+07	5.19E+08	1.67E+10	3.37E+07	2.63E+10	1.85E+10	9.20E+09	1.42E+10	1.18E+07	1.54E+06	7.74E+04
	rank	4	6	9	5	11	10	7	8	3	2	1
	std	2.39E+07	2.98E+08	3.38E+09	1.84E+07	4.48E+09	5.38E+09	5.19E+09	4.02E+09	1.27E+07	1.75E+06	3.61E+05
F20	mean	6.91E+03	7.15E+03	7.91E+03	6.14E+03	7.95E+03	7.08E+03	7.60E+03	7.14E+03	6.35E+03	7.57E+03	5.59E+03
	rank	4	7	10	2	11	5	9	6	3	8	1
	std	7.35E+02	6.30E+02	3.73E+02	4.95E+02	3.17E+02	5.23E+02	2.92E+02	5.16E+02	6.04E+02	3.38E+02	3.38E+02
F21	mean	4.75E+03	4.47E+03	4.92E+03	4.40E+03	5.11E+03	4.67E+03	3.87E+03	4.66E+03	4.49E+03	3.69E+03	3.31E+03
	rank	9	5	10	4	11	8	3	7	6	2	1
	std	2.59E+02	2.30E+02	1.83E+02	2.03E+02	2.00E+02	1.99E+02	9.36E+01	1.81E+02	2.21E+02	1.24E+02	9.29E+01
F22	mean	3.03E+04	3.22E+04	3.53E+04	2.75E+04	3.51E+04	3.23E+04	3.30E+04	3.23E+04	1.99E+04	3.44E+04	2.40E+04
	rank	4	5	11	3	10	6	8	7	1	9	2
	std	2.06E+03	1.37E+03	6.38E+02	1.35E+03	6.78E+02	1.30E+03	1.35E+03	1.25E+03	1.38E+03	8.20E+02	7.44E+02
F23	mean	5.93E+03	5.34E+03	7.89E+03	5.82E+03	6.78E+03	7.45E+03	5.62E+03	7.39E+03	5.87E+03	4.11E+03	3.87E+03
	rank	7	3	11	5	8	10	4	9	6	2	1
	std	4.51E+02	2.73E+02	5.11E+02	3.94E+02	2.89E+02	4.89E+02	6.10E+02	5.17E+02	3.65E+02	1.78E+02	1.25E+02
F24	mean	9.22E+03	6.75E+03	1.25E+04	8.03E+03	1.05E+04	1.22E+04	8.25E+03	1.21E+04	7.83E+03	4.77E+03	4.44E+03
	rank	7	3	11	5	8	10	6	9	4	2	1
	std	9.18E+02	3.99E+02	7.73E+02	6.22E+02	9.74E+02	8.67E+02	7.86E+02	8.43E+02	3.34E+02	2.22E+02	1.32E+02
F25	mean	4.99E+03	1.08E+04	2.44E+04	6.80E+03	2.95E+04	3.74E+04	2.72E+04	2.54E+04	9.05E+03	6.46E+03	3.60E+03
	rank	2	6	7	4	10	11	9	8	5	3	1
	std	3.41E+02	1.03E+03	2.00E+03	6.25E+02	1.71E+03	5.81E+03	2.44E+03	3.34E+03	4.53E+03	9.06E+02	5.29E+01
F26	mean	3.71E+04	3.85E+04	5.13E+04	3.16E+04	5.32E+04	5.59E+04	4.20E+04	4.90E+04	3.73E+04	2.17E+04	1.62E+04
	rank	4	6	9	3	10	11	7	8	5	2	1
	std	5.05E+03	3.33E+03	1.98E+03	2.46E+03	2.62E+03	5.08E+03	8.74E+03	4.38E+03	9.49E+03	3.29E+03	5.26E+03
F27	mean	6.42E+03	6.38E+03	1.42E+04	6.58E+03	1.52E+04	1.32E+04	8.33E+03	1.29E+04	8.19E+03	3.98E+03	3.71E+03
	rank	4	3	10	5	11	9	7	8	6	2	1
	std	1.69E+03	9.14E+02	1.06E+03	1.09E+03	1.76E+03	1.31E+03	1.34E+03	1.30E+03	1.73E+03	2.49E+02	1.09E+02
F28	mean	5.57E+03	1.47E+04	3.09E+04	9.53E+03	3.06E+04	3.73E+04	2.96E+04	3.08E+04	1.45E+04	8.01E+03	3.72E+03
	rank	2	6	10	4	8	11	7	9	5	3	1
	std	5.44E+02	1.55E+03	1.52E+03	8.43E+02	1.22E+03	3.70E+03	3.13E+03	3.11E+03	5.28E+03	1.05E+03	6.25E+01
F29	mean	1.58E+04	2.16E+04	2.18E+05	1.29E+04	7.95E+05	3.04E+05	8.66E+04	1.41E+05	1.29E+04	9.29E+03	8.96E+03
	rank	5	6	9	4	11	10	7	8	3	2	1
	std	1.93E+03	5.22E+03	1.12E+05	1.27E+03	6.12E+05	4.69E+05	1.58E+05	1.37E+05	2.46E+03	1.52E+03	

Table S5 10D CEC 2022 test set results

Function	Metric	PSO	WOA	GWO	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
F1	mean	3.00E+02	2.75E+04	2.70E+03	1.12E+03	7.94E+03	1.35E+04	8.41E+03	1.21E+04	4.29E+03	2.71E+03	3.00E+02
	rank	2	11	4	3	7	10	8	9	6	5	1
	std	4.80E-02	1.27E+04	2.23E+03	5.08E+02	1.92E+03	6.32E+03	4.28E+03	5.75E+03	3.93E+03	1.81E+03	3.20E-02
F2	mean	4.23E+02	4.74E+02	4.36E+02	4.50E+02	1.59E+03	1.10E+03	4.94E+02	9.86E+02	4.43E+02	4.09E+02	4.03E+02
	rank	3	7	4	6	11	10	8	9	5	2	1
	std	2.50E+01	8.93E+01	3.88E+01	7.25E+01	6.17E+02	5.02E+02	7.15E+01	4.50E+02	4.88E+01	3.52E+00	1.53E+00
F3	mean	6.00E+02	6.40E+02	6.01E+02	6.39E+02	6.46E+02	6.33E+02	6.12E+02	6.33E+02	6.57E+02	6.00E+02	6.00E+02
	rank	2	9	4	8	10	6	5	7	11	3	1
	std	3.38E-01	1.35E+01	1.38E+00	1.19E+01	8.87E+00	8.22E+00	1.76E+00	1.06E+01	1.29E+01	5.20E-01	1.90E-01
F4	mean	8.15E+02	8.40E+02	8.16E+02	8.27E+02	8.51E+02	8.41E+02	8.31E+02	8.40E+02	8.48E+02	8.34E+02	8.13E+02
	rank	2	8	3	4	11	9	5	7	10	6	1
	std	6.78E+00	1.39E+01	7.49E+00	7.25E+00	9.30E+00	1.40E+01	4.91E+00	1.35E+01	1.77E+01	8.08E+00	4.28E+00
F5	mean	9.00E+02	1.54E+03	9.13E+02	1.40E+03	1.42E+03	1.27E+03	1.01E+03	1.24E+03	2.01E+03	9.04E+02	9.00E+02
	rank	2	10	4	8	9	7	5	6	11	3	1
	std	4.40E-01	4.31E+02	2.15E+01	1.66E+02	1.87E+02	2.37E+02	8.79E+01	2.29E+02	6.13E+02	1.10E+01	5.64E-02
F6	mean	4.34E+03	5.60E+03	6.32E+03	6.04E+03	1.44E+07	1.01E+08	1.08E+07	1.01E+08	3.71E+03	5.25E+03	1.83E+03
	rank	3	5	7	6	9	10	8	11	2	4	1
	std	2.46E+03	3.29E+03	2.49E+03	3.26E+03	2.05E+07	1.73E+08	8.75E+07	1.84E+08	1.85E+03	2.13E+03	1.49E+01
F7	mean	2.02E+03	2.08E+03	2.04E+03	2.09E+03	2.09E+03	2.07E+03	2.05E+03	2.07E+03	2.15E+03	2.02E+03	2.02E+03
	rank	2	8	4	9	10	7	5	6	11	3	1
	std	8.30E+00	3.48E+01	1.65E+01	3.81E+01	2.07E+01	2.79E+01	6.38E+00	2.96E+01	6.25E+01	6.18E+00	7.73E+00
F8	mean	2.23E+03	2.24E+03	2.23E+03	2.23E+03	2.24E+03	2.27E+03	2.24E+03	2.28E+03	2.39E+03	2.23E+03	2.22E+03
	rank	3	7	4	5	8	9	6	10	11	2	1
	std	3.28E+01	1.16E+01	2.88E+01	1.11E+01	1.45E+01	1.33E+02	1.32E+01	7.94E+01	1.46E+02	5.94E+00	7.02E+00
F9	mean	2.54E+03	2.61E+03	2.58E+03	2.60E+03	2.75E+03	2.72E+03	2.57E+03	2.71E+03	2.63E+03	2.53E+03	2.49E+03
	rank	3	7	5	6	11	10	4	9	8	2	1
	std	2.85E+01	4.73E+01	3.96E+01	4.34E+01	4.56E+01	6.24E+01	2.47E+01	4.76E+01	4.80E+01	2.07E+01	1.18E+00
F10	mean	2.59E+03	2.66E+03	2.57E+03	2.61E+03	2.73E+03	2.74E+03	2.58E+03	2.67E+03	3.14E+03	2.59E+03	2.54E+03
	rank	5	7	2	6	9	10	3	8	11	4	1
	std	9.41E+01	2.86E+02	6.75E+01	1.72E+02	1.92E+02	3.19E+02	2.22E+02	2.45E+02	6.15E+02	5.58E+01	5.35E+01
F11	mean	2.73E+03	3.03E+03	2.99E+03	2.81E+03	3.84E+03	9.59E+03	3.06E+03	6.16E+03	2.60E+04	2.65E+03	2.60E+03
	rank	3	6	5	4	8	10	7	9	11	2	1
	std	1.42E+02	1.97E+02	1.45E+02	1.21E+02	4.67E+02	3.27E+03	3.05E+02	2.12E+03	2.80E+04	9.94E+01	4.00E+01
F12	mean	2.87E+03	2.90E+03	2.87E+03	2.93E+03	2.96E+03	3.03E+03	2.90E+03	3.03E+03	3.00E+03	2.87E+03	2.86E+03
	rank	4	6	3	7	8	10	5	11	9	2	1
	std	1.79E+01	5.65E+01	9.67E+00	5.03E+01	5.55E+01	7.68E+01	3.47E+01	6.16E+01	7.83E+01	1.11E+01	1.47E+00

Table S6 20D CEC 2022 test set results

Function	Metric	PSO	WOA	GWO	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
F1	mean	7.10E+03	3.71E+04	1.65E+04	2.47E+04	4.97E+04	4.48E+04	7.61E+04	4.33E+04	2.76E+04	3.40E+04	1.00E+04
	rank	1	7	3	4	10	9	11	8	5	6	2
	std	6.53E+03	1.46E+04	5.90E+03	8.79E+03	1.79E+04	1.62E+04	2.29E+04	1.35E+04	1.05E+04	9.36E+03	4.00E+03
F2	mean	4.75E+02	6.25E+02	5.13E+02	5.37E+02	2.90E+03	1.75E+03	9.52E+02	1.46E+03	5.27E+02	4.61E+02	4.26E+02
	rank	3	7	4	6	11	10	8	9	5	2	1
	std	4.23E+01	7.61E+01	4.53E+01	4.99E+01	6.48E+02	5.86E+02	3.96E+02	4.22E+02	5.73E+01	2.26E+01	2.08E+01
F3	mean	6.02E+02	6.70E+02	6.07E+02	6.62E+02	6.83E+02	6.61E+02	6.28E+02	6.58E+02	6.75E+02	6.04E+02	6.00E+02
	rank	2	9	4	8	11	7	5	6	10	3	1
	std	2.30E+00	1.37E+01	4.13E+00	8.24E+00	9.14E+00	9.91E+00	5.09E+00	1.02E+01	1.15E+01	3.82E+00	3.35E-01
F4	mean	8.46E+02	9.39E+02	8.63E+02	8.88E+02	9.78E+02	9.44E+02	9.25E+02	9.36E+02	9.29E+02	9.25E+02	8.57E+02
	rank	1	9	3	4	11	10	5	8	7	6	2
	std	1.83E+01	3.37E+01	3.04E+01	1.44E+01	1.49E+01	2.51E+01	1.18E+01	2.19E+01	3.99E+01	2.21E+01	1.32E+01
F5	mean	9.92E+02	4.20E+03	1.25E+03	3.00E+03	3.55E+03	3.12E+03	2.28E+03	2.89E+03	3.91E+03	2.11E+03	9.41E+02
	rank	2	11	3	7	9	8	5	6	10	4	1
	std	2.51E+02	1.57E+03	3.44E+02	2.89E+02	3.45E+02	8.96E+02	5.09E+02	7.78E+02	1.38E+03	7.00E+02	1.22E+02
F6	mean	5.28E+05	1.00E+07	5.77E+06	2.12E+05	2.31E+09	8.18E+08	8.36E+07	6.95E+08	6.05E+03	9.29E+03	1.14E+05
	rank	5	7	6	4	11	10	8	9	1	2	3
	std	4.32E+06	2.53E+07	1.20E+07	1.20E+05	1.01E+09	6.49E+08	7.63E+07	6.25E+08	4.59E+03	7.67E+03	5.30E+04
F7	mean	2.07E+03	2.22E+03	2.10E+03	2.19E+03	2.22E+03	2.18E+03	2.12E+03	2.19E+03	2.36E+03	2.10E+03	2.06E+03
	rank	2	9	3	7	10	6	5	8	11	4	1
	std	4.23E+01	6.79E+01	4.27E+01	6.51E+01	4.43E+01	6.52E+01	5.53E+01	6.40E+01	1.26E+02	3.95E+01	1.40E+01
F8	mean	2.28E+03	2.31E+03	2.26E+03	2.31E+03	2.44E+03	2.44E+03	2.26E+03	3.00E+03	2.62E+03	2.24E+03	2.23E+03
	rank	5	7	4	6	8	9	3	11	10	2	1
	std	6.97E+01	8.68E+01	5.46E+01	9.68E+01	1.38E+02	2.19E+02	2.11E+01	2.94E+03	1.94E+02	1.44E+01	1.63E+00
F9	mean	2.51E+03	2.59E+03	2.52E+03	2.55E+03	3.44E+03	3.07E+03	2.66E+03	3.04E+03	2.60E+03	2.48E+03	2.47E+03
	rank	3	6	4	5	11	10	8	9	7	2	1
	std	3.48E+01	5.10E+01	2.69E+01	4.43E+01	3.68E+02	2.42E+02	8.98E+01	2.23E+02	8.13E+01	8.12E-01	8.23E-01
F10	mean	3.08E+03	5.03E+03	3.53E+03	4.11E+03	6.43E+03	5.10E+03	5.76E+03	5.11E+03	5.15E+03	3.55E+03	2.95E+03
	rank	2	6	3	5	11	7	10	8	9	4	1
	std	4.53E+02	1.20E+03	8.17E+02	8.60E+02	1.31E+03	1.13E+03	2.02E+03	1.24E+03	9.43E+02	1.29E+03	7.50E+02
F11	mean	2.90E+03	4.12E+03	3.77E+03	3.74E+03	9.04E+03	4.07E+04	7.47E+03	2.26E+04	8.74E+04	2.94E+03	2.92E+03
	rank	1	6	5	4	8	10	7	9	11	3	2
	std	2.13E+00	8.20E+02	4.75E+02	7.32E+02	6.10E+02	1.03E+04	1.09E+03	8.38E+03	7.00E+04	1.65E+02	7.83E+01
F12	mean	3.01E+03	3.10E+03	2.98E+03	3.23E+03	3.59E+03	3.80E+03	3.20E+03	3.80E+03	3.75E+03	2.98E+03	2.92E+03
	rank	4	5	2	7	8	11	6	10	9	3	1
	std	5.64E+01	1.13E+02	2.39E+01	2.07E+02	2.35E+02	2.01E+02	1.32E+02	2.12E+02	3.04E+02	3.12E+01	8.32E+00

Table S7 Wilcoxon rank sum test results on 10D CEC 2022 test sets

Function	WOA	GWO	HHO	COA	DBO	ANA	FHO	GGO	GOOSE
	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value
F1	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	5.22E-06
F2	3.18E-06	1.73E-06	4.29E-06	1.73E-06	2.60E-06	1.73E-06	1.73E-06	1.73E-06	2.22E-04
F3	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F4	1.73E-06	1.99E-01	3.18E-06	1.73E-06	1.73E-06	2.13E-06	1.73E-06	2.35E-06	1.92E-06
F5	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F6	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F7	1.73E-06	2.16E-05	1.73E-06	1.73E-06	1.11E-02	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F8	1.73E-06	3.41E-05	1.73E-06	1.73E-06	7.51E-05	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F9	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F10	4.11E-03	2.56E-02	1.89E-04	1.24E-05	1.25E-04	6.32E-05	8.73E-03	9.63E-04	9.32E-06
F11	1.73E-06	2.60E-06	5.75E-06	1.73E-06	2.11E-03	1.73E-06	1.73E-06	1.73E-06	5.75E-06
F12	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
+/-/=	12/0/0	11/1/0	12/0/0	12/0/0	12/0/0	12/0/0	12/0/0	12/0/0	12/0/0

Table S8 Wilcoxon rank sum test results on 20D CEC 2022 test sets

Function	WOA	GWO	HHO	COA	DBO	ANA	FHO	GGO	GOOSE
	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value
F1	1.73E-06	3.59E-04	1.92E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	9.32E-06
F2	1.73E-06	3.88E-06	1.73E-06	1.73E-06	2.37E-05	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F3	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F4	1.73E-06	3.71E-01	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F5	1.73E-06	3.41E-05	1.73E-06	1.73E-06	7.69E-06	1.73E-06	1.92E-06	1.73E-06	1.73E-06
F6	1.73E-06	3.38E-03	1.20E-03	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.92E-06
F7	1.73E-06	1.17E-02	1.92E-06	1.73E-06	6.34E-06	1.73E-06	2.35E-06	1.73E-06	1.73E-06
F8	1.73E-06	6.42E-03	1.92E-06	1.73E-06	4.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F9	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F10	2.37E-05	1.48E-03	7.51E-05	1.73E-06	2.41E-03	1.64E-05	7.69E-06	1.49E-05	1.73E-06
F11	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.32E-02	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F12	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
+/-/=	12/0/0	11/1/0	12/0/0	12/0/0	12/0/0	12/0/0	12/0/0	12/0/0	12/0/0

Table S9 Wilcoxon rank sum test results on 30D CEC 2017 test sets

Function	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO
	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value
F1	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.60E-05	1.73E-06
F3	2.35E-06	1.73E-06	2.41E-04	2.58E-03	8.19E-05	4.73E-06	3.49E-01	1.73E-06	2.35E-06	1.59E-03
F4	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.60E-06
F5	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.88E-06
F6	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.88E-06
F7	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.35E-06
F8	1.73E-06	1.73E-06	1.73E-06	2.13E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.25E-04
F9	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.92E-06	1.73E-06	1.73E-06
F10	1.73E-06	1.73E-06	1.73E-06	1.92E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.05E-04	1.73E-06
F11	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.92E-06
F12	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.13E-05	7.04E-01
F13	1.06E-04	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	3.33E-02	3.29E-01
F14	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F15	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.74E-04
F16	1.73E-06	1.73E-06	1.73E-06	2.13E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.85E-02
F17	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.97E-05
F18	1.92E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.88E-06	1.73E-06
F19	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.16E-01
F20	1.73E-06	2.35E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.35E-06	1.73E-06	6.34E-06
F21	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F22	1.73E-06	1.49E-05	2.13E-06	7.16E-04	1.73E-06	1.73E-06	1.36E-05	1.73E-06	1.73E-06	1.75E-02
F23	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	3.88E-06
F24	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F25	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.92E-06	6.32E-05
F26	2.60E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.59E-01
F27	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F28	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F29	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.35E-06	1.73E-06	1.73E-06	5.67E-03
F30	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.11E-01
+/-/=	29/0/0	29/0/0	29/0/0	29/0/0	29/0/0	29/0/0	28/1/0	29/0/0	29/0/0	24/5/0

Table S10 Wilcoxon rank sum test results on 100D CEC 2017 test sets

Function	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO
	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value	P Value
F1	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F3	5.45E-02	1.73E-06	8.73E-03	4.07E-05	3.88E-06	3.41E-05	1.04E-03	5.31E-05	1.73E-06	9.59E-01
F4	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F5	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.61E-04	3.88E-06
F6	1.92E-06	1.73E-06	1.73E-06	3.88E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	4.95E-02	1.64E-05
F7	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F8	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	6.98E-06	6.34E-06
F9	9.92E-01	7.51E-05	1.73E-06	1.64E-05	1.73E-06	2.88E-06	2.13E-06	1.15E-04	4.95E-02	3.52E-06
F10	1.73E-06	1.73E-06	1.73E-06	1.92E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F11	6.42E-03	1.73E-06	1.73E-06	7.69E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F12	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F13	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	4.68E-03	1.73E-06
F14	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	2.21E-01	2.13E-06
F15	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	3.41E-05	3.11E-05
F16	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.48E-04	6.98E-06
F17	1.73E-06	1.73E-06	1.73E-06	5.22E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.38E-03	7.69E-06
F18	1.36E-05	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	6.88E-01	2.60E-06
F19	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F20	1.92E-06	1.92E-06	1.73E-06	7.51E-05	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.15E-04	1.73E-06
F21	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F22	1.73E-06	1.73E-06	1.73E-06	1.92E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F23	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	3.52E-06
F24	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	4.45E-05
F25	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F26	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	9.32E-06
F27	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	4.73E-06
F28	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06
F29	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	5.17E-01
F30	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.73E-06	1.02E-05
+/-/=	28/1/0	29/0/0	29/0/0	29/0/0	29/0/0	29/0/0	29/0/0	29/0/0	27/2/0	27/2/0

Table S11 Friedman test results on CEC 2022 test sets

CEC 2022	Friedman test result									
	ADBO	WOA	GWO	HHO	COA	DBO	ANA	FHO	GGO	GOOSE
D = 10	1.75	5.42	3.58	5.42	6.33	6.00	5.58	6.50	6.50	7.92
D = 20	1.50	4.92	4.75	5.00	7.00	7.58	5.08	6.50	6.33	6.33

Table S12 Friedman test results on CEC 2017 test sets

CEC 2017	Friedman test result										
	HLOA	WOA	FWA	HHO	COA	ANA	FHO	GGO	GOOSE	DBO	ADBO
D = 30	9.10	7.31	7.28	5.07	6.17	4.79	5.52	6.31	5.48	4.76	4.21
D = 100	7.59	7.93	5.76	4.28	6.48	6.34	5.86	6.17	6.45	4.72	4.41

Table S13 Experimental results of FPRM on area optimization

Name	Metric	PSO	DE	GWO	GOOSE	ANA	GGO	FHO	ADBO
br1	mean	309.10	299.90	319.30	311.40	279.60	319.50	266.00	266.00
	rank	5	4	7	6	3	8	1	1
	std	51.00	37.24	51.48	46.65	29.14	38.89	0.00	0.00
br2	mean	135.80	135.80	137.10	137.80	137.10	134.60	134.00	134.00
	rank	4	4	6	8	6	3	1	1
	std	4.05	4.05	5.30	5.43	5.30	1.90	0.00	0.00
t3	mean	153.40	142.60	148.30	146.50	140.70	140.50	135.80	131.00
	rank	8	5	7	6	4	3	2	1
	std	27.40	15.40	16.24	13.96	7.63	9.13	6.34	0.00
amd	mean	459.00	456.20	455.80	458.30	453.60	455.50	456.10	447.00
	rank	8	6	4	7	2	3	5	1
	std	5.60	8.61	7.19	8.62	6.33	8.14	4.63	0.00
misex3	mean	2195.40	2188.60	2197.30	2206.30	2172.90	2222.20	2070.90	2049.30
	rank	5	4	6	7	3	8	2	1
	std	108.19	146.89	160.92	134.46	123.07	167.49	136.20	75.92
mp2d	mean	19.00	15.00	18.00	18.00	15.00	16.00	13.00	11.00
	rank	8	3	6	6	3	5	2	1
	std	4.22	5.16	4.83	4.83	5.16	5.27	4.22	0.00
In0	mean	729.60	732.10	747.70	759.60	769.90	778.60	751.00	674.30
	rank	2	3	4	6	7	8	5	1
	std	56.87	39.06	49.69	52.98	49.28	60.74	44.86	35.10
newtpla	mean	57.20	58.30	57.00	61.10	59.60	58.40	54.30	45.00
	rank	4	5	3	8	7	6	2	1
	std	11.76	15.33	11.20	10.30	9.94	9.62	10.07	3.89
b2	mean	4060.90	4121.90	4015.50	4194.00	4148.60	3985.60	3988.10	3704.40
	rank	5	6	4	8	7	2	3	1
	std	233.30	210.26	252.91	359.05	250.51	319.91	264.61	48.78
t2	mean	91.80	91.30	97.10	96.00	89.00	94.30	83.60	82.40
	rank	5	4	8	7	3	6	2	1
	std	9.53	8.88	7.17	7.77	10.20	8.69	5.80	5.06
table5	mean	271.00	300.60	293.10	263.40	284.20	306.70	263.00	255.80
	rank	4	7	6	3	5	8	2	1
	std	20.63	42.81	39.18	10.32	23.26	44.00	9.52	1.03

Table S14 Experimental results of MPRM on area optimization

Name	Metric	PSO	DE	GWO	GOOSE	ANA	GGO	FHO	ADBO
alu2	mean	9.40	9.00	9.50	9.10	8.90	7.00	9.30	7.00
	rank	7	4	8	5	3	1	6	1
	std	1.71	1.76	1.35	1.85	1.66	0.00	1.64	0.00
apla	mean	97.80	101.30	100.30	100.70	101.50	101.10	99.80	94.00
	rank	2	7	4	5	8	6	3	1
	std	4.10	2.91	3.53	3.83	3.03	0.32	4.13	0.00
clip	mean	274.00	280.80	272.80	277.20	272.30	276.00	274.10	260.00
	rank	4	8	3	7	2	6	5	1
	std	6.94	17.18	3.61	15.02	8.42	8.55	12.11	0.00
clip-1	mean	282.10	275.10	271.30	272.50	275.10	272.70	272.50	260.70
	rank	8	6	2	3	6	5	3	1
	std	13.82	6.14	8.99	7.32	7.00	7.66	8.32	2.21
ex1010	mean	2084.20	2041.70	2234.10	2115.60	2053.90	1761.00	2191.80	1750.90
	rank	5	3	8	6	4	2	7	1
	std	236.27	206.94	138.31	194.95	222.64	193.96	97.85	172.73
exps	mean	74.20	69.20	69.40	70.40	72.20	61.60	71.40	51.00
	rank	8	3	4	5	7	2	6	1
	std	8.44	8.08	10.45	9.85	8.34	4.53	8.10	0.00
Sao2	mean	182.90	182.50	186.60	180.00	194.40	175.40	192.80	175.00
	rank	5	4	6	3	8	2	7	1
	std	10.46	11.39	13.91	9.01	13.79	1.26	14.76	0.00
alu1	mean	8.60	8.00	7.70	8.10	8.00	7.00	8.10	7.00
	rank	8	4	3	6	4	1	6	1
	std	0.97	0.47	0.48	0.32	0.47	0.00	0.32	0.00
br1	mean	169.40	163.30	164.40	170.90	159.50	152.60	171.50	141.00
	rank	6	4	5	7	3	2	8	1
	std	16.04	18.74	18.30	17.06	17.17	6.96	18.36	9.82
br2	mean	112.70	119.50	116.70	101.50	135.30	105.10	124.30	79.10
	rank	4	6	5	2	8	3	7	1
	std	17.91	16.41	24.57	18.99	15.72	14.68	18.92	2.51
newapla	mean	29.50	27.30	22.00	25.20	24.40	18.40	24.90	18.90
	rank	8	7	3	6	4	1	5	2
	std	5.50	3.62	3.27	5.59	7.17	3.20	3.11	3.18
t3	mean	148.70	146.40	141.50	145.60	147.30	139.20	155.30	134.50
	rank	7	5	3	4	6	2	8	1
	std	15.51	12.34	9.71	12.51	15.49	14.22	16.50	9.35
misex3	mean	2925.10	2870.50	2745.90	2677.70	2704.20	2101.60	2778.20	1165.30
	rank	8	7	5	3	4	2	6	1
	std	335.10	354.09	346.98	399.66	338.04	206.82	270.14	169.49
table3	mean	3144.90	3227.70	3193.60	3091.30	3165.70	2759.40	3183.20	1721.80
	rank	4	8	7	3	5	2	6	1
	std	350.56	261.41	448.97	523.24	540.18	378.61	385.11	186.63
amd	mean	410.50	433.10	410.90	413.10	415.80	399.60	405.10	340.00
	rank	4	8	5	6	7	2	3	1
	std	29.65	42.22	22.54	53.00	42.18	19.48	26.71	17.18