

Research article

Differential evolution with quasi-reflection-based mutation

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Supplementary

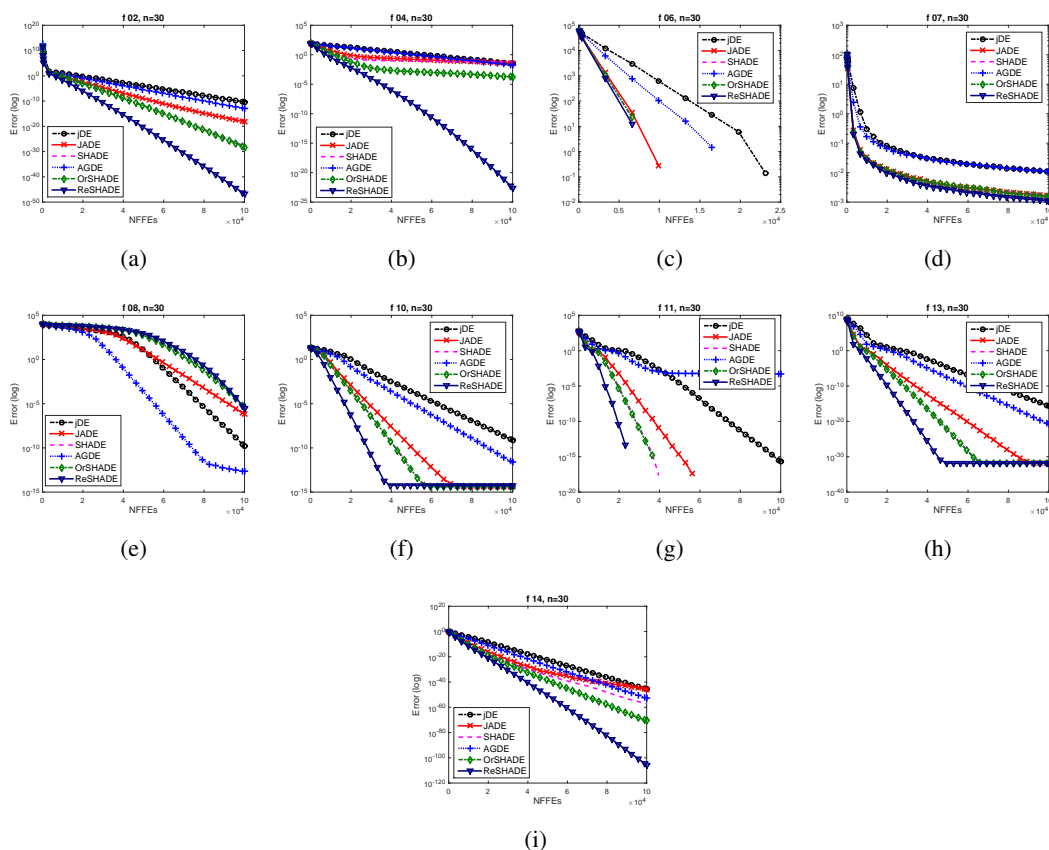


Figure S1. Convergence curves of different algorithms for the selected functions. (a) f02, (b) f04, (c) f06, (d) f07, (e) f08, (f) f10, (g) f11, (h) f13 and (i) f14.

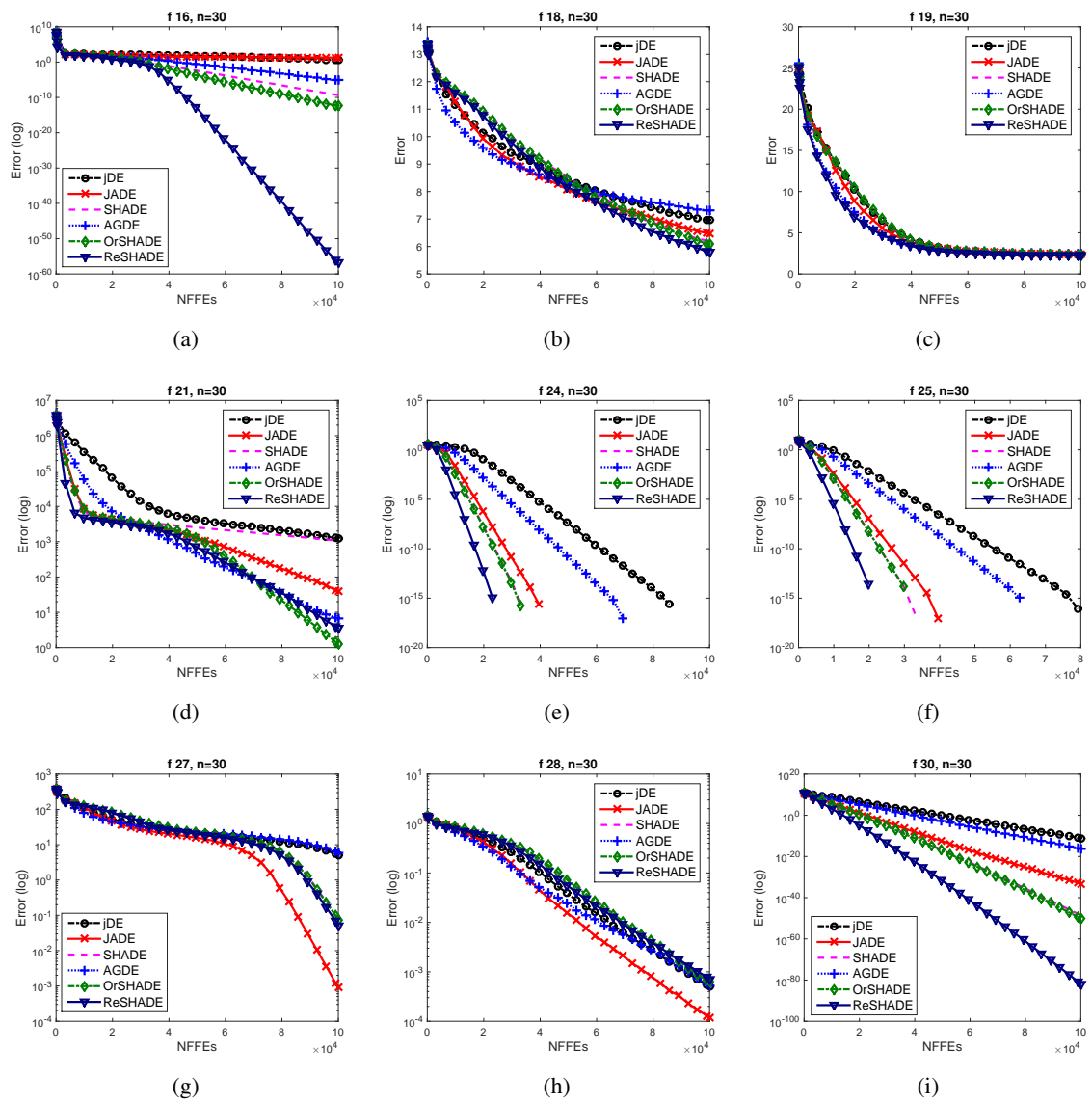


Figure S2. Convergence curves of different algorithms for the selected functions. (a) f16, (b) f18, (c) f19, (d) f21, (e) f24, (f) f25, (g) f27, (h) f28 and (i) f30.

Table S1. The 30 benchmark functions used in our experimental study, where n is the number of variables and $S \subseteq \mathbb{R}^n$. All of the functions are minimized, and the minimal value of each function is 0 at $n = 30$.

Prob.	S
$f_{01} = \sum_{i=1}^n x_i^2$	$[-100, 100]^n$
$f_{02} = \sum_{i=1}^n x_i + \prod_{i=1}^n x_i $	$[-10, 10]^n$
$f_{03} = \sum_{i=1}^n (\sum_{j=1}^i x_j)^2$	$[-100, 100]^n$
$f_{04} = \max_i \{ x_i , 1 \leq i \leq n\}$	$[-100, 100]^n$
$f_{05} = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	$[-30, 30]^n$
$f_{06} = \sum_{i=1}^{n-1} (x_i + 0.5)^2$	$[-100, 100]^n$
$f_{07} = \sum_{i=1}^n x_i^4 + \text{rndreal}[0, 1]$	$[-1.28, 1.28]^n$
$f_{08} = \sum_{i=1}^n (-x_i \sin(\sqrt{ x_i })) + 418.98288727243369 \times n$	$[-500, 500]^n$
$f_{09} = \sum_{i=1}^n (x_i^2 - 10 \cos(2\pi x_i) + 10)$	$[-5.12, 5.12]^n$
$f_{10} = -20 \exp(-0.2 \sqrt{\frac{1}{n} \sum_{i=1}^n x_i^2}) - \exp(\frac{1}{n} \sum_{i=1}^n \cos(2\pi x_i)) + 20 + \exp(1)$	$[-32, 32]^n$
$f_{11} = \frac{1}{4000} \sum_{i=1}^n x_i^2 - \prod_{i=1}^n \cos(\frac{x_i}{\sqrt{i}}) + 1$	$[-600, 600]^n$
$f_{12} = \frac{\pi}{n} \{10 \sin^2(\pi y_i) + \sum_{i=1}^{n-1} (y_i - 1)^2 \cdot [1 + 10 \sin^2(\pi y_{i+1})] + (y_n - 1)^2\} + \sum_{i=1}^n u(x_i, 10, 100, 4)$	$[-50, 50]^n$
$f_{13} = \frac{1}{10} \{ \sin^2(3\pi x_1) + \sum_{i=1}^{n-1} (x_i - 1)^2 [1 + \sin^2(3\pi x_{i+1})] + (x_n - 1)^2 [1 + \sin^2(2\pi x_n)] \} + \sum_{i=1}^n u(x_i, 5, 100, 4)$	$[-50, 50]^n$
$f_{14} = \sum_{i=1}^n x_i ^{i+1}$	$[-100, 100]^n$
$f_{15} = -\sum_{i=1}^n \sin(x_i) \left(\sin\left(\frac{x_i^2}{\pi}\right) \right)^{20} + 29.6308838503244$	$[0, \pi]^n$
$f_{16} = \sum_{i=1}^n x_i^2 + \left(\sum_{i=1}^n 0.5ix_i\right)^2 + \left(\sum_{i=1}^n 0.5ix_i\right)^4$	$[-100, 100]^n$
$f_{17} = \sum_{i=1}^n x_i \sin x_i + 0.1x_i $	$[-100, 100]^n$
$f_{18} = \sum_{i=1}^{n-1} \left(0.5 + \frac{\sin^2(\sqrt{100x_i^2 + x_{i+1}^2}) - 0.5}{1 + 0.001(x_i^2 - 2x_ix_{i+1} + x_{i+1}^2)^2} \right)$	$[-100, 100]^n$
$f_{19} = n - 1 + \sum_{i=1}^{n-1} \left(\exp\left(\frac{-(x_i^2 + x_{i+1}^2 + 0.5x_ix_{i+1})}{8}\right) \times \cos\left(4\sqrt{x_i^2 + x_{i+1}^2 + 0.5x_ix_{i+1}}\right) \right)$	$[-5, 5]^n$
$f_{20} = 1 - \exp\left(0.5 \sum_{i=1}^n x_i^2\right)$	$[-1, 1]^n$
$f_{21} = \sum_{i=1}^n (x_i - 1)^2 + \sum_{i=2}^n x_i x_{i-1} + \frac{n(n+4)(n-1)}{6}$	$[-n^2, n^2]^n$
$f_{22} = -\left(1 + \frac{0.2k}{K+0.1}\right) \cos(K\pi) \exp\left(-\frac{K}{2\pi}\right) + 1.143833$	
$k = \sqrt{\sum_{i=1}^n (x_i - b_i)^2}$	$[-15, 15]^n$
$K = \sqrt{n} (\max x_i - b_i)$	
$f_{23} = \sum_{i=1}^n [(\log(x_i - 2))^2 + (\log(10 - x_i))^2] - \left(\prod_{i=1}^n x_i\right)^{0.2} + 997867.468759785$	$[2, 10]^n$
$f_{24} = -\left(A \prod_{i=1}^n \sin(x_i - z) + \prod_{i=1}^n \sin(B(x_i - z))\right) + A + 1$, where $A = 2.5, B = 5, z = 30$	$[0, \pi]^n$
$f_{25} = 0.1n - 0.1 * \sum_{i=1}^n \cos(5\pi x_i) + \sum_{i=1}^n x_i^2$	$[-100, 100]^n$
$f_{26} = \sum_{i=1}^n \left(\sum_{k=0}^{k_{\max}} [a^k \cos(2\pi b^k(x_i + 0.5))]\right) - n \sum_{k=0}^{k_{\max}} [a^k \cos(\pi b^k)]$, where $a = 0.5, b = 3, k_{\max} = 20$	$[-0.5, 0.5]^n$
$f_{27} = 10n + \sum_{i=1}^n [y_i^2 + 10 \cos(2\pi y_i)]$	
$y_i = \begin{cases} x_i, & x_i < 0.5 \\ \text{round}(2x_i)/2, & \text{otherwise} \end{cases}$	$[-100, 100]^n$
$f_{28} = -0.0001 \left(\left \left(\prod_{i=1}^n \sin x_i \right) \exp\left(\left 100 - \frac{\sqrt{\sum_{i=1}^n x_i^2}}{\pi} \right \right) \right + 1 \right)^{0.1} + 1.68347744296512$	$[-10, 10]^n$
$f_{29} = \frac{1}{n} \sum_{i=1}^n (x_i^4 - 16x_i^2 + 5x_i) + 78.3323314075429$	$[-5, 5]^n$
$f_{30} = x_1^2 + 10^6 \sum_{i=2}^n x_i^2$	$[-100, 100]^n$

Table S2. Comparison on the errors of jDE, JADE, SHADE, AGDE, CoBiDE, OrSHADE, and ReSHADE in all benchmark functions.

Prob.	jDE	JADE	SHADE	AGDE	CoBiDE	OrSHADE	ReSHADE
f01	1.12E-17 ± 9.82E-18 +	4.25E-39 ± 2.86E-38 +	1.65E-55 ± 3.06E-55 +	8.04E-23 ± 6.57E-23 +	4.41E-09 ± 2.55E-09 +	9.75E-57 ± 2.24E-56 +	1.20E-88 ± 3.58E-88
f02	4.10E-11 ± 1.94E-11 +	8.44E-19 ± 2.17E-18 +	1.57E-28 ± 1.96E-28 +	1.08E-13 ± 4.86E-14 +	1.06E-05 ± 2.87E-06 +	5.48E-29 ± 7.80E-29 +	1.73E-47 ± 2.61E-47
f03	2.97E+01 ± 2.73E+01 +	9.88E+02 ± 2.10E+03 +	2.73E-06 ± 4.01E-06 +	1.79E-03 ± 2.06E-03 +	3.23E+00 ± 1.91E+00 +	2.08E-09 ± 6.39E-09 +	7.44E-48 ± 5.31E-47
f04	3.39E-02 ± 9.87E-03 +	3.56E-02 ± 1.64E-02 +	6.54E-02 ± 9.84E-02 +	1.81E-02 ± 4.45E-03 +	1.48E+00 ± 2.49E-01 +	1.71E-04 ± 4.99E-04 +	2.45E-23 ± 5.47E-23
f05	2.27E+01 ± 1.67E+00 +	3.09E+00 ± 1.33E+00 +	7.37E+00 ± 1.22E+00 +	6.13E+00 ± 8.07E+00 +	2.13E+01 ± 8.27E-01 +	6.80E-02 ± 1.04E-01 +	3.20E-01 ± 1.11E+00
f06	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.99E+03 ± 5.56E+02 +	3.53E+01 ± 8.76E+00 +	2.17E+01 ± 4.13E+00 +	7.76E+02 ± 2.27E+02 +	4.44E+03 ± 1.16E+03 +	2.32E+01 ± 4.42E+00 +	4.00E-02 ± 1.96E-01
f07	1.11E-02 ± 2.51E-03 +	1.62E-03 ± 5.94E-04 +	1.67E-03 ± 5.12E-04 +	1.10E-02 ± 3.35E-03 +	2.29E-02 ± 5.87E-03 +	1.49E-03 ± 5.55E-04 +	7.86E-04 ± 3.34E-04
f08	1.58E-10 ± 1.64E-10 -	6.37E-07 ± 3.97E-07 -	3.10E-06 ± 3.01E-06 +	2.50E-13 ± 6.32E-13 -	5.22E-03 ± 6.78E-03 +	3.59E-06 ± 3.76E-06 =	2.87E-06 ± 5.09E-06
f09	2.34E-04 ± 4.55E-04 +	1.24E-06 ± 7.16E-07 -	2.40E-04 ± 2.52E-04 +	2.26E-04 ± 6.81E-04 =	5.46E+00 ± 1.63E+00 +	2.03E-02 ± 1.39E-01 +	1.95E-02 ± 1.39E-01
f10	7.12E-10 ± 4.08E-10	4.14E-15 ± 0.00E+00	4.14E-15 ± 0.00E+00	2.32E-12 ± 9.51E-13	1.91E-05 ± 5.51E-06	4.14E-15 ± 0.00E+00	5.12E-15 ± 1.60E-15
	1.16E+01 ± 7.06E-01 +	3.02E+00 ± 2.36E-01 +	2.54E+00 ± 1.69E-01 +	7.41E+00 ± 7.09E-01 +	1.29E+01 ± 6.25E-01 +	2.62E+00 ± 1.66E-01 +	3.01E-01 ± 5.22E-02
f11	1.92E-16 ± 7.27E-16	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	5.38E-04 ± 2.22E-03	6.69E-08 ± 1.43E-07	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.82E+01 ± 6.15E+00 +	1.33E+00 ± 9.25E-02 +	1.18E+00 ± 3.87E-02 +	7.92E+00 ± 1.52E+00 +	3.90E+01 ± 7.04E+00 +	1.19E+00 ± 3.20E-02 +	7.49E-01 ± 1.02E-01
f12	8.16E-19 ± 7.69E-19	1.57E-32 ± 0.00E+00	1.57E-32 ± 0.00E+00	4.14E-24 ± 3.18E-24	6.04E-10 ± 5.12E-10	1.57E-32 ± 0.00E+00	1.57E-32 ± 0.00E+00
	1.73E+05 ± 1.59E+05 +	1.45E+00 ± 4.86E-01 +	8.65E-01 ± 2.70E-01 +	6.90E+01 ± 2.26E+02 +	4.14E+05 ± 3.35E+05 +	9.52E-01 ± 3.13E-01 +	1.13E-02 ± 5.19E-03
f13	1.93E-16 ± 2.68E-16	1.35E-32 ± 0.00E+00	1.35E-32 ± 0.00E+00	1.39E-21 ± 1.75E-21	9.34E-07 ± 1.11E-06	1.35E-32 ± 0.00E+00	1.35E-32 ± 0.00E+00
	2.16E+06 ± 9.93E+05 +	1.78E+01 ± 5.18E+00 +	1.20E+01 ± 2.95E+00 +	4.17E+04 ± 6.87E+04 +	3.64E+06 ± 1.87E+06 +	1.23E+01 ± 2.62E+00 +	8.70E-01 ± 2.94E-01
f14	2.64E-46 ± 8.01E-46 +	2.32E-45 ± 1.66E-44 +	8.49E-58 ± 4.17E-57 +	1.89E-53 ± 5.47E-53 +	8.84E-28 ± 1.22E-27 +	3.00E-71 ± 1.88E-70 +	2.07E-106 ± 4.65E-106
f15	1.22E+00 ± 2.15E-01 +	7.49E-01 ± 1.13E-01 -	8.06E-01 ± 1.23E-01 =	1.48E+00 ± 3.10E-01 +	3.09E+00 ± 3.48E-01 +	8.62E-01 ± 1.34E-01 =	8.56E-01 ± 1.39E-01
f16	3.52E+00 ± 2.90E+00 +	1.89E+01 ± 2.15E+01 +	4.32E-10 ± 8.85E-10 +	7.64E-06 ± 1.57E-05 +	1.07E-02 ± 7.54E-03 +	4.29E-13 ± 1.51E-12 +	1.93E-57 ± 9.46E-57
f17	4.85E-04 ± 1.66E-04 +	5.99E-05 ± 5.06E-05 +	1.03E-13 ± 5.12E-13 +	2.38E-04 ± 1.57E-04 +	1.34E-02 ± 3.10E-03 +	3.75E-21 ± 1.27E-20 +	1.26E-45 ± 5.32E-45
f18	6.96E+00 ± 3.16E-01 +	6.46E+00 ± 3.54E-01 +	6.18E+00 ± 3.29E-01 +	7.30E+00 ± 2.94E-01 +	8.05E+00 ± 2.58E-01 +	6.09E+00 ± 3.09E-01 +	5.80E+00 ± 2.89E-01
f19	2.35E+00 ± 5.37E-02 +	2.38E+00 ± 3.68E-02 +	2.29E+00 ± 3.12E-02 +	2.46E+00 ± 7.45E-02 +	2.76E+00 ± 1.35E-01 +	2.29E+00 ± 3.42E-02 +	2.24E+00 ± 3.86E-02
f20	4.89E-20 ± 5.45E-20	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	6.38E-20 ± 5.39E-20	3.15E-13 ± 1.49E-13	0.00E+00 ± 0.00E+00	4.55E-20 ± 5.35E-20
	1.40E-01 ± 2.91E-02 +	1.82E-03 ± 5.13E-04 +	9.35E-04 ± 1.92E-04 +	3.77E-02 ± 8.13E-03 +	1.90E-01 ± 3.19E-02 +	1.05E-03 ± 2.12E-04 +	2.78E-05 ± 6.99E-06
f21	1.24E+03 ± 7.40E+02 +	3.84E+01 ± 6.48E+01 +	1.07E+03 ± 4.68E+02 +	6.54E+00 ± 1.21E+01 +	1.22E+02 ± 1.25E+02 +	1.33E+00 ± 2.76E+00 -	3.52E+00 ± 5.85E+00
f22	1.14E+00 ± 2.00E-04 +	1.14E+00 ± 7.60E-04 +	9.22E-01 ± 9.31E-02 +	1.14E+00 ± 1.03E-04 +	1.14E+00 ± 2.34E-04 +	8.34E-01 ± 8.69E-02 +	7.24E-01 ± 7.79E-02
f23	1.39E-08 ± 1.23E-08	2.12E-05 ± 3.20E-05	3.49E-10 ± 0.00E+00	6.30E-10 ± 4.31E-10	3.99E+02 ± 1.49E+02	3.47E-10 ± 1.63E-11	3.40E-10 ± 3.16E-11
	4.51E+05 ± 3.18E+04 +	2.93E+05 ± 1.83E+04 +	2.50E+05 ± 1.33E+04 +	2.76E+05 ± 2.22E+04 +	5.75E+05 ± 2.45E+04 +	2.06E+05 ± 1.24E+04 +	1.32E+05 ± 1.16E+04
f24	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	3.68E-11 ± 2.03E-11	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.87E+00 ± 1.95E-01 +	5.44E-01 ± 1.31E-01 +	2.26E-01 ± 6.76E-02 +	1.43E+00 ± 1.35E-01 +	2.75E+00 ± 1.62E-01 +	2.03E-01 ± 5.55E-02 +	1.08E-02 ± 3.52E-03
f25	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	3.92E-11 ± 2.28E-11	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.03E+00 ± 2.12E-01 +	1.29E-01 ± 4.22E-02 +	6.29E-02 ± 1.56E-02 +	1.04E+00 ± 1.88E-01 +	2.72E+00 ± 2.37E-01 +	6.78E-02 ± 1.50E-02 +	1.46E-03 ± 4.11E-04
f26	4.43E-10 ± 4.16E-10	1.35E-10 ± 7.99E-10	0.00E+00 ± 0.00E+00	1.27E-14 ± 1.96E-14	4.06E-03 ± 6.34E-04	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	1.95E+01 ± 1.27E+00 +	7.46E+00 ± 6.99E-01 +	5.87E+00 ± 4.78E-01 +	1.34E+01 ± 1.02E+00 +	2.39E+01 ± 1.03E+00 +	6.10E+00 ± 5.14E-01 +	1.90E+00 ± 2.00E-01
f27	5.08E+00 ± 1.64E+00 +	8.99E-04 ± 5.90E-04 -	7.15E-02 ± 5.23E-02 +	5.93E+00 ± 2.99E+00 +	1.50E+01 ± 1.28E+00 +	7.40E-02 ± 8.23E-02 +	5.15E-02 ± 3.04E-02
f28	5.04E-04 ± 1.92E-04 -	1.16E-04 ± 2.33E-05 -	6.19E-04 ± 2.77E-04 =	5.17E-04 ± 4.01E-04 -	8.16E-03 ± 1.93E-03 +	6.40E-04 ± 2.08E-04 -	7.21E-04 ± 1.75E-04
f29	6.35E-14 ± 7.16E-15 -	1.85E-02 ± 1.32E-01 -	1.85E-02 ± 1.32E-01 -	6.72E-14 ± 6.40E-15 -	9.74E-10 ± 6.23E-10 -	7.39E-02 ± 2.56E-01 -	8.32E-01 ± 8.97E-01
f30	8.20E-12 ± 5.63E-12 +	5.95E-34 ± 4.13E-33 +	2.76E-49 ± 5.36E-49 +	6.43E-17 ± 6.25E-17 +	4.02E-03 ± 2.07E-03 +	8.53E-51 ± 1.45E-50 +	1.57E-82 ± 3.32E-82
w/t/l	27/0/3	24/0/6	27/2/1	26/1/3	29/0/1	24/3/3	-

Table S3. Comparison on the errors of jDE, JADE, SHADE, AGDE, CoBiDE, OrSHADE, and ReSHADE in all benchmark functions.

Prob.	jDE	JADE	SHADE	AGDE	CoBiDE	OrSHADE	ReSHADE
f01	1.12E-17 ± 9.82E-18 +	4.25E-39 ± 2.86E-38 +	1.65E-55 ± 3.06E-55 +	8.04E-23 ± 6.57E-23 +	4.41E-09 ± 2.55E-09 +	9.75E-57 ± 2.24E-56 +	1.20E-88 ± 3.58E-88
f02	4.10E-11 ± 1.94E-11 +	8.44E-19 ± 2.17E-18 +	1.57E-28 ± 1.96E-28 +	1.08E-13 ± 4.86E-14 +	1.06E-05 ± 2.87E-06 +	5.48E-29 ± 7.80E-29 +	1.73E-47 ± 2.61E-47
f03	2.97E+01 ± 2.73E+01 +	9.88E+02 ± 2.10E+03 +	2.73E-06 ± 4.01E-06 +	1.79E-03 ± 2.06E-03 +	3.23E+00 ± 1.91E+00 +	2.08E-09 ± 6.39E-09 +	7.44E-48 ± 5.31E-47
f04	3.39E-02 ± 9.87E-03 +	3.56E-02 ± 1.64E-02 +	6.54E-02 ± 9.84E-02 +	1.81E-02 ± 4.45E-03 +	1.48E+00 ± 2.49E-01 +	1.71E-04 ± 4.99E-04 +	2.45E-23 ± 5.47E-23
f05	2.27E+01 ± 1.67E+00 +	3.09E+00 ± 1.33E+00 +	7.37E+00 ± 1.22E+00 +	6.13E+00 ± 8.07E+00 +	2.13E+01 ± 8.27E-01 +	6.80E-02 ± 1.04E-01 +	3.20E-01 ± 1.11E+00
f06	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.99E+03 ± 5.56E+02 +	3.53E+01 ± 8.76E+00 +	2.17E+01 ± 4.13E+00 +	7.76E+02 ± 2.27E+02 +	4.44E+03 ± 1.16E+03 +	2.32E+01 ± 4.42E+00 +	4.00E-02 ± 1.96E-01
f07	1.11E-02 ± 2.51E-03 +	1.62E-03 ± 5.94E-04 +	1.67E-03 ± 5.12E-04 +	1.10E-02 ± 3.35E-03 +	2.29E-02 ± 5.87E-03 +	1.49E-03 ± 5.55E-04 +	7.86E-04 ± 3.34E-04
f08	1.58E-10 ± 1.64E-10 -	6.37E-07 ± 3.97E-07 -	3.10E-06 ± 3.01E-06 +	2.50E-13 ± 6.32E-13 -	5.22E-03 ± 6.78E-03 +	3.59E-06 ± 3.76E-06 =	2.87E-06 ± 5.09E-06
f09	2.34E-04 ± 4.55E-04 +	1.24E-06 ± 7.16E-07 -	2.40E-04 ± 2.52E-04 +	2.26E-04 ± 6.81E-04 =	5.46E+00 ± 1.63E+00 +	2.03E-02 ± 1.39E-01 +	1.95E-02 ± 1.39E-01
f10	7.12E-10 ± 4.08E-10	4.14E-15 ± 0.00E+00	4.14E-15 ± 0.00E+00	2.32E-12 ± 9.51E-13	1.91E-05 ± 5.51E-06	4.14E-15 ± 0.00E+00	5.12E-15 ± 1.60E-15
	1.16E+01 ± 7.06E-01 +	3.02E+00 ± 2.36E-01 +	2.54E+00 ± 1.69E-01 +	7.41E+00 ± 7.09E-01 +	1.29E+01 ± 6.25E-01 +	2.62E+00 ± 1.66E-01 +	3.01E-01 ± 5.22E-02
f11	1.92E-16 ± 7.27E-16	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	5.38E-04 ± 2.22E-03	6.69E-08 ± 1.43E-07	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.82E+01 ± 6.15E+00 +	1.33E+00 ± 9.25E-02 +	1.18E+00 ± 3.87E-02 +	7.92E+00 ± 1.52E+00 +	3.90E+01 ± 7.04E+00 +	1.19E+00 ± 3.20E-02 +	7.49E-01 ± 1.02E-01
f12	8.16E-19 ± 7.69E-19	1.57E-32 ± 0.00E+00	1.57E-32 ± 0.00E+00	4.14E-24 ± 3.18E-24	6.04E-10 ± 5.12E-10	1.57E-32 ± 0.00E+00	1.57E-32 ± 0.00E+00
	1.73E+05 ± 1.59E+05 +	1.45E+00 ± 4.86E-01 +	8.65E-01 ± 2.70E-01 +	6.90E+01 ± 2.26E+02 +	4.14E+05 ± 3.35E+05 +	9.52E-01 ± 3.13E-01 +	1.13E-02 ± 5.19E-03
f13	1.93E-16 ± 2.68E-16	1.35E-32 ± 0.00E+00	1.35E-32 ± 0.00E+00	1.39E-21 ± 1.75E-21	9.34E-07 ± 1.11E-06	1.35E-32 ± 0.00E+00	1.35E-32 ± 0.00E+00
	2.16E+06 ± 9.93E+05 +	1.78E+01 ± 5.18E+00 +	1.20E+01 ± 2.95E+00 +	4.17E+04 ± 6.87E+04 +	3.64E+06 ± 1.87E+06 +	1.23E+01 ± 2.62E+00 +	8.70E-01 ± 2.94E-01
f14	2.64E-46 ± 8.01E-46 +	2.32E-45 ± 1.66E-44 +	8.49E-58 ± 4.17E-57 +	1.89E-53 ± 5.47E-53 +	8.84E-28 ± 1.22E-27 +	3.00E-71 ± 1.88E-70 +	2.07E-106 ± 4.65E-106
f15	1.22E+00 ± 2.15E-01 +	7.49E-01 ± 1.13E-01 -	8.06E-01 ± 1.23E-01 =	1.48E+00 ± 3.10E-01 +	3.09E+00 ± 3.48E-01 +	8.62E-01 ± 1.34E-01 =	8.56E-01 ± 1.39E-01
f16	3.52E+00 ± 2.90E+00 +	1.89E+01 ± 2.15E+01 +	4.32E-10 ± 8.85E-10 +	7.64E-06 ± 1.57E-05 +	1.07E-02 ± 7.54E-03 +	4.29E-13 ± 1.51E-12 +	1.93E-57 ± 9.46E-57
f17	4.85E-04 ± 1.66E-04 +	5.99E-05 ± 5.06E-05 +	1.03E-13 ± 5.12E-13 +	2.38E-04 ± 1.57E-04 +	1.34E-02 ± 3.10E-03 +	3.75E-21 ± 1.27E-20 +	1.26E-45 ± 5.32E-45
f18	6.96E+00 ± 3.16E-01 +	6.46E+00 ± 3.54E-01 +	6.18E+00 ± 3.29E-01 +	7.30E+00 ± 2.94E-01 +	8.05E+00 ± 2.58E-01 +	6.09E+00 ± 3.09E-01 +	5.80E+00 ± 2.89E-01
f19	2.35E+00 ± 5.37E-02 +	2.38E+00 ± 3.68E-02 +	2.29E+00 ± 3.12E-02 +	2.46E+00 ± 7.45E-02 +	2.76E+00 ± 1.35E-01 +	2.29E+00 ± 3.42E-02 +	2.24E+00 ± 3.86E-02
f20	4.89E-20 ± 5.45E-20	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	6.38E-20 ± 5.39E-20	3.15E-13 ± 1.49E-13	0.00E+00 ± 0.00E+00	4.55E-20 ± 5.35E-20
	1.40E-01 ± 2.91E-02 +	1.82E-03 ± 5.13E-04 +	9.35E-04 ± 1.92E-04 +	3.77E-02 ± 8.13E-03 +	1.90E-01 ± 3.19E-02 +	1.05E-03 ± 2.12E-04 +	2.78E-05 ± 6.99E-06
f21	1.24E+03 ± 7.40E+02 +	3.84E+01 ± 6.48E+01 +	1.07E+03 ± 4.68E+02 +	6.54E+00 ± 1.21E+01 +	1.22E+02 ± 1.25E+02 +	1.33E+00 ± 2.76E+00 -	3.52E+00 ± 5.85E+00
f22	1.14E+00 ± 2.00E-04 +	1.14E+00 ± 7.60E-04 +	9.22E-01 ± 9.31E-02 +	1.14E+00 ± 1.03E-04 +	1.14E+00 ± 2.34E-04 +	8.34E-01 ± 8.69E-02 +	7.24E-01 ± 7.79E-02
f23	1.39E-08 ± 1.23E-08	2.12E-05 ± 3.20E-05	3.49E-10 ± 0.00E+00	6.30E-10 ± 4.31E-10	3.99E+02 ± 1.49E+02	3.47E-10 ± 1.63E-11	3.40E-10 ± 3.16E-11
	4.51E+05 ± 3.18E+04 +	2.93E+05 ± 1.83E+04 +	2.50E+05 ± 1.33E+04 +	2.76E+05 ± 2.22E+04 +	5.75E+05 ± 2.45E+04 +	2.06E+05 ± 1.24E+04 +	1.32E+05 ± 1.16E+04
f24	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	3.68E-11 ± 2.03E-11	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.87E+00 ± 1.95E-01 +	5.44E-01 ± 1.31E-01 +	2.26E-01 ± 6.76E-02 +	1.43E+00 ± 1.35E-01 +	2.75E+00 ± 1.62E-01 +	2.03E-01 ± 5.55E-02 +	1.08E-02 ± 3.52E-03
f25	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	3.92E-11 ± 2.28E-11	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.03E+00 ± 2.12E-01 +	1.29E-01 ± 4.22E-02 +	6.29E-02 ± 1.56E-02 +	1.04E+00 ± 1.88E-01 +	2.72E+00 ± 2.37E-01 +	6.78E-02 ± 1.50E-02 +	1.46E-03 ± 4.11E-04
f26	4.43E-10 ± 4.16E-10	1.35E-10 ± 7.99E-10	0.00E+00 ± 0.00E+00	1.27E-14 ± 1.96E-14	4.06E-03 ± 6.34E-04	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	1.95E+01 ± 1.27E+00 +	7.46E+00 ± 6.99E-01 +	5.87E+00 ± 4.78E-01 +	1.34E+01 ± 1.02E+00 +	2.39E+01 ± 1.03E+00 +	6.10E+00 ± 5.14E-01 +	1.90E+00 ± 2.00E-01
f27	5.08E+00 ± 1.64E+00 +	8.99E-04 ± 5.90E-04 -	7.15E-02 ± 5.23E-02 +	5.93E+00 ± 2.99E+00 +	1.50E+01 ± 1.28E+00 +	7.40E-02 ± 8.23E-02 +	5.15E-02 ± 3.04E-02
f28	5.04E-04 ± 1.92E-04 -	1.16E-04 ± 2.33E-05 -	6.19E-04 ± 2.77E-04 =	5.17E-04 ± 4.01E-04 -	8.16E-03 ± 1.93E-03 +	6.40E-04 ± 2.08E-04 -	7.21E-04 ± 1.75E-04
f29	6.35E-14 ± 7.16E-15 -	1.85E-02 ± 1.32E-01 -	1.85E-02 ± 1.32E-01 -	6.72E-14 ± 6.40E-15 -	9.74E-10 ± 6.23E-10 -	7.39E-02 ± 2.56E-01 -	8.32E-01 ± 8.97E-01
f30	8.20E-12 ± 5.63E-12 +	5.95E-34 ± 4.13E-33 +	2.76E-49 ± 5.36E-49 +	6.43E-17 ± 6.25E-17 +	4.02E-03 ± 2.07E-03 +	8.53E-51 ± 1.45E-50 +	1.57E-82 ± 3.32E-82
w/t/l	27/0/3	24/0/6	27/2/1	26/1/3	29/0/1	24/3/3	-

Table S4. Influence of reflection-based mutation on other mutation strategies. SHADE1 and ReSHADE1 use “rand-to-*p*best/1” without archive; SHADE2 and ReSHADE2 use “current-to-*p*best/1” without archive.

Prob.	SHADE1		ReSHADE1		SHADE2		ReSHADE2	
f01	1.65E-55 ± 3.06E-55	+	1.20E-88 ± 3.58E-88		2.27E-44 ± 4.58E-44	+	4.40E-86 ± 1.25E-85	
f02	1.57E-28 ± 1.96E-28	+	1.73E-47 ± 2.61E-47		2.49E-22 ± 1.75E-22	+	2.87E-45 ± 3.65E-45	
f03	2.73E-06 ± 4.01E-06	+	7.44E-48 ± 5.31E-47		2.71E-06 ± 7.40E-06	+	8.06E-58 ± 2.69E-57	
f04	6.54E-02 ± 9.84E-02	+	2.45E-23 ± 5.47E-23		4.98E-03 ± 8.59E-03	+	1.62E-24 ± 3.39E-24	
f05	7.37E+00 ± 1.22E+00	+	3.20E-01 ± 1.11E+00		6.18E+00 ± 1.74E+00	+	3.31E-01 ± 8.70E-01	
f06	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	
	2.17E+01 ± 4.13E+00	+	4.00E-02 ± 1.96E-01		5.74E+01 ± 1.17E+01	+	1.80E-01 ± 3.84E-01	
f07	1.67E-03 ± 5.12E-04	+	7.86E-04 ± 3.34E-04		2.29E-03 ± 6.12E-04	+	7.68E-04 ± 2.85E-04	
f08	3.10E-06 ± 3.01E-06	+	2.87E-06 ± 5.09E-06		6.58E-03 ± 3.55E-03	-	2.83E-01 ± 3.01E-01	
f09	2.40E-04 ± 2.52E-04	+	1.95E-02 ± 1.39E-01		1.50E-02 ± 1.16E-02	-	1.04E-01 ± 3.28E-02	
f10	4.14E-15 ± 0.00E+00		5.12E-15 ± 1.60E-15		4.14E-15 ± 0.00E+00		6.86E-15 ± 1.82E-15	
	2.54E+00 ± 1.69E-01	+	3.01E-01 ± 5.22E-02		3.44E+00 ± 2.19E-01	+	4.32E-01 ± 7.55E-02	
f11	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	
	1.18E+00 ± 3.87E-02	+	7.49E-01 ± 1.02E-01		1.53E+00 ± 9.63E-02	+	8.69E-01 ± 8.34E-02	
f12	1.57E-32 ± 0.00E+00		1.57E-32 ± 0.00E+00		1.57E-32 ± 0.00E+00		1.57E-32 ± 0.00E+00	
	8.65E-01 ± 2.70E-01	+	1.13E-02 ± 5.19E-03		2.33E+00 ± 6.23E-01	+	2.54E-02 ± 1.33E-02	
f13	1.35E-32 ± 0.00E+00		1.35E-32 ± 0.00E+00		1.35E-32 ± 0.00E+00		1.35E-32 ± 0.00E+00	
	1.20E+01 ± 2.95E+00	+	8.70E-01 ± 2.94E-01		2.66E+01 ± 5.29E+00	+	1.38E+00 ± 5.52E-01	
f14	8.49E-58 ± 4.17E-57	+	2.07E-106 ± 4.65E-106		3.68E-55 ± 1.57E-54	+	9.17E-98 ± 2.84E-97	
f15	8.06E-01 ± 1.23E-01	=	8.56E-01 ± 1.39E-01		1.11E+00 ± 1.40E-01	=	1.18E+00 ± 1.54E-01	
f16	4.32E-10 ± 8.85E-10	+	1.93E-57 ± 9.46E-57		2.46E-09 ± 4.06E-09	+	9.79E-59 ± 6.74E-58	
f17	1.03E-13 ± 5.12E-13	+	1.26E-45 ± 5.32E-45		6.37E-04 ± 2.62E-04	+	3.27E-18 ± 2.33E-17	
f18	6.18E+00 ± 3.29E-01	+	5.80E+00 ± 2.89E-01		6.00E+00 ± 3.01E-01	+	5.68E+00 ± 3.84E-01	
f19	2.29E+00 ± 3.12E-02	+	2.24E+00 ± 3.86E-02		2.32E+00 ± 3.31E-02	+	2.25E+00 ± 2.78E-02	
f20	0.00E+00 ± 0.00E+00		4.55E-20 ± 5.35E-20		0.00E+00 ± 0.00E+00		6.72E-20 ± 1.52E-20	
	9.35E-04 ± 1.92E-04	+	2.78E-05 ± 6.99E-06		2.85E-03 ± 5.63E-04	+	4.54E-05 ± 1.51E-05	
f21	1.07E+03 ± 4.68E+02	+	3.52E+00 ± 5.85E+00		1.54E+02 ± 1.67E+02	+	1.12E+01 ± 2.30E+01	
f22	9.22E-01 ± 9.31E-02	+	7.24E-01 ± 7.79E-02		8.33E-01 ± 7.19E-02	+	6.87E-01 ± 8.25E-02	
f23	3.49E-10 ± 0.00E+00		3.40E-10 ± 3.16E-11		3.49E-10 ± 0.00E+00		5.59E-06 ± 3.87E-05	
	2.50E+05 ± 1.33E+04	+	1.32E+05 ± 1.16E+04		3.50E+05 ± 2.04E+04	+	1.76E+05 ± 1.55E+04	
f24	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	
	2.26E-01 ± 6.76E-02	+	1.08E-02 ± 3.52E-03		6.13E-01 ± 1.13E-01	+	1.95E-02 ± 7.83E-03	
f25	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	
	6.29E-02 ± 1.56E-02	+	1.46E-03 ± 4.11E-04		3.77E-01 ± 9.36E-02	+	2.63E-03 ± 7.32E-04	
f26	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	
	5.87E+00 ± 4.78E-01	+	1.90E+00 ± 2.00E-01		9.72E+00 ± 5.89E-01	+	2.37E+00 ± 2.37E-01	
f27	7.15E-02 ± 5.23E-02	+	5.15E-02 ± 3.04E-02		7.16E-01 ± 3.49E-01	-	1.29E+00 ± 6.76E-01	
f28	6.19E-04 ± 2.77E-04	=	7.21E-04 ± 1.75E-04		8.34E-04 ± 1.99E-04	-	1.79E-03 ± 4.04E-04	
f29	1.85E-02 ± 1.32E-01	-	8.32E-01 ± 8.97E-01		5.77E-14 ± 3.38E-15	-	2.96E-01 ± 5.49E-01	
f30	2.76E-49 ± 5.36E-49	+	1.57E-82 ± 3.32E-82		2.38E-38 ± 4.17E-38	+	9.06E-80 ± 5.11E-79	
w/t/l	27/2/1		-		24/1/5		-	

Table S5. Influence of reflection-based mutation on other mutation strategies. SHADE3 and ReSHADE3 use “rand-to-*p*best/1” with archive; SHADE4 and ReSHADE4 use “current-to-*p*best/1” with archive.

Prob.	SHADE3		ReSHADE3	SHADE4		ReSHADE4
f01	1.00E-52 ± 1.48E-52	+	1.04E-85 ± 2.52E-85	2.12E-43 ± 3.68E-43	+	8.90E-83 ± 2.77E-82
f02	1.05E-26 ± 1.17E-26	+	1.09E-44 ± 1.98E-44	3.17E-21 ± 2.47E-21	+	1.24E-42 ± 1.76E-42
f03	6.80E-11 ± 1.17E-10	+	3.63E-43 ± 2.01E-42	7.11E-10 ± 1.69E-09	+	2.70E-46 ± 9.17E-46
f04	8.25E-15 ± 1.25E-14	+	2.43E-25 ± 6.78E-25	1.77E-12 ± 2.15E-12	+	9.50E-26 ± 1.06E-25
f05	2.37E-02 ± 6.48E-02	+	7.82E-02 ± 5.58E-01	6.71E-01 ± 1.28E+00	+	1.94E-01 ± 9.02E-01
f06	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	4.31E+01 ± 7.24E+00	+	9.40E-01 ± 9.47E-01	9.20E+01 ± 1.76E+01	+	2.16E+00 ± 1.08E+00
f07	1.78E-03 ± 4.04E-04	+	8.12E-04 ± 2.85E-04	2.27E-03 ± 7.46E-04	+	9.04E-04 ± 2.88E-04
f08	8.06E-06 ± 1.00E-05	+	4.38E-06 ± 1.07E-05	7.78E-03 ± 3.44E-03	-	1.74E-01 ± 1.57E-01
f09	1.99E-02 ± 1.39E-01	+	5.11E-05 ± 6.08E-05	1.69E-02 ± 7.54E-03	-	1.04E-01 ± 2.89E-02
f10	4.14E-15 ± 0.00E+00		4.14E-15 ± 0.00E+00	4.63E-15 ± 1.23E-15		4.21E-15 ± 4.97E-16
	3.10E+00 ± 1.71E-01	+	5.83E-01 ± 1.05E-01	3.89E+00 ± 2.07E-01	+	7.84E-01 ± 1.40E-01
f11	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	1.38E+00 ± 6.44E-02	+	9.58E-01 ± 3.77E-02	1.82E+00 ± 1.60E-01	+	9.95E-01 ± 3.73E-02
f12	1.57E-32 ± 0.00E+00		1.57E-32 ± 0.00E+00	1.57E-32 ± 0.00E+00		1.57E-32 ± 0.00E+00
	1.44E+00 ± 3.67E-01	+	3.41E-02 ± 1.74E-02	3.18E+00 ± 5.86E-01	+	6.50E-02 ± 3.38E-02
f13	1.35E-32 ± 0.00E+00		1.35E-32 ± 0.00E+00	1.35E-32 ± 0.00E+00		1.35E-32 ± 0.00E+00
	1.92E+01 ± 4.68E+00	+	1.47E+00 ± 4.43E-01	3.70E+01 ± 7.99E+00	+	2.13E+00 ± 5.38E-01
f14	1.47E-73 ± 4.41E-73	+	1.08E-91 ± 6.37E-91	1.81E-61 ± 6.36E-61	+	7.35E-88 ± 3.61E-87
f15	8.08E-01 ± 1.30E-01	=	8.00E-01 ± 1.38E-01	1.06E+00 ± 1.65E-01	-	1.24E+00 ± 1.41E-01
f16	4.46E-14 ± 1.37E-13	+	2.56E-49 ± 1.40E-48	3.66E-12 ± 1.25E-11	+	7.54E-47 ± 5.38E-46
f17	3.70E-18 ± 2.07E-17	+	2.72E-43 ± 1.88E-42	7.70E-04 ± 2.39E-04	+	1.01E-37 ± 4.00E-37
f18	6.08E+00 ± 2.68E-01	+	5.79E+00 ± 3.15E-01	5.94E+00 ± 3.15E-01	+	5.72E+00 ± 3.22E-01
f19	2.30E+00 ± 3.01E-02	+	2.24E+00 ± 3.37E-02	2.33E+00 ± 4.54E-02	+	2.26E+00 ± 2.91E-02
f20	0.00E+00 ± 0.00E+00		6.51E-21 ± 2.57E-20	4.25E-20 ± 5.35E-20		2.39E-20 ± 4.49E-20
	1.89E-03 ± 3.80E-04	+	7.30E-05 ± 1.68E-05	4.41E-03 ± 8.20E-04	+	1.03E-04 ± 2.58E-05
f21	5.64E-04 ± 1.33E-03	-	9.61E-02 ± 4.56E-01	9.19E-03 ± 2.49E-02	-	1.10E-01 ± 2.77E-01
f22	9.32E-01 ± 8.46E-02	+	7.48E-01 ± 6.35E-02	8.12E-01 ± 8.89E-02	=	7.05E-01 ± 8.32E-02
f23	3.49E-10 ± 0.00E+00		3.45E-10 ± 2.28E-11	3.49E-10 ± 0.00E+00		3.56E-10 ± 3.62E-11
	2.41E+05 ± 1.56E+04	+	1.39E+05 ± 9.31E+03	3.24E+05 ± 1.51E+04	+	1.70E+05 ± 1.16E+04
f24	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	3.47E-01 ± 6.44E-02	+	1.84E-02 ± 5.55E-03	7.26E-01 ± 1.12E-01	+	2.85E-02 ± 1.06E-02
f25	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	1.37E-01 ± 3.17E-02	+	3.80E-03 ± 1.04E-03	5.63E-01 ± 1.29E-01	+	6.67E-03 ± 1.92E-03
f26	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	7.36E+00 ± 4.88E-01	+	2.61E+00 ± 2.29E-01	1.13E+01 ± 7.44E-01	+	3.09E+00 ± 2.96E-01
f27	8.11E-02 ± 6.00E-02	+	5.64E-02 ± 3.33E-02	6.81E-01 ± 4.02E-01	-	1.21E+00 ± 5.03E-01
f28	6.05E-04 ± 2.15E-04	-	7.51E-04 ± 1.82E-04	8.50E-04 ± 1.76E-04	-	1.78E-03 ± 3.41E-04
f29	3.70E-02 ± 1.85E-01	-	5.73E-01 ± 6.82E-01	6.07E-14 ± 6.40E-15	-	6.10E-01 ± 6.48E-01
f30	2.25E-46 ± 4.33E-46	+	4.19E-79 ± 7.43E-79	2.70E-37 ± 3.60E-37	+	1.91E-76 ± 6.37E-76
w/t/l	26/1/3		-	22/1/7		-

Table S6. Influence of reflection-based mutation on other DE methods, jDE vs ReJDE and JADE vs ReJADE.

Prob.	jDE		RejDE	JADE		ReJADE
f01	1.12E-17 ± 9.82E-18	+	9.86E-45 ± 2.58E-44	4.25E-39 ± 2.86E-38	+	3.56E-71 ± 1.84E-70
f02	4.10E-11 ± 1.94E-11	+	1.13E-23 ± 9.05E-24	8.44E-19 ± 2.17E-18	+	1.80E-36 ± 1.11E-35
f03	2.97E+01 ± 2.73E+01	+	4.89E-02 ± 6.78E-02	9.88E+02 ± 2.10E+03	+	4.69E-60 ± 3.35E-59
f04	3.39E-02 ± 9.87E-03	+	7.05E-03 ± 1.68E-02	3.56E-02 ± 1.64E-02	+	3.27E-04 ± 3.33E-04
f05	2.27E+01 ± 1.67E+00	+	1.82E+01 ± 8.96E-01	3.09E+00 ± 1.33E+00	+	7.82E-02 ± 5.58E-01
f06	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	2.99E+03 ± 5.56E+02	+	6.46E+01 ± 1.96E+01	3.53E+01 ± 8.76E+00	+	2.00E-02 ± 1.40E-01
f07	1.11E-02 ± 2.51E-03	+	1.97E-03 ± 5.77E-04	1.62E-03 ± 5.94E-04	+	7.95E-04 ± 3.51E-04
f08	1.58E-10 ± 1.64E-10	+	3.57E-14 ± 2.55E-13	6.37E-07 ± 3.99E-07	+	1.32E-07 ± 1.21E-07
f09	2.34E-04 ± 4.55E-04	+	1.81E-12 ± 9.31E-12	1.24E-06 ± 7.20E-07	+	7.72E-08 ± 7.45E-08
f10	7.12E-10 ± 4.08E-10		5.53E-15 ± 1.75E-15	4.14E-15 ± 0.00E+00		4.14E-15 ± 0.00E+00
	1.16E+01 ± 7.06E-01	+	3.46E+00 ± 3.74E-01	3.02E+00 ± 2.36E-01	+	3.76E-01 ± 9.84E-02
f11	1.92E-16 ± 7.27E-16		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	2.82E+01 ± 6.15E+00	+	1.50E+00 ± 1.87E-01	1.33E+00 ± 9.25E-02	+	7.80E-01 ± 1.20E-01
f12	8.16E-19 ± 7.69E-19		1.57E-32 ± 0.00E+00	1.57E-32 ± 0.00E+00		1.57E-32 ± 0.00E+00
	1.73E+05 ± 1.59E+05	+	1.96E+00 ± 6.81E-01	1.45E+00 ± 4.86E-01	+	1.52E-02 ± 6.69E-03
f13	1.93E-16 ± 2.68E-16		1.35E-32 ± 0.00E+00	1.35E-32 ± 0.00E+00		1.35E-32 ± 0.00E+00
	2.16E+06 ± 9.93E+05	+	2.91E+01 ± 1.23E+01	1.78E+01 ± 5.18E+00	+	9.20E-01 ± 3.50E-01
f14	2.64E-46 ± 8.01E-46	+	7.49E-51 ± 4.41E-50	2.32E-45 ± 1.66E-44	+	4.15E-57 ± 2.68E-56
f15	1.22E+00 ± 2.15E-01	=	1.16E+00 ± 2.03E-01	7.49E-01 ± 1.13E-01	-	8.10E-01 ± 1.07E-01
f16	3.52E+00 ± 2.90E+00	+	1.37E-04 ± 3.06E-04	1.89E+01 ± 2.15E+01	+	4.11E+00 ± 1.06E+01
f17	4.85E-04 ± 1.66E-04	+	9.81E-19 ± 4.71E-18	5.99E-05 ± 5.06E-05	+	5.30E-12 ± 3.79E-11
f18	6.96E+00 ± 3.16E-01	+	6.32E+00 ± 3.51E-01	6.46E+00 ± 3.54E-01	+	6.41E+00 ± 3.41E-01
f19	2.35E+00 ± 5.37E-02	+	2.32E+00 ± 4.21E-02	2.38E+00 ± 3.68E-02	+	2.35E+00 ± 3.94E-02
f20	4.89E-20 ± 5.45E-20		5.53E-20 ± 5.47E-20	0.00E+00 ± 0.00E+00		8.50E-21 ± 2.94E-20
	1.40E-01 ± 2.91E-02	+	2.77E-03 ± 1.04E-03	1.82E-03 ± 5.13E-04	+	3.67E-05 ± 1.28E-05
f21	1.24E+03 ± 7.40E+02	+	5.63E+02 ± 4.86E+02	3.84E+01 ± 6.48E+01	+	1.94E-04 ± 6.10E-04
f22	1.14E+00 ± 2.00E-04	+	1.13E+00 ± 1.08E-02	1.14E+00 ± 7.60E-04	+	1.14E+00 ± 1.84E-03
f23	1.39E-08 ± 1.23E-08	+	3.49E-10 ± 0.00E+00	2.12E-05 ± 3.20E-05	+	3.58E-10 ± 3.16E-11
f24	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	2.87E+00 ± 1.95E-01	+	9.21E-01 ± 2.28E-01	5.44E-01 ± 1.31E-01	+	2.71E-02 ± 1.24E-02
f25	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00		0.00E+00 ± 0.00E+00
	2.03E+00 ± 2.12E-01	+	1.67E-01 ± 7.67E-02	1.29E-01 ± 4.22E-02	+	1.74E-03 ± 7.36E-04
f26	4.43E-10 ± 4.16E-10	+	0.00E+00 ± 0.00E+00	1.35E-10 ± 7.99E-10	+	0.00E+00 ± 0.00E+00
f27	5.08E+00 ± 1.64E+00	+	3.57E+00 ± 1.83E+00	8.99E-04 ± 5.90E-04	+	1.94E-04 ± 1.12E-04
f28	5.04E-04 ± 1.92E-04	+	4.85E-04 ± 2.57E-04	1.16E-04 ± 2.33E-05	-	1.93E-04 ± 3.87E-05
f29	6.35E-14 ± 7.16E-15	=	6.13E-14 ± 6.66E-15	1.85E-02 ± 1.32E-01	-	5.54E-01 ± 6.84E-01
f30	8.20E-12 ± 5.63E-12	=	1.32E-37 ± 4.19E-37	5.95E-34 ± 4.13E-33	+	3.89E-65 ± 2.65E-64
w/t/l	27/3/0		-	27/0/3		-

Table S7. Comparison on the errors of jDE, JADE, SHADE, AGDE, OrSHADE, and ReSHADE in the CEC2013 benchmark functions at $n = 10$.

Prob.	jDE	JADE	SHADE	AGDE	OrSHADE	ReSHADE
F01	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	1.06E+01 ± 4.66E+00 +	6.64E-02 ± 3.01E-02 +	1.31E-02 ± 5.24E-03 +	2.71E-01 ± 1.14E-01 +	1.00E-02 ± 4.15E-03 +	1.02E-03 ± 4.56E-04
F02	2.21E+00 ± 1.57E+01 +	1.21E-25 ± 5.70E-26 +	6.84E-26 ± 2.77E-26 +	5.85E-02 ± 3.80E-01 +	5.81E-26 ± 3.14E-26 +	4.75E-26 ± 2.19E-26
F03	2.03E-05 ± 6.97E-05 +	7.35E+02 ± 2.10E+03 +	1.61E-27 ± 1.25E-27 =	2.50E-04 ± 1.57E-03 +	1.38E-27 ± 8.73E-28 =	1.49E-27 ± 4.92E-28
F04	1.09E+00 ± 1.81E+00 +	1.53E+02 ± 3.32E+02 +	1.24E-01 ± 8.84E-01 +	7.60E-01 ± 1.66E+00 +	1.40E-03 ± 9.99E-03 =	1.12E-02 ± 2.62E-02
F05	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	8.15E+00 ± 1.83E+00 +	3.59E-01 ± 1.13E-01 +	8.59E-02 ± 2.78E-02 +	6.62E-01 ± 2.28E-01 +	7.24E-02 ± 2.57E-02 +	1.89E-02 ± 7.23E-03
F06	5.77E+00 ± 4.88E+00 =	7.70E+00 ± 4.08E+00 =	7.70E+00 ± 4.08E+00 =	3.27E+00 ± 4.67E+00 -	8.47E+00 ± 3.41E+00 =	8.47E+00 ± 3.41E+00
F07	6.11E-03 ± 6.22E-03 +	2.77E-01 ± 5.37E-01 +	2.89E-05 ± 1.10E-04 =	5.12E-02 ± 5.81E-02 +	1.57E-06 ± 3.59E-06 -	1.81E-05 ± 5.72E-05
F08	2.04E+01 ± 7.37E-02 =	2.03E+01 ± 8.64E-02 =	2.04E+01 ± 6.80E-02 =	2.04E+01 ± 8.24E-02 =	2.04E+01 ± 7.04E-02 =	2.04E+01 ± 5.79E-02
F09	4.63E+00 ± 1.04E+00 +	4.49E+00 ± 1.14E+00 +	9.64E-01 ± 1.23E+00 +	2.77E+00 ± 1.85E+00 +	8.12E-01 ± 1.25E+00 +	5.85E-01 ± 7.15E-01
F10	5.62E-02 ± 3.31E-02 +	3.40E-02 ± 3.33E-02 +	3.87E-02 ± 3.98E-02 +	6.58E-02 ± 5.18E-02 +	4.85E-02 ± 4.16E-02 +	1.57E-02 ± 1.63E-02
F11	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00	0.00E+00 ± 0.00E+00
	2.34E+01 ± 3.67E+00 +	2.08E+01 ± 3.11E+00 +	2.05E+01 ± 3.52E+00 +	1.33E+01 ± 2.58E+00 -	1.98E+01 ± 3.94E+00 =	2.00E+01 ± 3.33E+00
F12	1.17E+01 ± 2.90E+00 +	6.10E+00 ± 2.15E+00 +	4.54E+00 ± 2.46E+00 =	1.44E+01 ± 3.75E+00 +	4.84E+00 ± 1.89E+00 +	3.71E+00 ± 1.05E+00
F13	1.34E+01 ± 3.15E+00 +	7.03E+00 ± 2.32E+00 +	6.59E+00 ± 3.19E+00 +	1.46E+01 ± 4.66E+00 +	7.11E+00 ± 5.22E+00 +	3.52E+00 ± 1.41E+00
F14	1.22E-03 ± 8.75E-03 -	8.57E-03 ± 2.17E-02 -	2.45E-02 ± 4.34E-02 -	1.36E-02 ± 2.59E-02 -	3.80E-02 ± 5.31E-02 =	2.47E-02 ± 3.31E-02
F15	1.01E+03 ± 2.01E+02 +	8.75E+02 ± 2.28E+02 +	5.86E+02 ± 2.12E+02 -	1.09E+03 ± 1.58E+02 +	5.60E+02 ± 2.70E+02 -	6.81E+02 ± 1.52E+02
F16	1.05E+00 ± 1.63E-01 -	1.15E+00 ± 2.20E-01 =	1.12E+00 ± 2.82E-01 =	1.21E+00 ± 1.94E-01 =	1.13E+00 ± 1.94E-01 =	1.17E+00 ± 1.44E-01
F17	1.01E+01 ± 1.15E-09 =	1.01E+01 ± 0.00E+00 =	1.01E+01 ± 5.80E-11 =	1.01E+01 ± 5.24E-02 +	1.01E+01 ± 0.00E+00 =	1.01E+01 ± 0.00E+00
F18	3.30E+01 ± 4.06E+00 +	2.73E+01 ± 4.68E+00 +	1.89E+01 ± 5.86E+00 -	3.33E+01 ± 4.43E+00 +	1.90E+01 ± 5.80E+00 -	2.36E+01 ± 3.65E+00
F19	4.21E-01 ± 6.94E-02 +	3.59E-01 ± 4.05E-02 =	3.49E-01 ± 3.72E-02 =	5.94E-01 ± 9.28E-02 +	3.56E-01 ± 3.22E-02 =	3.42E-01 ± 5.06E-02
F20	2.86E+00 ± 2.22E-01 +	2.22E+00 ± 5.26E-01 +	1.81E+00 ± 4.99E-01 =	2.74E+00 ± 3.05E-01 +	1.77E+00 ± 4.37E-01 =	1.86E+00 ± 4.25E-01
F21	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00
F22	2.37E+01 ± 1.01E+01 +	1.83E+00 ± 3.41E+00 -	3.59E+00 ± 4.16E+00 =	8.78E+01 ± 2.53E+01 +	6.06E+00 ± 1.42E+01 =	1.77E+01 ± 4.04E+01
F23	1.17E+03 ± 2.07E+02 +	7.36E+02 ± 2.75E+02 +	4.38E+02 ± 2.53E+02 +	1.11E+03 ± 2.19E+02 +	4.16E+02 ± 2.04E+02 +	2.89E+02 ± 1.88E+02
F24	1.69E+02 ± 3.53E+01 -	2.00E+02 ± 8.00E-01 +	2.00E+02 ± 2.29E-05 =	2.00E+02 ± 9.23E+00 +	2.00E+02 ± 9.95E-01 =	1.99E+02 ± 7.44E+00
F25	2.40E+02 ± 3.48E+01 +	2.80E+02 ± 1.47E+00 +	2.81E+02 ± 2.12E+00 +	2.50E+02 ± 3.53E+01 +	2.80E+02 ± 2.00E+00 +	2.07E+02 ± 1.90E+01
F26	1.17E+02 ± 5.36E+00 +	1.43E+02 ± 4.25E+01 +	1.25E+02 ± 3.96E+01 +	1.44E+02 ± 3.33E+01 +	1.25E+02 ± 3.96E+01 +	1.14E+02 ± 2.98E+01
F27	3.00E+02 ± 3.87E-03 +	3.00E+02 ± 1.15E+00 +	3.00E+02 ± 0.00E+00 =	3.06E+02 ± 2.37E+01 +	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00
F28	2.84E+02 ± 5.43E+01 =	3.00E+02 ± 0.00E+00 =	2.96E+02 ± 2.80E+01 =	2.88E+02 ± 4.75E+01 =	3.00E+02 ± 0.00E+00 =	3.00E+02 ± 0.00E+00
w/t/l	20/5/3	19/7/2	11/14/3	21/4/3	10/15/3	-



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