



## Supplementary materials for

Zhiyu DUAN, Shunkun YANG, Qi SHAO, Minghao YANG, 2024. PEGA: probabilistic environmental gradient-driven genetic algorithm considering epigenetic traits to balance global and local optimizations. *Front Inform Technol Electron Eng*, 25(6):839-855. <https://doi.org/10.1631/FITEE.2300170>

### 1 The pseudocode of three types of epigenetic operators: position effect operator (PEO), gene imprinting operator (GIO), and paramutation operator (PMO)

#### 1.1 Position effect

The position effect operator (PEO) is an order-sensitive epigenetic operator (OSEO) established by the gene position effect. The gene position effect consists of gene expression changes in relation to shifts in gene location, often caused by translocation. The gene position effect greatly increases the randomness of variation by randomly changing the gene sequence, especially in solving combinatorial optimization problems. To realize PEO, first, the solution vector and nucleosome vector of the affected individual were extracted. The solution vector was split according to the rule described in Algorithm S1.

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#### Algorithm S1 Position effect

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##### Input:

An epigenetic individual,  $I$ ;  
 Environmental influence possibility,  $P_e$ ;

##### Output:

The epigenetic operator modified individual,  $I$ ;

- 1: nucleosome  $\leftarrow$  Extract nucleosome( $I$ );
- 2: gene  $\leftarrow$  Extract gene( $I$ );
- 3: **if** random() $<P_e$  **then**
- 4:   split gene into pieces according to the nucleosome;// mark the borders of the “0”s and “1”s of the nucleosome on the DNA chain, and then split the DNA chain at these marked sites.
- 5:    $i_1, i_2 \leftarrow$  randomInteger();// generate two random numbers  $i_1, i_2$  within the range of pieces.
- 6:   temp  $\leftarrow$  pieces[ $i_1$ ];// change the order of pieces.
- 7:   pieces[ $i_1$ ]  $\leftarrow$  pieces[ $i_2$ ];
- 8:   pieces[ $i_2$ ]  $\leftarrow$  temp;
- 9:    $I \leftarrow$  put pieces together;
- 10: **else**
- 11:   Do nothing.
- 12: **end if**
- 13: **return**  $I$ ;

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#### 1.2 Gene imprinting

The gene imprinting operator (GIO) is a position-sensitive epigenetic operator (PSEO) that refers to an epigenetic modification marker with a gene bookmark on the parental DNA strand. When this marker is detected, the gene is expressed in the parent-specific source, regardless of where it originally came from. An epigenetic marker is generated as an individual is created. If the location of the gene is critical, to avoid

failure to converge, we choose to periodically clean up these epigenetic marks and regenerate them to replace the original gene sequence.

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**Algorithm S2** Gene imprinting
 

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**Input:**

An epigenetic individual,  $I$ ;  
 Environmental influence possibility,  $P_e$ ;

**Output:**

The epigenetic operator modified individual,  $I$ ;

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1: gene ← Extract gene( $I$ );
2: motherGene, fatherGene ← Extract parentalGene( $I$ );
3: for  $i \in [0, \text{length}]$  do
4:   if detect gene modification on site  $i$  then
5:     if father gene is forced to express then
6:       gene[ $i$ ] ← father gene[ $i$ ];
7:     end if
8:     if mother gene is forced to express then
9:       gene[ $i$ ] ← mother gene[ $i$ ];
10:    end if
11:  end if
12: end for
13:  $I \leftarrow$  gene;
14: return  $I$ ;
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### 1.3 Paramutation

The paramutation operator (PMO) refers to the transformation of the source of the expressed gene. This operator uses the genetic information of the parents recorded in  $\mathbf{H}^{n \times 2}$ . In particular, the PMO has a lower priority than the GIO.

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**Algorithm S3** Paramutation
 

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**Input:**

An epigenetic individual,  $I$ ;  
 Environmental influence possibility,  $P_e$ ;

**Output:**

The epigenetic operator modified individual,  $I$ ;

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1: gene ← Extract gene( $I$ );
2: mother gene, father gene ← ExtractParentalGene( $I$ );
3: for  $i \in [0, \text{length}]$  do
4:   // if the father's gene and mother's gene are different here, then an exchange could be made.
5:   if random() <  $P_e$  and mother gene[ $i$ ] = father gene[ $i$ ] then
6:     if gene[ $i$ ] = mother gene[ $i$ ] then
7:       gene[ $i$ ] ← father gene[ $i$ ];
8:     else
9:       gene[ $i$ ] ← mother gene[ $i$ ];
10:    end if
11:  end if
12: end for
13:  $I \leftarrow$  gene;
14: return  $I$ ;
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## 2 The ablation experimental results of the probabilistic environmental gradient (PEG) and variable nucleosome reorganization (VNR) strategies

The population size ( $N$ ) was set to be 500,  $n$  was set to be  $15 \times D$ , the possibility of nucleosome generation ( $P_n$ ) was set to 0.4, the nucleosome radius ( $R$ ) was set to 25, and the probability of environmental influence was set to 0.15. The accuracy and stability of the results are listed in Tables S1 and S2, respectively. If the PEGA exhibits a significant improvement ( $>1\%$ ) in the accuracy or stability, the result is marked (-); if it is weakened, the result is marked (+); if there is no obvious effect, the result is marked ( $\approx$ ).

**Table S1 PEG, VNR, and PEG+VNR strategy comparison on the accuracy**

Func	Base line	PEG		VNR		PEG+VNR	
		Acc.	Gain	Acc.	Gain	Acc.	Gain
F1	1.5937E+10	5.1429E+09	(-)67.73%	1.0378E+10	(-)34.88%	9.8126E+06	(-)99.94%
F2	3.9366E+05	4.0636E+05	(+)3.22%	3.7716E+05	(-)4.19%	3.4426E+05	(-)12.55%
F3	1.7756E+03	3.1474E+02	(-)82.27%	3.0295E+02	(-)82.94%	2.6018E+02	(-)85.35%
F4	5.9701E+02	1.0378E+03	(+)73.83%	1.0195E+03	(+)70.77%	7.4875E+01	(-)87.46%
F5	3.4684E+01	6.3812E+00	(-)81.60%	8.7997E+00	(-)74.63%	5.7563E+00	(-)83.40%
F6	2.0887E+03	9.8082E+02	(-)53.06%	1.8991E+03	(-)9.12%	2.6353E+02	(-)87.39%
F7	5.9340E+02	1.0564E+02	(-)82.20%	1.2895E+02	(-)78.27%	7.8344E+01	(-)86.80%
F8	6.2399E+03	1.2453E+03	(-)80.04%	5.8869E+03	(-)5.66%	6.7025E+01	(-)98.93%
F9	1.2393E+04	1.5456E+03	(+)1.2E+07	7.1636E+02	(+)5.8E+06	1.5290E+02	(-)98.77%
F10	2.8222E+04	2.3957E+04	(-)15.11%	2.3199E+04	(-)17.80%	2.2643E+04	(-)19.77%
F11	2.2259E+08	7.7117E+07	(+)3.5E+15	7.8460E+07	(+)3.5E+15	1.6858E+05	(-)99.92%
F12	4.3433E+06	2.1195E+05	(-)95.12%	1.2467E+07	(+)1.9E+00	5.2568E+02	(-)99.99%
F13	7.5326E+02	4.3238E+02	(-)42.60%	4.3049E+03	(+)4.7E+00	5.1147E+01	(-)93.21%
F14	5.8943E+04	5.1767E+06	(+)8.7E+01	6.9788E+04	(+)18.40%	1.9265E+02	(-)99.67%
F15	1.9633E+03	1.7788E+02	(+)9.1E+04	9.4442E+01	(+)4.8E+04	8.3518E+01	(-)95.75%
F16	1.1786E+03	1.4501E+02	(-)87.70%	1.5180E+02	(-)87.12%	7.6292E+01	(-)93.53%
F17	4.6893E+03	1.4724E+03	(-)68.60%	2.3038E+04	(+)391.30%	7.0506E+01	(-)98.50%
F18	1.7904E+05	1.3264E+04	(-)92.59%	1.2750E+06	(+)612.11%	4.4582E+01	(-)99.98%
F19	7.0339E+02	8.3629E+01	(-)88.11%	9.0044E+01	(-)87.20%	7.1137E+01	(-)89.89%
F20	1.3839E+03	1.1590E+03	(-)16.25%	1.1723E+03	(-)15.29%	1.1185E+03	(-)19.18%
F21	1.2423E+04	1.2766E+04	(+)2.76%	1.2476E+04	( $\approx$ )0.42%	9.0790E+03	(-)26.92%
F22	2.2579E+03	5.1878E+03	(+)129.76%	5.1408E+03	(+)127.68%	1.9602E+03	(-)13.18%
F23	2.6461E+03	2.3537E+03	(-)8.9E+05	2.4258E+03	(+)9.2E+05	2.2744E+03	(-)14.05%
F24	3.9491E+03	3.2366E+03	(-)18.04%	3.2619E+03	(-)17.40%	3.2048E+03	(-)18.85%
F25	1.0485E+04	7.3484E+03	(-)29.91%	7.7859E+03	(-)25.74%	7.2906E+03	(-)30.47%
F26	2.1389E+03	2.1309E+03	( $\approx$ )0.37%	2.1460E+03	( $\approx$ )0.33%	2.1121E+03	(-)1.25%
F27	8.5865E+03	5.1106E+03	(+)6.0E+05	5.1323E+03	(+)6.0E+05	4.8482E+03	(-)43.54%
F28	2.9922E+03	7.8054E+03	(+)160.86%	7.7128E+03	(+)157.76%	3.2387E+03	(+)8.24%
F29	2.2889E+08	1.4673E+08	(-)35.90%	1.4672E+08	(-)35.90%	1.4558E+08	(-)36.40%
-/+			17/11		14/13		28/1

**Table S2 PEG, VNR, and PEG+VNR strategy comparison on the stability**

Func	Base line	PEG		VNR		PEG+VNR	
		Sta.	Gain	Sta.	Gain	Sta.	Gain
F1	2.2599E+09	2.6008E+09	(+)3.2E+02	1.0378E+10	(+)1.3E+03	7.9865E+06	(-)99.65%
F2	3.0191E+04	2.6980E+04	(-)13.88%	3.7716E+05	(+)1.5E+01	2.3691E+04	(-)21.53%
F3	2.5529E+02	9.8105E+01	(-)36.67%	3.0295E+02	(+)322.05%	7.1781E+01	(-)71.88%
F4	4.5386E+01	1.0727E+01	(-)42.07%	1.0195E+03	(+)9.4E+01	1.0727E+01	(-)76.36%
F5	4.1902E+00	1.6716E+00	(+)5.70%	8.7997E+00	(+)456.42%	1.5815E+00	(-)62.26%
F6	3.2476E+02	2.1958E+02	(-)108.49%	1.8991E+03	(+)1.7E+01	1.0532E+02	(-)67.57%
F7	4.0380E+01	1.5084E+01	(-)43.49%	1.2895E+02	(+)1.1E+01	1.0512E+01	(-)73.97%
F8	6.0698E+02	6.8803E+02	(+)2.1E+01	5.8869E+03	(+)1.9E+02	3.1530E+01	(-)94.81%
F9	1.2082E+03	5.5047E+02	(+)5.6E+00	7.1636E+02	(+)7.6E+00	8.3471E+01	(-)93.09%
F10	1.0361E+04	6.3781E+03	(-)16.06%	2.3199E+04	(-)322.13%	5.4957E+03	(-)46.96%
F11	2.8644E+07	5.0383E+07	(+)2.7E+02	7.8460E+07	(+)4.1E+02	1.8877E+05	(-)99.34%
F12	1.1007E+06	2.9588E+05	(-)2.5E+03	1.2467E+07	(-)1.1E+05	1.1858E+02	(-)99.99%
F13	1.3122E+02	1.1967E+01	(-)4.0E+01	4.3049E+03	(-)3.6E+02	1.1967E+01	(-)90.88%
F14	2.5792E+04	7.2654E+06	(+)1.1E+05	6.9788E+04	(+)1.1E+03	6.5233E+01	(-)99.75%
F15	5.3319E+02	8.3320E+01	(-)2.1E+00	9.4442E+01	(-)2.5E+00	2.6655E+01	(-)95.00%
F16	2.4388E+02	6.9082E+01	(-)715.70%	1.5180E+02	(-)1.7E+01	8.4690E+00	(-)96.53%
F17	1.1053E+03	1.0519E+03	(-)6.1E+01	2.3038E+04	(+)1.4E+03	1.6929E+01	(-)98.47%
F18	9.2102E+04	1.8182E+04	(+)9.7E+02	1.2750E+06	(+)6.8E+04	1.8735E+01	(-)99.98%
F19	2.3878E+02	1.0364E+01	(-)44.12%	9.0044E+01	(+)385.44%	1.8549E+01	(-)92.23%
F20	8.0154E+01	6.0804E+01	(-)31.56%	1.1723E+03	(+)1.8E+01	6.0804E+01	(-)24.14%
F21	3.7439E+03	1.0588E+03	(-)6.53%	1.2476E+04	(+)1.2E+01	9.9396E+02	(-)73.45%
F22	4.1633E+01	3.9804E+01	(-)4.84%	5.1408E+03	(+)1.3E+02	3.9804E+01	(-)4.39%
F23	5.8698E+01	4.0591E+01	(-)6.7E-01	2.4258E+03	(-)1.9E+01	1.2264E+02	(+)108.93%
F24	4.8010E+02	1.8197E+02	(+)0.36%	3.2619E+01	(-)1.7E+01	1.8132E+02	(-)62.23%
F25	5.5579E+02	3.2180E+02	(-)12.55%	7.7859E+01	(-)2.0E+01	3.6800E+02	(-)33.79%
F26	5.4790E+01	3.9946E+01	(-)8.65%	2.1460E+03	(+)5.7E+01	3.6767E+01	(-)32.89%
F27	1.5791E+03	6.5594E+02	(-)1.4E-01	5.1323E+01	(-)5.7E+00	7.6610E+02	(-)51.49%
F28	4.8189E+02	3.6966E+02	(+)0.11%	7.7128E+01	(-)2.0E+01	3.6926E+02	(-)23.37%
F29	1.5451E+08	5.5968E+07	(-)1.83%	1.4672E+06	(-)162.15%	5.5968E+07	(-)63.78%
-/+			9/20		10/19		28/1

## 3 The complete results of performance experiments of the probabilistic environmental gradient-driven epigenetic algorithm (PEGA) ( $D=100, 50, 30$ , and $10$ )

The results reported in Tables S3, S4, and S5 were obtained from over 30 runs for each algorithm with 10, 30, 50, and 100 dimensions, solving the 29 benchmark functions of the Congress on Evolutionary

Computation-2017 (CEC' 17). The performance metrics were established considering the metrics outlined by CEC' 17.

$$SNE = 0.1 \sum_{i=1}^{29} ne_{10} + 0.2 \sum_{i=1}^{29} ne_{30} + 0.3 \sum_{i=1}^{29} ne_{50} + 0.4 \sum_{i=1}^{29} ne_{100}, \quad (S1)$$

where  $ne$  is an algorithm's mean error value for a given function and dimension, and  $SNE$  is the weighted sum of error values over all functions and dimensions.

$$SR = 0.1 \sum_{i=1}^{29} rank_{10} + 0.2 \sum_{i=1}^{29} rank_{30} + 0.3 \sum_{i=1}^{29} rank_{50} + 0.4 \sum_{i=1}^{29} rank_{100} \quad (S2)$$

where "rank" is the algorithm's rank among all algorithms for a given function and dimension based on its mean error value.

**Table S3 Comparison results of two unimodal and seven multimodal benchmark functions for PEGA and other algorithms**

D = 100	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F1	3.38E+06	3.58E+06	0	3.67E+09	0	1.78E+10	5.82E+09	2.08E+11	1.46E+08	1.97E+11	9.78E+06
F2	1.24E+05	1.00E+03	0	9.63E+03	1.68E+05	2.52E+05	9.45E+04	2.69E+05	1.53E+04	2.60E+05	2.28E+05
F3	1.03E+02	7.95E-01	0	7.29E+02	0	2.19E+03	3.35E+02	4.33E+04	3.33E+01	3.65E+04	1.90E+02
F4	1.70E+02	7.67E+00	0	6.37E+02	0	3.39E+02	6.48E+02	1.41E+03	4.66E+01	9.26E+02	5.72E+01
F5	2.61E+01	4.65E-01	0	1.38E+01	0	0	2.51E+01	1.14E+02	3.35E+00	7.27E+01	3.73E+00
F6	1.09E+03	6.34E+01	0	1.01E+03	0	1.45E+03	1.27E+03	9.19E+03	6.71E+02	8.76E+03	1.55E+02
F7	1.64E+02	7.02E+00	0	6.38E+02	0	3.35E+02	6.82E+02	1.40E+03	4.39E+01	9.11E+02	6.11E+01
F8	4.09E+03	1.06E+01	6.14E+00	1.24E+03	<b>3.79E+00</b>	8.42E+03	4.01E+03	6.67E+04	6.25E+01	1.65E+04	6.13E+01
F9	1.28E+04	1.55E+02	<b>1.09E-10</b>	1.71E+04	<b>1.09E-10</b>	7.08E+03	2.59E+04	3.20E+04	9.94E+02	1.97E+04	1.34E+02
D = 50	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F1	6.69E+02	8.79E+05	0	9.61E+08	0	9.70E+08	1.06E+09	8.00E+10	6.92E+07	6.65E+10	2.79E+04
F2	3.43E+04	1.17E+02	0	2.81E+03	6.65E+04	1.04E+05	2.81E+04	1.12E+05	4.78E+03	1.10E+05	7.06E+04
F3	4.83E+01	2.75E-01	0	2.68E+02	0	3.78E+02	1.18E+02	1.18E+04	1.49E+01	8.57E+03	3.86E+01
F4	9.25E+01	2.04E+00	0	2.32E+02	0	6.75E+01	2.39E+02	6.21E+02	1.02E+01	3.30E+02	1.36E+01
F5	2.30E+01	3.37E-01	0	9.73E+00	0	0	1.96E+01	9.55E+01	2.87E+00	5.93E+01	1.32E+00
F6	4.62E+02	2.43E+01	0	4.06E+02	0	2.30E+02	4.87E+02	3.51E+03	2.83E+02	3.26E+03	6.73E+01
F7	9.05E+01	2.63E+00	0	2.35E+02	0	8.32E+01	2.34E+02	6.16E+02	1.11E+01	3.20E+02	1.35E+01
F8	1.41E+03	4.91E+00	2.42E+00	3.25E+02	<b>1.56E+00</b>	1.20E+03	1.50E+03	2.36E+04	2.51E+01	6.46E+03	4.09E+00
F9	5.96E+03	7.96E+01	<b>1.82E-11</b>	6.24E+03	<b>1.82E-11</b>	1.26E+03	1.03E+04	1.42E+04	2.30E+02	7.49E+03	1.22E+01
D = 30	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F1	6.95E+02	1.29E+05	0	2.94E+08	0	1.43E+07	2.07E+08	3.41E+10	3.10E+07	2.37E+10	2.82E+01
F2	7.93E+03	1.10E+01	0	1.05E+03	2.20E+04	5.57E+04	9.11E+03	5.62E+04	1.22E+03	5.09E+04	4.27E+04
F3	2.80E+01	3.72E-02	0	1.27E+02	0	1.20E+02	4.39E+01	3.19E+03	7.24E+00	1.80E+03	2.35E+01
F4	5.08E+01	6.58E-01	0	9.31E+01	0	2.28E+01	9.75E+01	3.15E+02	2.25E+00	1.60E+02	3.96E+00
F5	1.66E+01	2.23E-01	0	6.84E+00	0	0	1.51E+01	7.89E+01	2.26E+00	5.13E+01	6.61E-01
F6	2.24E+02	8.79E+00	0	1.93E+02	0	7.32E+01	2.43E+02	1.55E+03	1.38E+02	1.33E+03	3.46E+01
F7	4.93E+01	8.31E-01	0	9.47E+01	0	1.79E+01	9.66E+01	3.20E+02	2.52E+00	1.57E+02	3.61E+00
F8	7.05E+02	2.48E+00	9.64E-01	1.05E+02	<b>7.05E-01</b>	1.08E+02	4.62E+02	9.66E+03	1.18E+01	3.48E+03	1.16E+00
F9	3.34E+03	2.61E+01	0	2.57E+03	0	3.22E+02	5.02E+03	7.50E+03	4.38E+01	3.97E+03	5.21E+00
D = 10	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F1	3.38E+06	3.58E+06	0	3.67E+09	0	1.78E+10	5.82E+09	2.08E+11	1.46E+08	1.97E+11	1.07E-02
F2	1.34E-07	1.57E-05	0	8.10E+01	1.35E+02	8.76E+03	2.56E+02	7.12E+03	4.98E+00	2.04E+03	2.56E+03
F3	1.03E+02	7.95E-01	0	7.29E+02	0	2.19E+03	3.35E+02	4.33E+04	3.33E+01	3.65E+04	7.37E-00
F4	1.24E+01	3.89E-03	0	2.86E+00	3.60E+00	1.42E+00	1.12E+01	5.66E+01	4.42E-02	2.92E+01	1.78E-06
F5	3.68E+00	4.52E-03	0	1.99E+00	0	9.85E-01	4.50E+00	3.70E+01	2.83E-01	2.02E+01	3.42E-02
F6	3.05E-01	1.66E-01	0	2.93E+01	4.64E+01	1.15E+01	3.86E+01	1.71E+02	4.89E+00	1.17E+02	6.36E+00
F7	1.64E+02	7.02E+00	0	6.38E+02	0	3.35E+02	6.82E+02	1.40E+03	4.39E+01	9.11E+02	1.64E-06
F8	1.31E+01	7.63E-02	7.46E-02	4.49E+00	8.01E-02	<b>8.57E-07</b>	1.30E+01	7.02E+02	1.81E-01	3.38E+02	3.82E-01
F9	1.28E+04	1.55E+02	<b>1.09E-10</b>	1.71E+04	<b>1.09E-10</b>	7.18E+03	2.59E+04	3.20E+04	9.94E+02	1.97E+04	1.34E+00

Table S4 Comparison results of 10 hybrid functions for PEGA and other algorithms

D = 100	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F10	5.87E+03	1.36E+01	<b>1.09E-10</b>	1.69E+03	1.06E+04	3.91E+04	7.43E+03	6.09E+04	1.18E+03	5.80E+04	2.06E+04
F11	6.27E+07	6.89E+05	0	7.32E+08	0	8.77E+08	8.57E+08	6.51E+10	3.14E+07	5.58E+10	1.68E+05
F12	6.35E+03	1.36E+05	0	2.92E+08	0	8.79E+08	2.17E+08	3.48E+10	1.75E+07	3.02E+10	3.83E+02
F13	1.18E+06	7.42E+01	0	1.50E+06	0	2.01E+03	1.54E+06	1.33E+08	1.19E+05	8.33E+07	3.23E+01
F14	5.98E+03	4.69E+03	0	1.05E+08	9.88E-03	2.24E+05	5.13E+07	1.57E+10	6.73E+06	1.25E+10	1.43E+02
F15	5.48E+03	3.01E+01	<b>4.54E-13</b>	3.86E+03	7.45E-02	1.20E+03	5.19E+03	1.51E+04	2.56E+02	9.97E+03	5.75E+01
F16	3.30E+03	1.85E+01	<b>1.13E-12</b>	2.43E+03	1.72E-03	8.55E+02	3.28E+03	3.43E+04	2.49E+02	1.92E+04	4.77E+01
F17	2.08E+06	1.05E+02	<b>2.95E-12</b>	2.65E+06	0	9.79E+02	4.45E+06	2.39E+08	1.75E+05	1.60E+08	4.62E+01
F18	7.98E+04	4.74E+03	<b>6.82E-13</b>	1.08E+08	0	9.55E+05	3.57E+07	1.53E+10	7.02E+06	1.25E+10	2.79E+01
F19	2.59E+03	2.34E+01	<b>6.82E-13</b>	1.35E+03	5.30E-02	3.53E+02	2.78E+03	4.86E+03	1.27E+02	2.79E+03	3.41E+01
D = 50	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F10	2.81E+02	2.39E+00	0	5.25E+02	4.11E+01	1.20E+04	1.68E+03	1.83E+04	5.76E+01	1.51E+04	1.77E+03
F11	1.56E+07	2.81E+04	1.13E-12	1.41E+08	0	1.30E+07	1.00E+08	1.89E+10	1.33E+07	1.25E+10	3.21E+02
F12	4.70E+03	2.65E+02	0	4.42E+07	0	1.42E+04	1.16E+07	8.11E+09	5.30E+06	4.25E+09	1.10E+02
F13	2.10E+05	1.20E+01	2.95E-12	1.03E+05	0	1.72E+02	1.75E+05	1.10E+07	5.15E+03	2.55E+06	1.25E+01
F14	3.96E+03	1.65E+01	0	1.01E+07	2.12E-02	1.07E+03	1.59E+06	2.10E+09	1.34E+06	5.46E+08	2.34E+01
F15	2.01E+03	7.55E+00	<b>2.27E-13</b>	1.02E+03	1.01E+01	1.83E+02	1.64E+03	5.24E+03	9.26E+01	3.09E+03	1.58E+01
F16	1.21E+03	9.35E+00	0	6.00E+02	0	2.47E+02	1.03E+03	3.98E+03	1.17E+02	2.33E+03	2.45E+01
F17	5.43E+05	1.14E+01	0	3.54E+05	3.39E-02	5.38E+02	3.52E+05	3.46E+07	1.71E+04	8.26E+06	1.64E+01
F18	1.13E+05	1.69E+01	0	9.52E+06	0	5.07E+02	1.60E+06	2.22E+09	1.42E+06	6.18E+08	1.52E+01
F19	9.29E+02	1.25E+01	<b>1.62E-10</b>	2.89E+02	5.97E-03	9.22E+01	6.23E+02	1.79E+03	4.70E+01	1.02E+03	1.99E+01
D = 30	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F10	7.41E+01	3.85E-01	0	2.06E+02	1.58E+01	1.97E+03	3.33E+02	5.85E+03	2.77E+01	2.89E+03	2.46E+02
F11	4.79E+06	6.42E+02	0	3.73E+07	0	6.27E+04	1.72E+07	6.02E+09	4.70E+06	1.44E+09	2.42E+02
F12	3.28E+03	2.65E+01	0	7.04E+06	0	7.43E+02	7.12E+05	1.35E+09	1.33E+06	6.51E+07	2.56E+01
F13	3.35E+04	3.60E+00	0	8.47E+03	0	4.59E+01	9.70E+03	6.60E+05	5.50E+02	5.87E+04	5.81E+00
F14	3.76E+03	1.73E+00	0	7.67E+05	3.03E-02	1.53E+02	5.23E+04	1.93E+08	7.80E+03	6.67E+03	2.45E+01
F15	8.83E+02	2.58E+00	0	3.15E+02	2.81E-02	1.13E+02	5.47E+02	2.29E+03	3.53E+01	1.09E+03	8.55E+00
F16	5.77E+02	6.05E+00	0	2.01E+02	6.79E+01	3.42E+01	3.05E+02	1.48E+03	6.55E+01	6.72E+02	3.06E+00
F17	1.85E+05	4.89E+00	0	6.11E+04	1.77E-02	9.03E+01	8.15E+04	7.21E+06	3.63E+03	3.97E+05	7.70E+00
F18	1.10E+05	3.21E+00	0	9.04E+05	0	4.34E+01	5.91E+04	1.66E+08	3.18E+04	6.57E+05	1.27E+00
F19	4.26E+02	7.83E+00	<b>3.43E-09</b>	1.14E+02	2.98E-03	4.43E+01	2.20E+02	7.52E+02	2.62E+01	4.38E+02	1.22E+01
D = 10	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F10	1.31E+01	4.81E-05	0	1.27E+01	3.98E-01	2.30E+00	1.24E+01	1.23E+02	2.72E+01	3.29E+01	1.08E+00
F11	5.63E+05	7.33E-02	0	2.6157E+05	0	1.14E+01	1.63E+05	4.74E+07	2.61E+03	8.52E+06	6.88E-01
F12	2.88E+03	9.64E-02	0	5.53E+02	0	8.39E+00	1.43E+03	1.32E+05	1.44E+02	2.69E+04	5.83E+00
F13	5.49E+01	1.28E-01	0	3.85E+01	0	8.61E+00	8.24E+01	2.04E+02	2.83E+01	5.04E+01	4.41E-01
F14	5.98E+03	4.69E+03	0	1.05E+08	9.88E-03	2.24E+05	5.13E+07	1.57E+10	6.73E+06	1.25E+10	1.06E+00
F15	5.48E+03	3.01E+01	<b>4.54E-13</b>	3.86E+03	7.45E-02	1.20E+03	5.19E+03	1.51E+04	2.56E+02	9.97E+03	1.57E+00
F16	3.30E+03	1.85E+01	<b>2.95E-12</b>	2.43E+03	0	9.79E+02	3.28E+03	3.43E+04	2.49E+02	1.92E+04	9.22E-01
F17	2.08E+06	1.05E+02	<b>1.36E-12</b>	2.65E+06	4.06E-02	4.79E+04	4.45E+06	2.39E+08	1.75E+05	1.60E+08	7.48E-02
F18	8.81E+01	1.36E-01	0	1.49E+01	0	1.82E+00	1.08E+02	1.12E+03	8.73E+00	1.88E+01	6.26E-02
F19	5.37E+01	2.06E+00	1.40E-08	2.39E+01	0	2.77E+01	5.24E+01	1.14E+02	3.16E+00	6.88E+01	4.87E+00
F20	7.28E+02	1.47E+03	1.19E+03	1.55E+03	1.42E+03	5.60E+02	1.45E+03	2.00E+03	1.36E+03	1.55E+03	<b>1.15E+02</b>

Table S5 Comparison results of 10 composition benchmark functions for PEGA and other algorithms

D = 100	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F20	7.28E+02	1.47E+03	1.19E+03	1.55E+03	1.42E+03	5.60E+02	1.45E+03	2.00E+03	1.36E+03	1.55E+03	<b>4.62E-02</b>
F21	1.49E+04	1.36E+04	2.08E+04	2.46E+04	7.28E+03	<b>7.25E+03</b>	2.86E+04	3.19E+04	1.32E+04	1.99E+04	8.13E-03
F22	1.46E+03	2.41E+03	2.17E+03	4.27E+03	2.75E+03	1.01E+03	2.68E+03	3.93E+03	2.43E+03	3.41E+03	<b>7.82E-02</b>
F23	1.65E+03	2.62E+03	2.31E+03	4.65E+03	3.18E+03	1.21E+03	3.03E+03	5.26E+03	2.96E+03	5.03E+03	<b>9.58E-02</b>
F24	<b>1.22E+03</b>	1.08E+04	1.24E+03	1.31E+03	5.20E+03	5.33E+03	4.72E+03	4.23E+04	8.74E+03	3.83E+04	1.34E+03
F25	1.18E+04	1.93E+04	1.40E+04	2.18E+04	1.66E+04	6.00E+03	1.55E+04	3.23E+04	2.00E+04	2.93E+04	<b>3.96E+03</b>
F26	1.88E+03	2.83E+03	<b>5.00E+02</b>	6.74E+03	<b>5.00E+02</b>	7.51E+02	3.20E+03	6.33E+03	2.57E+03	5.70E+03	6.68E-02
F27	1.26E+03	1.13E+04	<b>5.00E+02</b>	1.19E+04	<b>5.00E+02</b>	7.50E+03	4.09E+03	2.61E+04	1.11E+04	2.48E+04	3.02E+03
F28	7.59E+03	1.10E+04	9.09E+03	4.45E+04	1.01E+04	1.95E+03	8.27E+03	6.62E+04	9.63E+03	4.70E+04	<b>2.05E+03</b>
F29	1.67E+08	2.46E+09	4.88E+08	1.10E+10	1.46E+09	<b>1.78E+07</b>	2.77E+09	2.05E+10	1.26E+09	1.79E+10	1.33E+08
SN <sub>E</sub> 100	2.36E+08	2.47E+09	4.88E+08	1.59E+10	1.46E+09	1.87E+10	9.77E+09	3.60E+11	1.47E+09	3.26E+11	<b>1.43E-08</b>
D = 50	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F20	4.07E+02	7.01E+02	5.76E+02	7.12E+02	6.11E+02	<b>2.88E+02</b>	6.67E+02	9.63E+02	6.49E+02	6.29E+02	2.92E+02
F21	5.91E+03	3.35E+03	7.19E+03	5.19E+03	1.05E+04	1.58E+03	8.07E+03	1.34E+04	2.71E+03	8.10E+03	<b>5.97E-02</b>
F22	6.79E+02	1.06E+03	9.18E+02	1.72E+03	1.16E+03	5.12E+02	1.00E+03	1.61E+03	1.03E+03	1.30E+03	<b>4.96E-02</b>
F23	7.87E+02	1.11E+03	1.07E+03	1.87E+03	1.34E+03	6.03E+02	1.27E+03	2.03E+03	1.19E+03	1.79E+03	<b>5.87E-02</b>
F24	<b>6.79E+02</b>	3.21E+03	6.70E+02	5.03E+03	2.05E+03	9.47E+02	1.38E+03	1.44E+04	2.44E+03	1.16E+04	7.64E-02
F25	4.59E+03	7.17E+03	6.01E+03	9.19E+03	6.84E+03	1.93E+03	6.23E+03	1.23E+04	6.94E+03	1.00E+04	<b>1.81E-03</b>
F26	9.62E+02	1.14E+03	<b>5.00E+02</b>	3.30E+03	<b>5.00E+02</b>	5.38E+02	1.36E+03	2.70E+03	1.19E+03	2.17E+03	5.61E-02
F27	6.24E+02	3.33E+03	<b>5.00E+02</b>	4.53E+03	<b>5.00E+02</b>	3.18E+03	1.19E+03	8.59E+03	2.50E+03	7.46E+03	8.19E-02
F28	2.98E+03	3.28E+03	3.43E+03	1.08E+04	3.47E+03	<b>4.66E+02</b>	2.63E+03	6.44E+03	2.64E+03	4.09E+03	5.61E-02
F29	2.09E+07	2.07E+08	8.13E+07	1.93E+09	5.89E+07	<b>2.54E+05</b>	1.06E+08	2.79E+09	5.45E+07	1.10E+09	1.18E-07
SN <sub>E</sub> 50	3.75E+07	2.08E+08	8.13E+07	3.10E+09	5.90E+07	9.83E+08	1.28E+09	1.14E+11	1.45E+08	8.56E+10	<b>1.20E-07</b>
D = 30	ALO	SSA	GSKA	GA	GWO	MSA	PSO	ASO	SSO	ABC	PEGA
F20	2.91E+02	4.11E+02	3.45E+02	3.63E+02	3.81E+02	<b>2.27E+02</b>	4.05E+02	5.76E+02	3.78E+02	3.93E+02	2.48E+02
F21	7.06E+02	9.51E+02	<b>1.37E+02</b>	1.69E+03	2.41E+03	3.06E+02	9.37E+02	5.16E+03	6.04E+02	4.32E+03	2.41E+02
F22	4.55E+02	6.20E+02	5.68E+02	1.00E+03	6.50E+02	<b>3.66E+02</b>	6.27E+02	9.18E+02	6.18E+02	7.42E+02	3.75E+02
F23	5.34E+02	6.83E+02	6.43E+02	1.05E+03	7.60E+02	<b>4.55E+02</b>	7.12E+02	1.12E+03	7.08E+02	9.57E+02	4.55E+02
F24	<b>5.48E+02</b>	1.05E+03	5.41E+02	2.21E+03	8.77E+02	5.68E+02	6.74E+02	5.07E+03	9.75E+02	3.08E+03	6.11E+02
F25	2.34E+03	3.08E+03	3.00E+03	4.23E+03	3.24E+						