和 similar,其中,better,worse and similar 分别表示其他算法的结果比本算法 DEA/NC 优、差和无显著差异这 3 种情况.

Table 1 Results got by DEA/NC on CEC2014 benchmarks for 10, 30, 50 and 100 dimensions in 50 runs

表 1 测试问题维度为 10,30,50 和 100 时,DEA/NC 算法在 CEC2014 测试集上 50 次计算中得到的结果

函数	*Dim*=10			*Dim*=30			*Dim*=50			*Dim*=100		
	Min	Mean	Std	Min	Mean	Std	Min	Mean	Std	Min	Mean	Std
F1	0.00E+00	1.23E−13	3.15E−13	1.12E+03	2.33E+04	1.98E+04	9.04E+04	3.10E+05	1.48E+05	1.24E+05	1.91E+06	4.84E+05
F2	0.00E+00	1.17E−14	1.41E−14	1.42E−11	1.99E−09	4.30E−09	4.81E−05	9.23E−02	2.65E−01	1.42E+00	1.66E+01	1.60E+00
F3	0.00E+00	2.79E−14	3.83E−14	3.98E−13	8.16E−10	1.28E−09	2.12E−01	1.66E+02	2.90E+02	3.94E+00	3.95E+02	3.98E+02
F4	0.00E+00	1.70E+01	1.69E+01	2.76E−09	1.69E−01	1.56E−01	2.14E−01	5.79E+01	3.67E+01	9.59E+01	1.70E+02	6.99E+01
F5	1.14E−13	1.96E+01	3.88E+00	2.04E+01	2.09E+01	8.73E−02	2.10E+01	2.11E+01	3.20E−02	2.02E+01	2.02E+01	2.12E−02
F6	5.99E−02	1.43E+00	1.17E+00	8.32E+00	1.39E+01	2.64E+00	1.93E+01	2.67E+01	3.76E+00	5.91E+01	6.70E+01	6.80E+00
F7	9.86E−03	8.60E−02	5.27E−02	1.14E−13	2.01E−02	1.96E−02	4.55E−13	1.03E−02	1.31E−02	0.00E+00	0.00E+00	0.00E+00
F8	0.00E+00	4.49E−01	6.98E−01	3.98E+00	1.40E+01	4.99E+00	2.29E+01	3.79E+01	7.45E+00	8.79E+01	1.18E+02	2.14E+01
F9	2.98E+00	1.04E+01	4.57E+00	3.28E+01	6.77E+01	1.70E+01	9.45E+01	1.56E+02	3.22E+01	3.95E+02	4.61E+02	4.51E+01
F10	6.89E+00	1.40E+02	1.12E+02	3.53E+00	3.21E+02	2.07E+02	1.32E+02	7.16E+02	3.74E+02	1.02E+03	1.75E+03	4.33E+02
F11	4.37E−01	3.56E+02	2.05E+02	1.44E+03	2.76E+03	5.39E+02	2.73E+03	5.33E+03	8.67E+02	1.08E+04	1.17E+04	6.22E+02
F12	2.12E−01	8.65E−01	3.03E−01	2.03E−01	1.90E+00	6.33E−01	3.33E−01	2.73E+00	7.48E−01	2.90E+00	3.26E+00	3.12E−01
F13	3.73E−02	1.32E−01	6.53E−02	2.03E−01	3.53E−01	7.69E−02	3.19E−01	4.88E−01	8.79E−02	4.97E−01	5.37E−01	4.26E−02
F14	4.41E−02	2.25E−01	7.29E−02	1.83E−01	2.92E−01	7.81E−02	2.32E−01	3.49E−01	9.74E−02	3.15E−01	3.41E−01	2.26E−02
F15	4.55E−01	9.91E−01	3.28E−01	3.06E+00	7.13E+00	2.45E+00	8.34E+00	1.79E+01	5.33E+00	3.89E+01	5.95E+01	1.33E+01
F16	8.38E−01	1.86E+00	4.29E−01	8.80E+00	1.03E+01	7.30E−01	1.73E+01	1.92E+01	8.82E−01	3.81E+01	3.99E+01	1.46E+00
F17	2.08E−01	1.02E+02	9.59E+01	6.92E+02	3.28E+03	3.25E+03	9.66E+03	4.73E+04	2.30E+04	2.28E+04	3.55E+05	1.09E+05
F18	1.03E+00	5.26E+00	3.93E+00	2.34E+01	7.81E+01	5.74E+01	6.55E+01	3.22E+02	3.08E+02	1.32E+02	1.63E+03	1.78E+03
F19	2.68E−02	6.86E-01	9.01E−01	2.41E+00	1.01E+01	1.63E+01	6.43E+00	1.19E+01	2.44E+00	6.09E+01	7.82E+01	2.28E+01
F20	1.11E−01	1.95E+00	1.19E+00	8.01E+00	4.94E+01	6.95E+01	5.61E+01	3.05E+02	2.43E+02	1.39E+02	5.47E+03	2.82E+03
F21	2.08E−02	3.69E+01	5.15E+01	2.99E+01	8.64E+02	7.91E+02	3.97E+03	2.30E+04	1.86E+04	1.23E+04	1.76E+05	4.41E+03
F22	3.38E−01	1.60E+01	8.48E+00	4.11E+01	2.93E+02	1.53E+02	2.70E+02	8.64E+02	2.93E+02	1.35E+03	1.77E+03	2.90E+02
F23	3.29E+02	3.29E+02	3.33E−13	3.15E+02	3.15E+02	5.59E−13	3.44E+02	3.44E+02	4.18E−13	3.31E+02	3.31E+02	1.07E−08
F24	1.08E+02	1.20E+02	6.76E+00	2.22E+02	2.25E+02	1.35E+00	2.54E+02	2.58E+02	2.54E+00	3.04E+02	3.12E+02	4.82E+00
F25	1.19E+02	1.58E+02	3.10E+01	2.00E+02	2.09E+02	3.35E+00	2.00E+02	2.11E+02	1.17E+01	1.90E+02	2.25E+02	2.00E+01
F26	1.00E+02	1.00E+02	3.88E−02	1.00E+02	1.06E+02	2.37E+01	1.00E+02	1.28E+02	4.49E+01	1.90E+02	1.90E+02	3.05E−02
F27	1.93E+00	1.98E+02	1.87E+02	4.01E+02	5.80E+02	1.54E+02	8.82E+02	1.11E+03	1.10E+02	1.89E+03	2.02E+03	1.23E+02
F28	3.57E+02	3.96E+02	4.36E+01	8.21E+02	1.09E+03	2.53E+02	1.31E+03	1.81E+03	5.08E+02	3.67E+03	4.53E+03	6.39E+02
F29	1.33E+02	1.95E+02	3.88E+01	2.87E+02	2.23E+06	3.86E+06	7.97E+02	2.55E+07	1.66E+07	7.97E+03	8.06E+07	9.27E+06
F30	3.31E+02	5.81E+02	1.33E+02	6.99E+02	1.97E+03	8.74E+02	8.29E+03	1.05E+04	2.00E+03	6.58E+03	8.61E+03	1.81E+03

Table 2 Comparison of DEA/NC with state-of-the-art algorithms on the CEC2014 benchmarks using the Wilcoxon Rank-Sum test (significantly, $p<0.05$)

表 2 DEA/NC 与其他较好的算法在 CEC2014 问题上的秩和检验(显著性水平 $p<0.05$)结果

Vs. DEA/NC	b3e3pbest			FCDE			FERDE			FWA-DE			POBL-ADE			RSDE		
Dim	10	30	50	10	30	50	10	30	50	10	30	50	10	30	50	10	30	50
better	1	6	6	1	1	1	2	3	3	9	17	10	6	15	16	17	19	16
worse	21	16	14	28	25	27	14	18	18	11	5	11	17	8	13	4	5	8
similar	8	8	10	1	4	2	14	9	9	10	8	9	7	7	1	9	6	6

通过表 2 的结果可以看出:本文算法 DEA/NC 在不同维度上较 b3e3pbest,FCDE 和 FERDE 算法得到的 better 的总数明显较多,表明本文算法求解的效果更好;而与算法 FWA-DE,POBL-ADE 的求解结果比较,其中 better, worse 和 similer 的总数显著性差异不大,表明算法与其具有相似的求解效果.结合表 1 和表 2 中的实验和比较的结果表明:当问题的维度加大时,在有限的测试次数下,已有的差分进化算法往往很难找到问题的最优解,需要极大地提高算法的搜索能力.

4 结 论

连续单目标优化问题是一个重要的研究领域,许多现实中的优化问题可以转化为单目标优化问题.而 DEA 在解决该类问题上具有显著的优势,本文在原有 DEA 的基础上提出了基于邻域差分和协方差信息的 DEA/NC 算法用于求解该类问题,算法使用了邻域个体的差分算子来避免差分信息失效的问题,通过协方差信息来度量差分变量对个体在每个维度上的影响.这种计算的方式因较少地利用最优解信息,可以较好地避免种群陷入局部最优.最后,本文对 CEC2014 测试集中的问题在 4 种不同维度上进行了测试,并将测试结果与已有的较好的差分进化算法进行比较.实验结果显示了本文提出的算法具有很强的竞争力,表明了算法的有效性.

References:

[1] Das S, Suganthan PN. Differential evolution: A survey of the state-of-the-art. IEEE Trans. on Evolutionary Computation, 2011, 15(1):4−31.

[2] Grefenstette JJ. Optimization of control parameters for genetic algorithms. IEEE Trans. on Systems, Man and Cybernetics, 1986, SMC16(1):122−128.

[3] Mo S, Zeng JC, Tan Y. Particle swarm optimization based on self-organisation topology driven by different fitness rank. Int'l Journal of Computational Science and Engineering, 2011,6(1):24−33.

[4] Ong YS, Lim M, Chen X. Memetic computation-past, present and future [research frontier]. Computational Intelligence Magazine, IEEE, 2010,5(2):24−31.

[5] Storn R, Price K. Differential evolution a simple and efficient heuristic for global optimization over continuous spaces. Journal of Global Optimization, 1997,11(4):341−359.

[6] Price KV, Storn RM, Lampinen JA. Differential Evolution: A Practical Approach to Global Optimization. New York: Springer-Verlag, 2005. 37−130.

[7] Zhang JQ, Avasarala V, Sanderson AC, Mullen T. Differential evolution for discrete optimization: An experimental study on combinatorial auction problems. In: Proc. of the IEEE Congress on Computational Intelligence. Hong Kong: IEEE Press, 2008. 2794−2800.

[8] Neri F, Tirronen V. Recent advances in differential evolution: A survey and experimental analysis. Artificial Intelligence Review, 2010,33:61−106.

[9] Wang Y, Cai Z, Zhang QF. Differential evolution with composite trial vector generation strategies and control parameters. IEEE Trans. on Evolutionary Computation, 2011,15(1):55−66.

[10] Qin AK, Huang VL, Suganthan PN. Differential evolution algorithm with strategy adaptation for global numerical optimization. IEEE Trans. on Evolutionary Computation, 2009,13(2):398−417.

[11] Brest J, Zumer V, Maucec MS. Self-Adaptive differential evolution algorithm in constrained real-parameter optimization. In: Proc. of the IEEE Congress on Evolutionary Computation. Canada: IEEE Press, 2006. 215−222.

[12] Zhang J, Sanderson AC. JADE: Adaptive differential evolution with optional external archive. IEEE Trans. on Evolutionary Computation, 2009,13(5):945−958.

[13] Mallipeddi R, Suganthan PN, Pan QK, Tasgetiren MF. Differential evolution algorithm with ensemble of parameters and mutation strategies. Applied Soft Computing, 2011,11(2):1679−1696.

[14] Fan QQ, Yan XF. Self-Adaptive differential evolution algorithm with zoning evolution of control parameters and adaptive mutation strategies. IEEE Trans. on Evolutionary Computation, 2016,46(1):219−232.

[15] Hansen N, Müller SD, Koumoutsakos P. Reducing the time complexity of the derandomized evolution strategy with covariance matrix adaptation (CMA-ES). Evolutionary Computation, 2003,11(1):1−18.

[16] Hansen N. The CMA evolution strategy: A comparing review. Studies in Fuzziness and Soft Computing, 2006,192:75−102.

[17] Chen L, Liu HL, Zheng Z, Xie SL. An evolutionary algorithm based on covariance matrix leaning and searching preference for solving CEC 2014 benchmark problems. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 2672−2677.

[18] Li XQ, Hao ZF, Huang H. An evolutionary algorithm with sorted race mechanism for global optimization, In: Proc. of the Int'l Conf. on Machine Learning and Computing. Qindao: IEEE Press, 2010. 1550−1555.

[19] Liang JJ, Qu BY, Suganthan PN. Problem definitions and evaluation criteria for the CEC 2014 special session and competition on single objective real-parameter numerical optimization. Technical Report, Zhengzhou: Zhengzhou University and Nanyang Technological University, 2013. 1−32.

[20] Bujok P, Tvrdik J, Polakova R. Differential evolution with rotation-invariant mutation and competing-strategies adaptation. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 2253−2258.

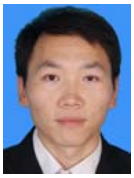
[21] Li ZH, Shang ZG, Qu BY, Liang JJ. Differential evolution strategy based on the constraint of fitness values classification. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 1454−1460.

[22] Qu BY, Liang JJ, Xiao JM, Shang ZG. Memetic differential evolution based on fitness Euclidean-distance ratio. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 2266−2273.

[23] Yu C, Kelley LC, Zheng SQ, Tan Y. Fireworks algorithm with differential mutation for solving the CEC 2014 competition problems. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 3238−3245.

[24] Hu ZY, Bao YK, Xiong T. Partial opposition-based adaptive differential evolution algorithms: Evaluation on the CEC 2014 benchmark set for real-parameter optimization. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 2259−2265.

[25] Xu CJ, Huang H, Ye SJ, A differential evolution with replacement strategy for real-parameter numerical optimization. In: Proc. of the IEEE Congress on Computational Intelligence. Beijing: IEEE Press, 2014. 1617−1624.



李学强(1983－),男,湖北黄冈人,博士,讲师,主要研究领域为智能计算,智能算法应用,多目标优化.

黄翰(1980－),男,博士,教授,博士生导师,CCF 高级会员,主要研究领域为智能算法理论,智能算法应用,计算机视觉,大数据分析.

郝志峰(1968－),男,博士,教授,博士生导师,CCF 专业会员,主要研究领域为代数的 Morita 理论及其在 Hopf 代数中的应用等基础理论,智能计算,数据挖掘,大数据分析.