Applied Intelligence (2024) 54:10833–10911
https://doi.org/10.1007/s10489-024-05675-9

AdaGuiDE: An adaptive and guided differential evolution for continuous optimization problems

Zhenglong Li[1] · Vincent Tam[1]

Accepted: 7 July 2024 / Published online: 31 August 2024

Abstract

Differential evolution (DE) has been proven as a simple yet powerful meta-heuristic algorithm on tackling continuous optimization problems. Nevertheless most existing DE methods still suffer from certain drawbacks including the use of ineffective mechanisms to adjust mutation strategies and their control parameters that may possibly mislead the search directions, and also the lack of intelligent guidance and reset mechanisms to escape from local optima. Therefore, to enhance the adaptability of DE-based search frameworks and the robustness on optimizing complex problems full of local optima, an adaptive and guided differential evolution (AdaGuiDE) algorithm is proposed. Essentially, the adaptability of the AdaGuiDE search framework is enhanced by three schemes to iteratively refine the search behaviour at two different levels. At the macroscopic level, the AdaGuiDE search framework revises the existing adaptive mechanism for selecting appropriate DE search strategies by counting the actual contributions in terms of solution quality. In addition, the adaption strategy is extended to the microscopic level where a penalty-based guided DE search is employed to guide the search escaping from local optima through temporarily penalizing the local optima and their neighborhood. Furthermore, a systematic boundary revision scheme is introduced to dynamically adjust the search boundary for locating any potential regions of interest during the search. For a rigorous evaluation of the proposed search framework, the AdaGuiDE algorithm is compared against other well-known meta-heuristic approaches on three sets of benchmark functions involving different dimensions in which the AdaGuiDE algorithm attained remarkable results especially on the high-dimensional and complex optimization problems. More importantly, the proposed AdaGuiDE framework shed lights on many possible directions to further enhance the adaptability of the underlying DE-based search strategies in tackling many challenging real-world applications.

Keywords Differential evolution · Guided search · Self-adaptive mechanism · Continuous optimization

1 Introduction

Optimization involves a very challenging yet ubiquitous task helping in making wise decisions or solving complex problems such as machine multilingual translation [1], energy use planning in building operations [2], multiple objects detection in autonomous driving [3] and protein structure prediction in bioinformatics [4] through scientific methods in real life. In particular, Continuous Optimization Problem (COP) is the most general case that can be found everywhere. Given a set of equality constraints and inequality constraints, solving COP is to search out an optimal solution that can achieve the maximal or minimal objective value in the continuous domain with the satisfaction of relevant constraints. A practical example of COP is to dynamically adjust the allocation of asset in a portfolio for promptly responding to the current financial market, given the expectations of investors to maximize returns while minimizing risks [5]. During trading, each decision should be constrained to ensure manageable risk exposure and not deviate from market regulations.

By exploring the nature of optimization tasks in various scenarios, most of them can be simplified to a kind of mathematical expression in which optimization techniques can efficiently yield a high-quality solution based on it. In the past few decades, researchers have proposed numerous

✉ Vincent Tam
vtam@eee.hku.hk

Zhenglong Li
lzlong@hku.hk

[1] Department of Electrical and Electronic Engineering, The University of Hong Kong, 999077 P.R.C Pokfulam, Hong Kong

solvers based on mathematical programming methods such as quadratic programming [6], integer programming [7] and second-order cone programming [8]. In general, their effectiveness can be explained with rigorous mathematical proofs so that the quality of solutions can be guaranteed. However, before applying such solvers, optimization tasks must be converted to a specific format and strictly satisfies the constraints required by solvers. In fact, some problems are difficult to be completely expressed in such formats. In addition, the complexity and computing time of solvers will dramatically raise since intensively computational resources are required for calculating large-scale matrices by the increasing of dimensions. In recent years, gradient-based methods have achieved amazing performance in real-world cases such as the face recognition [9], user recommendation system [10], sentiment analysis [11] and so on. Yet the major drawback is that deep learning models have to be redesigned and retrained for dealing with different tasks, which is typically learnt from large volume datasets with the extra training time. Moreover, when the objective function or constraints of problems include non-convex or non-differential functions, deep learning techniques may not work well any longer.

To tackle the problems involving non-linear, non-differentiable, non-convex, multi-modal or even not well-defined objective functions, meta-heuristic algorithms are extensively considered as an efficient tool in recent years. Unlike deterministic methods highly depending on the domain knowledge of specific problems, meta-heuristic approaches are the problem-agnostic method, conducting the exploration and exploitation search to seize feasible solutions within acceptable computing time. The word "meta" means that the algorithm is a generic method constructed in a higher level such that different types of problems can be optimized without any extra modifications, while the word "heuristic" inspires search paradigms from natural phenomena and biological behaviors. Recent studies [12, 13] have proven the effectiveness of meta-heuristic algorithms in solving many challenging tasks including designing the architecture of deep neural networks and optimizing combinatorial problems. Basically, from the perspective of individuals, it can be organized into two classes of methods. Neighborhood-based algorithms work on a single individual at each generation, then a new candidate is accepted with certain probability if its fitness excels that of the original individual. Simulated Annealing (SA) [14] and tabu search [15] are the most representative algorithms that usually are applied to conduct the local search. On the other hand, population-based algorithms own multiple individuals who cooperatively explore different regions of search space with the aid of sharing the search information among them. By mimicking animal foraging behaviors, the swarm intelligence algorithm maintains a group of candidates performing the search toward to various directions according to the designed rules, and the knowledge of problems can be gradually learnt by sharing known information among candidates. Based on similar design principles, some algorithms like Ant Colony Optimization (ACO) [16], Particle Swarm Optimization (PSO) [17] and Artificial Bee Colony Algorithm (ABC) [18] are still competitive against the state-of-the-art (SOTA) algorithms. Especially in solving the large-scale Traveling Salesman Problem (TSP), the variants of ACO demonstrate impressive results compared with others [19]. On the other branch of population-based algorithms, evolutionary computation techniques derive several classical yet powerful search paradigms as well. Differential Evolution (DE), a well-known evolutionary algorithm proposed by [20], has been widely studied for solving complex optimization problems, which benefits from several significant features like effective exploration and exploitation capabilities, good interpretability, simple implementation, etc. Similar to the Genetic Algorithm (GA), DE is inspired by the natural selection from Darwin's theory of evolution, mimicking several basic operators including mutation, crossover and selection for filtering inferior candidates while maintaining the superiority of the population. The main difference between them is the mutation mechanism that the GA changes the value of some bits (genes) of an individual with the preset probability while the DE approach generates a new trial vector by referring to the distance between the parents and reference individuals for which it can be called "differential". As the choice of reference individuals directly decides search directions, a series of mutation strategies are presented to conduct the exploration or exploitation search. Yet it should be pointed out that there is no single mutation strategy that can deal with all kinds of problems. Accordingly, recent studies [21, 22] adopt a multi-strategy method to maintain a pool of mutation strategies, attempting to apply several trial vector generation strategies to cover different types of searches and designing an adaptive mechanism to assign appropriate strategies over the evolutionary process. However, most of them focus on the design of adaptive mechanisms from only two aspects including choosing trial vector generation strategies and/or adjusting control parameters like scaling factors and crossover rates, which is not enough to guide algorithms adapting to the real-time environment. Meanwhile, some adaptive mechanisms may provide unreasonable advice due to less consideration on the contribution of candidates of different qualities. Moreover, especially in tackling multi-modal optimization problems, those existing DE variants are easily trapping into local minima since the currently best individual will always be kept as the center of the search so that the exploitation space is limited and the optimization ultimately fails to reach the global optimum.

In this paper, by introducing several mutation strategies to handle different cases during the search, a novel Adaptive and Guided Differential Evolution (AdaGuiDE) algorithm is proposed to tackle COPs. Compared with some conventional DE approaches, the adaptability of the AdaGuiDE comes from three aspects: 1) **Guided DE search**. Instead of using the original fitness value, a guided objective function is described to measure the performance of individuals by incorporating with a dynamic penalty mechanism, providing useful guidance to the current search toward to other promising regions except for the surroundings of local minima. 2) **Flexible scheme to select appropriate search strategies**. To timely balance the exploration and exploitation for the upcoming search, the AdaGuiDE approach adjusts search strategies and their control parameters through learning from the historical contributions of search strategies. The search strategy recently having more contributions will be performed with a high probability. 3) **Adaptive boundary revision technique**. The AdaGuiDE approach locates a Region of Interest (ROI) based on the guidance information from the guided DE search, and then narrows down the search region to enhance the efficiency of the search. Furthermore, the search region will be released back to the initial settings when the ROI has been explored. The innovations and contributions of this work are described as follows:

1. The AdaGuiDE is the first algorithm incorporating the Guided Local Search (GLS) to constantly monitor the performance of the underlying DE algorithm in solving the COPs with a diversity of features.
2. A novel boundary revision scheme is proposed to quickly locate the ROIs where the nearby regions of local minima were punished the most during the past period.
3. Learnt from the existing adaptive mechanism, a contribution-based scheme is further improved to select appropriate mutation strategies and adjust the control parameters of DE operators. The enhanced scheme helps the AdaGuiDE accurately classify the real contributions that truly reflect the performance of each strategy.
4. The multi-layer adaptive mechanism in the AdaGuiDE enables the search to timely accommodate to the current environment through close collaboration.

The rest of this paper is arranged as follows. The basic knowledge and latest studies of the DE are reviewed in Section 2. Section 3 describes the details of the proposed AdaGuiDE algorithm with its key components to realize dynamical mechanisms at different layers. The experimental settings and results are clearly demonstrated and analyzed in Section 4. Furthermore, Some characteristics of the AdaGuiDE including the convergence speed, stability, time cost, ablation study, and hyper-parameter analysis are discussed in Section 5. Lastly, Section 6 concludes this work, and sheds light on various directions for future investigation.

2 Related work

2.1 Adaptive differential evolution algorithms

The Differential Evolution (DE) approach was originally proposed to solve Chebyshev Polynomials problems and has been widely applied to deal with complex optimization problems in recent decades. Basically, a DE framework consists of four core components including initialization, mutation, crossover, and selection for iteratively generating high-quality solutions until the search meets stop criteria. Before starting the search, the search individuals in a population will be randomly assigned throughout the overall search space. Afterwards, different individuals periodically exchange the collected information with each other in each generation to produce promising solutions at the mutation stage. It is worth noting that different mutation strategies (also known as trial vector generation strategy) will directly impact the behaviors of search toward exploration or exploitation to balance the convergence and solution quality. Furthermore, the crossover operation mixes the information from the parent individuals and the newly generated individuals under pre-defined probabilities. Lastly, the newly generated offspring are evaluated by the objective function $f(u_i)$. The individuals with a smaller objective value are kept for the next generation at the selection stage when compared with their parent x_i.

Yet in tackling optimization in different fields, the conventional DE approaches may not be able to adapt to the nature of problems by dynamically adjusting the mutation strategies and essential hyperparameters such as scaling factors, crossover probabilities, and population sizes during the search stages. There are many investigations [23–27] giving useful suggestions on hyperparameter settings after conducting detailed experiments. However, most of the suggestions are customized for specific problems by using the trial-and-error scheme. Therefore, to enhance the universality of DE-based approaches to various cases and reduce the involvements of handcrafted settings, [28, 29] presented an efficient Self-adaptive Differential Evolution (SaDE) algorithm in which both mutation strategies and their control factors are dynamically adjusted by analyzing the historical profile in the previous search. More specifically, the scaling factor F of the SaDE is approximated by a Gaussian distribution with a fixed mean value while the crossover probability CR of the SaDE is sampled by a Gaussian distribution but with a dynamic mean value from the median of CR memory. Compared with the SaDE, the JADE [21] generates F according to a Cauchy distribution for diversifying the values to avoid concentrating local minima while the CR remains the same distribution as the SaDE. Besides, the mean values of the sampling distributions for both F and CR are adaptively adjusted in terms of the past values and current performance in the JADE. Moreover, a novel mutation strategy "DE/Current-to-pbest/1" is given in the JADE to avoid premature convergence, which has been a widely adopted strategy in the SOTA DE-based approaches. As an enhanced version of the JADE, the SHADE [30] further improves the robustness of the JADE by using a Success-History-based Adaptive mechanism to maintain a diverse set of control parameters rather than utilizing a single pair of control parameters in the JADE. Followed by the SHADE, there are many outstanding DE-based algorithms [31–35] in recent ten years, among which the L-SHADE [36] enhances the search efficiency by using linear population size reduction mechanism while the L-SHADE-RSP [37] further improves the L-SHADE with a rank-based selective pressure strategy for carefully choosing the reference individuals in the mutation to impact the search directions. Subsequently, through extending to the non-linear population size reduction and the linear bias change-based parameter adaptation, the NL-SHADE-RSP [38] and the NL-SHADE-LBC [39] have been recognized as top-ranking algorithms in the recent IEEE CEC (Congress on Evolutionary Computation) competitions. Besides, by learning from the JADE, the CSDE [22] proposes another popular mutation strategy "DE/pbest-to-rand/1" and a very systematically contribution-based cooperative rule to adjust control factors and the balance between exploration and exploitation.

2.2 The state-of-the-art meta-heuristic algorithms

Through extracting the correlation information among individuals, some novel Covariance Matrix Adaptation Evolution Strategies (CMA-ES) [40–42] achieve remarkable enhancements on objective optimization in which the covariance matrix is periodically updated to observe the population distribution in the search space and guide the search directions toward the promising areas. Recently, more studies [43–45] control the search behaviors by integrating the physical or chemical knowledge such that the trade-off between exploration and exploitation can be well balanced according to the insights of operating rules coming from the real world, especially when solving the optimization problems in the field of engineering. In addition, there are many powerful swarm intelligence algorithms [46–48] recently proposed to mimic biological swarm behaviors such as foraging, mating, and enemy defending for obtaining the species with the highly competitive advantages in natural selection as the final solutions.

2.3 The guided local search method

The conventional DE in solving multi-modal optimization problems lacks the abilities to locate more peaks and escape from local minima. As an efficient component, niching methods are integrated with evolutionary algorithms to maintain a diversity of populations for detecting possible peaks. The idea of niching methods is to distribute individuals to different sub-populations for locating and monitoring multiple peaks. The previous studies [49, 50] punished the worse individual who is near local minima in the niche, and then the individual is eliminated soon in the following generations. Conversely, Guided Local Search, an intelligent search scheme proposed by [51], encourages the search escaping from local minima by penalizing the local area where the currently local best solution drops into it. Then, the individuals temporarily search other promising regions where the better solution may hide at those areas. Over the past few years, the GLS integrating with individual-based search has been successfully applied to solve combinatorial problems like Traveling Salesman Problem [52, 53] and scheduling problem [54]. Furthermore, [55] extends the GLS to tackle Continuous Optimization Problems (COPs) with the dimension of 2. Yet there is no research that the GLS is incorporated into DE approaches to solve COPs with multiple dimensions.

To explore the potentials of the GLS, the AdaGuiDE algorithm further suggests a more flexible GLS-based penalty scheme and firstly integrate it with the DE search to solve relatively high-dimensional COPs (up to 100 dimensions). In the original GLS, the guided objective function $f(x_i)$ is revised as (1). In the following sections, the AdaGuiDE will extend the GLS to handle continuous optimization problems.

$$f(x_i) = h_1(x_i) + \lambda \sum_{k=1}^{K} p_k I_k(x_i) \tag{1}$$

where $h_1(x_i)$ is the original fitness value (i.e., the output of optimization functions), λ is the parameter controlling the strength of the whole penalty item, and $I_k(x_i)$ is the indicator function (2) to show the feature k whether be included in the solution x_i of i^{th} individual in a population. For example, the feature k indicates a route between two cities in TSPs in which a solution x_i involving the specific route k will be penalized. p_k is the current penalty factor of feature k, which is updated by the utility function defined as (3) once the local search algorithm falls into certain local minimum S_* exceeding the predefined generations.

$$I_k(x_i) = \begin{cases} 1, & \text{if } k \in x_i \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

$$util_k(S_*) = I_k(S_*) \times \frac{c_k}{1 + p_k} \tag{3}$$

where c_k is the cost of feature k. The features with the highest utility value are selected, and their penalty values will be increased by 1.

3 The adaptive and guided differential evolution framework

To enable DE algorithms for adapting various optimization tasks, the self-adaptive mechanism can replace the manual fine-tuning on adjusting parameters for specific problems. Meanwhile, the self-adaptive mechanism as a guider of the DE algorithm should be set at the top level of the overall framework to control the evolution and monitor the search, coordinating all components and evaluating their performance in terms of the real contribution in which most existing self-adaptive algorithms include inaccurate contribution of components. In addition, as most of the search space is unimportant and full of traps, the limited resource should be assigned to the ROI to speed up the convergence, thus timely revising the search region for adapting the current environment plays an important role of self-adaptive frameworks. Motivated by these observations, the idea of the AdaGuiDE is to achieve a flexible controller on the top of the conventional DE from multiple levels, in which the components of the DE can be coordinately adjusted for the same goal at different stages. The whole framework of the AdaGuiDE is shown in Algorithm 1. At the beginning of the search, the initialized individuals are randomly distributed throughout the overall search space, and their objective value are evaluated by the guided objective function instead of the raw fitness function. For each generation, the parameters on the strategy level and the individual level are updated by historical contributions. Then, with the consideration of strategy selection probabilities, the trial vector generation strategy for each individual is decided and performed. The new trial vectors are further integrated with their corresponding parent individuals to generate a new test vector. The parent individual is replaced by the test vector if the guided objective value of the test vector outperforms that of its parent. Followed by that, the AdaGuiDE updates the penalty factor based on the currently local minimum who has not been improved for generations, which forces the search toward to other regions. In addition, the boundary will be narrowed down and reset alternately once the DE stuck into certain local minima for several iterations. Lastly, the best solution found on the search is outputted when meeting stop criteria that are the maximum number of fitness function evaluations. Let $G_{noImprovement}$ be the accumulative number of iterations staying at the same local minimum, G_{trap} is the criterion for recognizing local minimum, $G_{trigger}$ is the threshold for triggering the boundary revision scheme, FP is the reset cycle for the contribution scheme parameter $CS_{m,g}$, K is the number of intervals being partitioned in the boundary revision scheme, ϵ is a control parameter in the neighborhood search, β is a relaxation factor in the boundary revision scheme, λ is the penalty factor in the guided DE search, NP is the population size, G is the number of iterations, $SP_{m,g}$ is the selection probability of the strategy m at the iteration g, M_g is the individual-independence factor of the adaptive parameter scheme, P_g is the modulo-based periodic factor of the adaptive parameter scheme, p_{best} is the index of the individual that are extracted from Top X best individuals, x_{pbest} is the individual that are extracted from Top X best individuals, x_{r1}, x_{r2} and x_{r3} are the reference individuals, F_i is the control factor in mutation strategies, and CR_i is the crossover rate.

Algorithm 1 The overall procedure of the AdaGuiDE.

Require: NP, G, G_{trap}, $G_{trigger}$, FP, K ϵ, β and λ.
Ensure: The currently best individual x_{best}.
Initialize the population by sampling from a uniform distribution.
Initialize the parameters $SP_{m,g}$, M_g, P_g, p_{best}, F_i, and CR_i.
for ($g = 1$ to G) **do**
  if ($mod(G, FP) = 0$) **then**
    Reset $SP_{m,g}$.
  end if
  Update M_g, P_g, p_{best} and $SP_{m,g}$ via (21).
  for ($i = 1$ to NP) **do**
    Select the x_{pbest}, x_{r1}, x_{r2} and x_{r3}.
    Select the mutation strategy based on $SP_{m,g}$.
    Update F_i and CR_i of the individual i.
    Generate the trial vector v_i via (4) to (7).
    Generate the offspring according to binomial crossover and CR_i.
    Update $f(u_i)$ and $h_1(u_i)$ via (9).
    Update $CS_{m,g}$ by comparing $h_1(u_i)$ and $h_1(x_i)$.
    Update x_i if $f(u_i) < f(x_i)$
  end for
  Update the currently best individual.
  if Fulfill the stop criteria **then**
    return The currently best individual x_{best}.
  end if
  if ($mod(G_{noImprovement}, G_{trap}) = 0$) **then**
    Update the penalty value p_{jk} in the guided DE search.
  end if
  if ($mod(G_{noImprovement}, G_{trigger}) = 0$) **then**
    Sample a reference cluster and perform the neighborhood search via (15).
    Revise the search boundary via (17) to (20).
  end if
end for

The flowchart of the AdaGuiDE is shown in Fig. 1, which has similar steps as most of the DE-based algorithms. The differences are that the proposed AdaGuiDE updates the parameters in the dynamic contribution mechanism at the beginning of each generation and then evaluates the guided objective values with penalty values after collecting new trial vectors for the guided DE search. Besides, it should be highlighted that the guided search scheme and boundary revision mechanism of the AdaGuiDE can dynamically adjust the strengths of penalties and promising search areas through monitoring the movements of local minima. In the following section, the core components of the AdaGuiDE will be described and evaluated in detail for discussing their

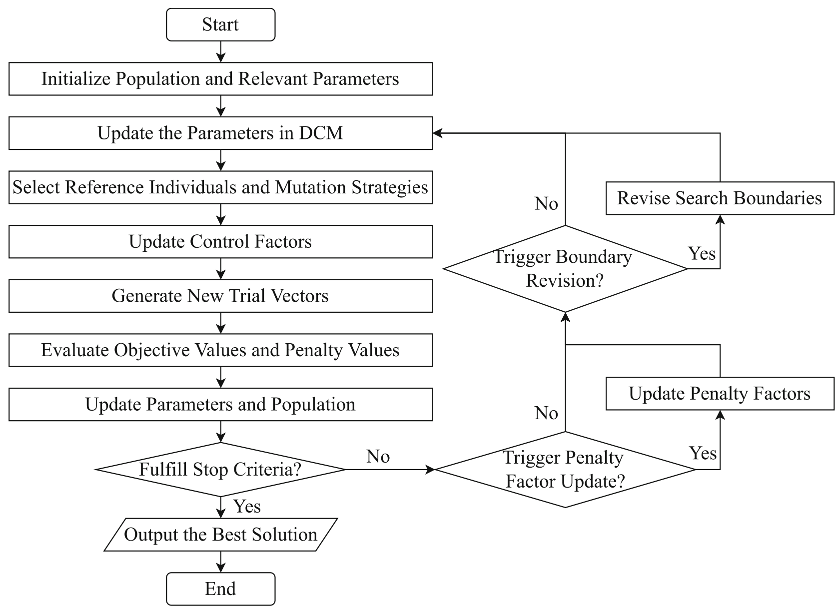


Fig. 1 The flowchart of AdaGuiDE

contributions, and all discussions in this paper are based on minimizing functions.

3.1 The generation strategy of trial vector

Since the gradient information on evaluation functions cannot be utilized by the DE, the direction of optimization is relied on the difference between the parent individual and the reference individuals, which is the meaning of "Differential". With the development of the DE, several simple yet effective trial vector generation strategies (also named mutation strategies) are proposed and employed to be a basic component of the DE, which can be roughly classified into two categories with respect to their search paradigms: exploration and exploitation. The exploration strategy encourages individuals toward to visit broader space where few individuals have been there before. Randomly choosing reference individuals on the exploration strategy increases the uncertainty of search behavior, which is propitious to escape from local minima, but it slows down the convergence speed at the early stage. Inversely, the exploitation strategy performs the local search around the currently best solution, whereas it more likely drops into local minima before getting the globally optimal solution on multi-modal problems. Hence, how to choose an appropriate generation strategy acts the most important feature of constructing an effective DE. To reduce the computational cost and fit into more problems, instead of fixing an applicable generation strategy through the trial-and-error search, the AdaGuiDE maintains a trial vector generation strategy candidate pool including four strategies that covers both the exploration and exploitation. After reviewing DE literatures, four strategies are extracted from the existing DE frameworks and other meta-heuristic algorithms, and their effectiveness have been verified either exploration or exploitation on some typical scenarios with their own characteristics.

- "DE/Current-to-pbest/1": the DE-based strategy is firstly introduced in the JADE [21]. The main idea is to replace the best solution by an individual who is randomly chosen from the candidate pool in which the top p individuals are included here. Compared with the "DE/current-to-best/1", the mentioned strategy prevents the search from tracking local minima only, which flexibly provides more outstanding reference individuals for increasing the diversity of promising regions at the beginning of evolution. The expression of the "DE/Current-to-pbest/1" is described as follows:

$$v_i = x_i + F_i^C \times \left(x_{pbest} - x_i\right) + F_i^C \times (x_{r1} - x_{r2}) \quad (4)$$

- "DE/Pbest-to-rand/1": Using the top p_{best} individuals as the base vector to improve the local exploitation ability of those competitive individuals promotes the search standing on the shoulders of giants. Instead of solely using the currently best individual as the center point of search regions, "DE/Pbest-to-rand/1", as a powerful component of the CSDE [22], distributes several center points to locate possible peaks and traps during the evolutionary process for which it can perform well on multi-modal problems. Its trial vector is generated by the following (5):

$$v_i = x_{pbest} + F_i^R \times (x_{r1} - x_i) + F_i^R \times (x_{r2} - x_i) \quad (5)$$

- “DE/Current-to-random/1”: Regarded as a good supplement component of balancing strategy, “DE/Current-to-random/1” executes the exploration toward to a random direction by combining three reference individuals. The manner of trial vector generation can be expressed as follows:

$$v_i = x_i + K_i^T \times (x_{r1} - x_i) + F_i^T \times (x_{r2} - x_{r3}) \quad (6)$$

- “AMPO Local search”: To further enhance the local exploitation ability of the AdaGuiDE, the local search strategy from [56] is introduced as a key strategy here, whose idea is to conduct the nearby search from the coarse-grained level to the fine-grained level within few iterations. The update formula can be found below:

$$v_i = x_i + Gaussian\,(0, \sigma_i) \times x_i \quad (7)$$

where F_i^C, F_i^R, F_i^T, K_i^T and σ_i are the control parameters of those mutation strategies, and p_{best} is the factor to manage the top individual list.

3.2 The guided DE search strategy

In most derivate DE frameworks or other meta-heuristic algorithms, the cost/fitness function to measure the performance of each individual in actual tasks is directly used as the objective function deciding whether individuals will be survived in the next generation. Nevertheless, this will possibly ignore that other essential elements of optimization should be carefully considered as well during the evolutionary process. One of examples is the recognition of local minima, which will adversely allocate the search efforts to the regions of pitfall and ultimately affect the search efficiency of the whole population. In particular, certain mutation strategies like the one namely “current-to-best” using the currently best solution as the main reference vector may lead to the whole population toward to search the surrounding areas of local minima whereas other promising areas have less opportunity to be explored. Accordingly, to carefully evaluate the quality of each candidate, some frameworks typically introduce a penalty item as a part of objective functions to implicitly point out the adverse effects that the solution may cause. Among those frameworks, the GLS prevents the search from being stuck into certain local minima through penalizing those individuals who select the features being included by the currently best solution since its intent encourages to explore other features which may be a key element to reach the global optimum in the following search.

In this section, instead of integrating the GLS into neighborhood-based approaches and then mainly being applied to tackle combinatorial problems or 2-dimensional continuous optimization problems [55], this is the first time to propose the guided DE search in which the GLS is thoroughly incorporated into the DE for solving the continuous problems with multiple dimensions. Different with the GLS on the combinatorial problems in which the penalties are added to features/dimensions being mostly included by the local minima found in the previous search, the guided DE search introduces soft constraints to certain intervals of each dimension at which the local optima locate. Intrinsically, those soft constraints depend on a critical assumption that the globally optimal solution has less probabilities appearing in the surrounding area of the currently best solution who has been penalized, thus the guided DE search hopefully turns to visit other promising areas through augmenting the objective value of the solution who stays at the neighborhood region of local minima. As clearly described by an example that the originally second or even lower ranking best solution from the original cost/fitness function is enhanced to the best solution after considering the penalty constraint, the reference point of “best” in certain mutation strategies is changed to the guided best solution. That is the search center has been revised from the originally best candidate to the guided best candidate, and ultimately the promising regions will be explored with more computational efforts. With more details, firstly the domain (i.e., the search range) of each dimension is equally divided into several intervals, and those non-overlapping intervals can be defined as the surrounding regions of candidates who locate at the same interval. Given an example that the feasible range of dimension j is $[L_j, U_j]$ and being partitioned into K independent yet adjacent intervals, the indicator function $I_{jk}(x_i)$ of the GLS is redefined as (8) with the consideration of different dimensions, indicating whether the candidate x_i lies at the k^{th} interval (i.e., k^{th} feature) for dimension j.

$$I_{jk}(x_i) = \begin{cases} 1, & \text{if } x_{ij} \in k \\ 0, & \text{otherwise} \end{cases}, (k = 1, 2, \ldots, K, \quad j = 1, 2, \ldots, D) \quad (8)$$

Furthermore, to carefully examine the significance of intervals at different search stages, the revised GLS further introduces the penalty factor p_{jk} to measure the current frequency of the k^{th} interval at the j^{th} dimension involved in the guided local minima. Initially, the penalty values of all intervals in each dimension are set to 0. Since the GLS is an online policy timely collecting and reflecting the up-to-date information during the whole search period, once the currently guided best candidate reaches the local minimum for several generations, the penalty value of the corresponding interval will be increased by one to reduce the opportunity of those pitfall areas being selected at the following search.

Accordingly, as clearly described by (9), the guided objective function $f(x_i)$ of the AdaGuiDE consists of two essential items. The regular item $h_1(x_i)$ outputs the original cost/fitness value of practical problems while the penalty item $h_2(x_i)$ shown in (10) counts the total penalty values from all dimensions as an extra cost such that the search will not be attracted by those local minima due to the higher objective values.

$$f(x_i) = h_1(x_i) + h_2(x_i) \tag{9}$$

$$h_2(x_i) = \lambda \sum_{j=1}^{D} \sum_{k=1}^{K} \left(I_{jk}(x_i) \times p_{jk} \right) \tag{10}$$

where λ is the penalty strength controlling the impact of the penalty item in the guided objective function. Lastly, the revised objective function is applied to measure the quality of newly generated candidates in the AdaGuiDE.

Yet in tackling large-scale continuous optimization problems, the penalty scheme of the original GLS may overpenalize a solution as it focuses on different intervals of each dimension but neglects the relative importance of dimensions. Therefore, to consider both the impact of the features of each dimension and the correlations among dimensions, a new variant of the AdaGuiDE namely AdaGuiDE-PS is proposed in this paper as well. The revised penalty factor p'_{jk} of the AdaGuiDE-PS is depicted as (11).

$$p'_{jk} = q_{jk} \times \phi_j(\{S_*\}) \times \varphi_j(\{S_*\}) \tag{11}$$

where $\{S_*\} = \{S_*^1, \ldots, S_*^{t-1}, S_*^t\}$ is the set of local minima from the search start until now. q_{jk} counts the number of generations that individuals stayed in the same interval k of the j^{th} dimension since the lastly visited local minimum S_*^{t-1} until the current local minimum S_*^t. A higher p'_{jk} indicates that this area was frequently visited in the past period yet the search is still stuck into local minima. Thus, such areas will be penalized, and the search should be toward other promising areas.

As shown in (12), $\phi_j(\{S_*\})$ indicates whether the sampled interval k for dimension j at the current local minimum S_*^t is different from the sampled interval k for dimension j at the last local minimum S_*^{t-1}.

$$\phi_j(\{S_*\}) = \begin{cases} 1, & \text{if } k_j^t = k_j^{t-1} \\ 0, & \text{otherwise} \end{cases} \tag{12}$$

where k_j^t is the interval that the current local minimum S_*^t stays at the j^{th} dimension, and k_j^{t-1} is the interval that the last local minimum S_*^{t-1} stays at the j^{th} dimension.

$\varphi_j(\{S_*\})$ is described as (13), measuring the normalized relative importance of the j^{th} dimension.

$$\varphi_j(\{S_*\}) = \frac{\bar{\varphi}_j(\{S_*\})}{\sum_{i=1}^{D} \bar{\varphi}_i(\{S_*\})} \tag{13}$$

$$\bar{\varphi}_j(\{S_*\}) = \frac{h'_{1,j}\left(S_*^t, S_*^{t-1}\right)}{h'_{1,j}\left(S_*^{t-1}, S_*^{t-2}\right)} \tag{14}$$

where $\bar{\varphi}_j(\{S_*\})$ in (14) is the unnormalized relative importance of the j^{th} dimension, $h'_{1,j}(S_*^t, S_*^{t-1}) = \frac{|h_1(S_*^t) - h_1(S_*^{t-1})|}{|S_{*,j}^t - S_{*,j}^{t-1}|}$ is the gradient between S_*^t and S_*^{t-1}, $h'_{1,j}(S_*^{t-1}, S_*^{t-2}) = \frac{|h_1(S_*^{t-1}) - h_1(S_*^{t-2})|}{|S_{*,j}^{t-1} - S_{*,j}^{t-2}|}$ is the gradient between S_*^{t-1} and S_*^{t-2}, and $h_1(\cdot)$ is the original objective value of the optimization function.

The intuition of $\varphi_j(\{S_*\})$ and $\bar{\varphi}_j(\{S_*\})$ is that, when the search jumps into a new local minimum, the variable j (i.e., dimension j) with a smaller movement may be still trapped in the region of local optimum, thus those variables would be recognized as being of high relative importance with a higher $\varphi_j(\{S_*\})$ value such that the search will intensify the punishment in the region of local optimum and is encouraged to explore other promising areas. Meanwhile, the trend of the current change between S_*^t and S_*^{t-1} and the last change between S_*^{t-1} and S_*^{t-2} is considered in this work to further highlight the important dimension for escaping from the local optima. Except for measuring the relative importance of dimensions, the proposed penalty scheme tries to identify the key interval of each dimension for more accurately guiding the search escaping from local minima through introducing p'_{jk} and $\phi_j(\{S_*\})$.

3.3 An adaptive boundary revision scheme

As described in detail by the penalty-based guidance mechanism and its important hypothesis in the last section, there is no sufficient confidence that we can say the surrounding area of local minima has been thoroughly searched and the globally optimal solution absolutely resides out of that area. Thus, it may unavoidably lead to a miscarriage of justice for penalizing the surrounding area of local minima, especially when inappropriately setting interval features of each dimension or the globally optimal solution is too close to the locally best candidate. Furthermore, it surely cannot find a perfect interval division scheme for all kinds of problems so that defining the surrounding area (i.e., the interval) is quite difficult when tackling different real-life problems since the peaks and valleys of the search space are unknown for us before starting to search. More importantly, the existing interval features are typically considered as fixed values throughout the evolutionary process in the original GLS for which it cannot better adapt to the latest search environment for correctly penalizing features.

Figure 2 demonstrates three scenarios of the relative position between the local minimum S_* and the global minimum S_{opt}. The yellow shadow area is the penalty area for the local

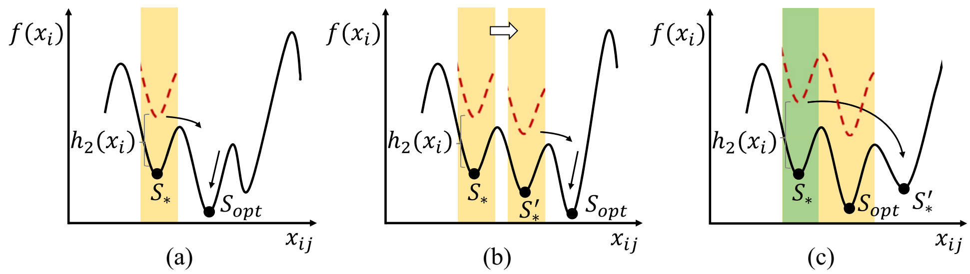


Fig. 2 Three scenarios of the relative position between the local and the global optimum

minimum and the red line of dashes is the guided objective value with the penalty item $h_2(x_i)$. As shown in Fig. 2(a), the globally optimal solution is outside but close to the penalty area in which the guided DE search will avoid searching and turn to other promising areas so as to discover the globally optimal solution. However, when the surrounding area of the local minimum S_* is punished and the population turns to search other promising areas, the search may trap into the new local minimum S'_* if the globally optimal solution actually is not staying at that promising area (see Fig. 2(b)). Then, the new local minimum will be confirmed, and its surrounding area will be penalized. Meanwhile, the guided DE search will keep exploring another promising area. Lastly, the global minimum is ultimately found after more challenging local minima are caught and more areas are excluded from the search space. Yet there is another possible case that the globally optimal solution is inside the penalty area of the local minimum due to the inappropriate penalty interval setting. Accordingly, the guided DE search will not find the optimal solution as described in the previous cases for a long time. To correct penalty intervals and improve the resolution of penalty areas, as shown in Fig. 2(c), the penalty interval should be narrowed down (i.e., the green shadow area) to reduce the inappropriate punishment on the globally optimal solution.

On the other hand, the larger search space is accompanied by the exponential increment of computational efforts. It is necessary to narrow down the search space after more information about the nature of the problem is gathered during the search process, especially when the size of the problem is in hundreds or even in thousands. Particularly, searching in the key area not only saves resources on the unpromising regions, but also reduces struggles on more possible trap areas where the search has to allocate more efforts for escaping.

As clearly concluded by the above major pitfalls, temporarily revising search boundaries can definitely enhance the efficiency of the search. However, which area is extracted for the fine-grained search is challenging since the computational resource is limited. It can be fairly considered that there may be no relatively outstanding solution hidden on those areas being called promising at the previously guided search stage when the currently best candidate is still the most excellent one among all evaluated solutions even it has been punished for many times. Hence the focal area of the search should be moved back to the surrounding area of the currently best candidate at certain periods so as to detect the globally optimal solution if it resides at the same interval as the local minimum (see Fig. 2(c)). Meanwhile, the interval of each dimension will be reallocated according to the revised search space, whose intent is to remedy the shortcoming that the globally optimal solution is unwittingly penalized due to the inappropriate interval partitioning.

To better adapt the search space, a simple yet efficient boundary revision approach is proposed to be an important component of the cooperatively adaptive mechanism in the AdaGuiDE, which is triggered once the search has stuck into a guided local minimum for a relatively long period. Accordingly, the following operations are executed consecutively during the revision process:

1. Initially, a certain number of individuals are randomly sampled from the current population and being formed as a cluster for reference at the following step. After sampling, those selected individuals perform a neighborhood search following by (15), respectively. ϵ is the control parameter to constrain the neighborhood search. Existing members in the cluster are replaced by their offspring if the performance of their offspring excels that of their corresponding parents by comparing the original cost of practical tasks without considering penalty values.

$$x'_i = x_i \pm \varepsilon \times (U - L) \times rand(0, 1) \tag{15}$$

2. Besides, a relaxation factor β is introduced to extend both two sides of the originally local best candidate in each dimension to be the soft boundary z_j^+ and z_j^- shown as follows.

$$z_j^{\pm} = x_j \pm \beta \times \left(U_j - L_j\right) \tag{16}$$

where x_j is the position of the originally local best candidate S_* in dimension j, L_j and U_j are the original lower bound and upper bound.

3. Before updating boundaries, it will check whether those new offspring generated by the neighborhood search outperform the originally local best candidate. If so, as

depicted in (17) and (18), the revised search space is set between the new currently best candidate x'_{best} and the originally best candidate.

$$L'_j = \min\left\{z_j^-, x'_{j,best}\right\} \quad (17)$$

$$U'_j = \max\left\{z_j^+, x'_{j,best}\right\} \quad (18)$$

Otherwise, there are three cases possibly occurring for revising boundaries in each dimension. As clearly shown in Fig. 3, the star represents the originally best candidate while the triangles are the sampled individuals in Step 1. The three possible scenarios of relative positions in j^{th} dimension between the originally best candidate and the sampled cluster are concluded. Figure 3(a) presents the value of j^{th} dimension of the currently best candidate is smaller than the lower bound of the sampled cluster, and Fig. 3(b) shows the value of the j^{th} dimension of the currently best candidate is between the upper and lower bounds of the sampled cluster. Lastly, Fig. 3(c) demonstrates the value of the j^{th} dimension of the currently best candidate is greater than the upper bound of the sampled cluster.

Except for the currently best individual, other candidates in the sampled cluster are also relatively good individuals when compared with the individual who has been eliminated during the evolutionary process, possibly implying valuable information for further investigation. Thus, the revised search region includes the surrounding area between the currently best candidate and the sampled cluster, whose boundaries are defined as (19) and (20). For the individual outside the revised boundaries in the current population, it will be moved to the updated search space for satisfying the boundary constraints.

$$L'_j = \min\left\{z_j^-, c_j^-\right\} \quad (19)$$

$$U'_j = \max\left\{z_j^+, c_j^+\right\} \quad (20)$$

where c_j^+ and c_j^- are the upper bound and lower bound of the sampling cluster.

4. Followed by the boundary revision, the interval of the penalty mechanism in the guided DE is reallocated in terms of the revised search region for further guidance that can realize the higher resolution of the penalty-based search. That is the new search space in each dimension is equally divided into K independent intervals again, and the penalty factor p_{jk} of all interval features will be reset to 0.
5. In addition, it can be fairly considered that the revised search region has been roughly explored when the search cannot obtain a better solution after several generations. At that time, the search boundaries will be recovered back to the initial boundaries. Meanwhile, the interval features and penalty factors are also reset for adapting the latest search environment. Lastly, the revision and recovering of the search boundaries are executed alternately once the search stuck into certain local minima for several generations, and ultimately realizing a flexible search mechanism on handling a diversity of problems.

3.4 The dynamic contribution-based mechanism

The previous investigations [57] claimed that there is no optimal parameter setting or certain operation strategy being adopted to tackle all kinds of problems. Consequently, assigning appropriate strategies and their corresponding parameters typically relies either on running the trial-and-error scheme to a particular problem or designing a self-adaptive mechanism for the widely applicability on more types of tasks. Generally speaking, the self-adaptive mechanism for the conventional DE can be considered from two aspects including the macro and micro views. From the macro view, dynamically selecting strategies for operations including mutation, selection and crossover not only can flexibly handle various problems at hand, but also can speed up the convergence and avoid trapping into local minima for a particular problem at different stages during the search process. On the other hand, the control parameters of strategies may

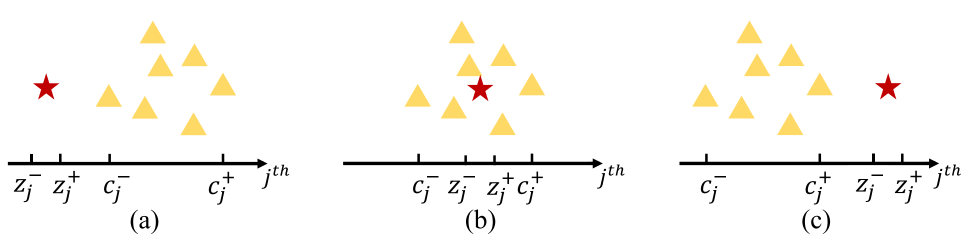


Fig. 3 Three scenarios of relative positions in j^{th} dimension between the currently best candidate and the sampled cluster

differ on various tasks and search stages, or even are specified for each individual, which can be seen as the micro view adaptation. In this section, learnt from the adaptive mechanism on the CSDE [22], a dynamic contribution-based mechanism is described to implement the adaptive AdaGuiDE from both two views mentioned above, which optimizes operations and their control parameters by counting the historical contributions of each strategy in the past learning period.

3.4.1 Adapting the mutation strategy

Due to the unpredictable nature of problems and the complex shape of the search space, a single mutation strategy chosen by the trial-and-error scheme may not be effectively utilized throughout the overall search process. Conversely, the more ideal way to enhance the applicability of mutation strategies is that a suitable mutation strategy can be picked from the provided strategy pool and periodically be switched to another strategy in terms of the historical performance of each strategy. For instance, exploration strategies should be applied to the early stage of the search for locating more promising areas whereas exploitation strategies focus on the neighborhood search at the later stage. More importantly, designing an effectively adaptive scheme to select appropriate search strategies is the key feature to achieve enhancements on challenging tasks. In particular, it is worth noting that some existing adaptive schemes [22] inaccurately count the invalid contributions of search strategies due to the inappropriately adaptive rule so that the mutation strategies will be mistakenly selected and cannot adapt to the current search. More specifically, the enhancements of different individuals are equally treated and counted the same contribution to their corresponding mutation strategies, which obviously ignores the significance of the mutation strategy who generates good individuals since poor individuals are generally more likely to achieve enhancements, yet it cannot say that the mutation strategy who generates those poor individuals is more suitable at the current stage.

Therefore, to carefully recognize the valid contributions of each pending mutation strategy described in Section 3.1, the mutation strategy adaptation scheme of the AdaGuiDE approach basically learns from the following aspects: 1) The contribution score of the corresponding mutation strategy will increase by one if its candidate is in the top candidate list and also obtains the enhancement against the best record of the candidate itself. 2) If an individual in the top candidate list outperforms the currently best candidate, an extra bonus will be added to the contribution score of the corresponding mutation strategy. 3) For the candidates outside the top candidate list, an award will be given if they have significant enhancement likes the ranking of the candidate has been remarkably improved.

After each generation, the total contribution score $CS_{m,g}$ of the strategy m at the generation g is summarized, and then the selection probability $SP_{m,g+1}$ of the strategy m at the next generation $g+1$ is calculated by (21). The strategy who got more contributions will be selected with higher probability at the next generation. Besides, the contribution score and selection probability will be reset every certain generations for reducing the influence of the early performance.

$$SP_{m,g+1} = \frac{CS_{m,g}}{\sum_{i=1}^{M} CS_{i,g}} \tag{21}$$

For each individual, the mutation strategy is decided by the Roulette Wheel Selection scheme and selection probabilities. After that, a well-known binomial crossover strategy is adopted to execute the crossover operation.

3.4.2 Adjusting the control parameters

Since the adaptive parameter scheme in [22] considering both the individual-independence factor M_g and modulo-based periodic factor P_g can effectively adjust the value of control parameters in terms of the individual performance and current evolutionary process, the control parameters and crossover rate CR_i of the "DE/Current-to-pbest/1" and "DE/Pbest-to-rand/1" in the AdaGuiDE follow the same adaptive manner in [22]. Besides, the parameters F_i^T and K_i^T in the "DE/Current-to-random/1" are updated by the same rules of F_i^R in the "DE/Pbest-to-rand/1" and F_i^C in the "DE/Current-to-pbest/1", respectively. Lastly, the update rule of σ_i in the "AMPO Local search" strategy also follows [56].

4 Empirical results

To carefully evaluate the performance of the proposed AdaGuiDE framework, experiments were conducted on three sets of well-known single objective bound constrained benchmark functions of different dimensions including the CEC 2014 benchmark set [58], CEC 2021 benchmark set [59] and classical benchmark set (see Appendix A). The selected benchmark datasets cover the most common characteristics of real-life optimization problems such as uni/multi-modal, hybrid/composition mode with different subcomponents, differentiable/non-differentiable, etc. The results are compared against those of the AdaGuiDE and popular meta-heuristic algorithms including the Genetic Algorithm (GA) [60], particle swarm optimization (PSO) [17], Whale Optimization problem (WOA) [46], Differential Evolution (DE) [20], Adaptive Multi-population Optimization (AMPO) [56] and CSDE [22]. Furthermore, there are six other SOTA algorithms being evaluated and compared in

Table 1 Comparative results against the state-of-the-art algorithms on functions $F1$-$F30$ with D=50 (CEC2014)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	5.48E+05	**1.66E+04**	8.79E+04	8.46E+05	1.43E+08	3.12E+08	8.89E+06	2.20E+06
	Std.	1.60E+05	9.22E+03	5.29E+04	6.72E+05	4.23E+07	0.00E+00	2.44E+07	2.34E+06
F2	Mean	2.30E+04	**2.00E+02**	2.00E+02	4.78E+03	1.97E+09	3.71E+10	9.98E+02	9.73E+02
	Std.	3.03E+04	0.00E+00	2.92E-05	4.19E+03	2.07E+09	0.00E+00	1.08E+03	1.42E+03
F3	Mean	3.10E+02	**3.00E+02**	3.00E+02	2.73E+03	2.87E+05	6.30E+04	3.03E+02	3.71E+02
	Std.	7.55E+00	0.00E+00	2.50E-02	1.43E+03	8.67E+04	0.00E+00	9.67E+00	2.08E+02
F4	Mean	5.17E+02	**4.16E+02**	4.42E+02	5.14E+02	1.02E+03	2.21E+03	4.97E+02	4.96E+02
	Std.	2.99E+01	2.37E+01	3.90E+01	4.01E+01	1.91E+02	0.00E+00	3.32E+00	2.44E+00
F5	Mean	5.20E+02	5.20E+02	5.20E+02	**5.20E+02**	5.21E+02	5.21E+02	5.21E+02	5.20E+02
	Std.	7.85E-02	1.18E-01	1.69E-01	4.23E-05	5.43E-02	0.00E+00	9.71E-02	1.95E-01
F6	Mean	6.29E+02	**6.00E+02**	6.08E+02	6.01E+02	6.48E+02	6.53E+02	6.05E+02	6.16E+02
	Std.	2.27E+00	1.83E-01	2.36E+00	1.37E+00	3.56E+00	0.00E+00	2.77E+00	8.29E+00
F7	Mean	7.00E+02	**7.00E+02**	7.00E+02	7.00E+02	7.43E+02	8.76E+02	7.01E+02	**7.00E+02**
	Std.	6.72E-02	0.00E+00	5.88E-03	6.66E-03	3.62E+01	0.00E+00	3.67E-01	0.00E+00
F8	Mean	8.03E+02	8.27E+02	**8.00E+02**	8.67E+02	1.16E+03	1.06E+03	8.26E+02	8.17E+02
	Std.	1.80E+00	6.54E+00	0.00E+00	1.06E+01	8.69E+01	0.00E+00	4.41E+00	4.71E+00
F9	Mean	1.02E+03	**9.25E+02**	9.79E+02	9.63E+02	1.33E+03	1.30E+03	9.46E+02	9.57E+02
	Std.	2.01E+01	7.21E+00	1.64E+01	1.41E+01	9.16E+01	0.00E+00	1.10E+01	1.91E+01
F10	Mean	1.03E+03	3.33E+03	**1.00E+03**	3.10E+03	8.82E+03	8.89E+03	1.54E+03	1.57E+03
	Std.	4.54E+01	7.19E+02	1.75E-01	4.38E+02	8.98E+02	0.00E+00	3.00E+02	2.70E+02
F11	Mean	5.26E+03	6.08E+03	5.36E+03	**4.05E+03**	1.32E+04	1.08E+04	5.98E+03	5.70E+03
	Std.	4.86E+02	8.41E+02	5.03E+02	6.79E+02	2.19E+03	0.00E+00	7.72E+02	6.26E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	4.78E-02	1.21E-01	8.75E-02	7.26E-03	1.56E+00	0.00E+00	3.77E-01	2.59E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**
	Std.	3.07E-02	4.86E-02	4.91E-02	8.49E-02	3.59E-01	0.00E+00	4.98E-02	3.16E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.43E+03	1.46E+03	1.40E+03	**1.40E+03**
	Std.	1.89E-02	3.31E-02	3.73E-02	3.05E-02	4.15E+01	0.00E+00	1.23E-01	2.58E-02
F15	Mean	1.51E+03	**1.51E+03**	1.51E+03	1.51E+03	1.81E+03	3.87E+05	1.51E+03	1.51E+03
	Std.	2.20E+00	7.51E-01	1.54E+00	1.61E+00	2.87E+02	0.00E+00	1.67E+00	3.52E+00
F16	Mean	1.62E+03	1.62E+03	**1.62E+03**	1.62E+03	1.62E+03	1.62E+03	1.62E+03	1.62E+03
	Std.	5.52E-01	1.00E+00	4.99E-01	7.25E-01	3.41E-01	0.00E+00	4.18E-01	7.75E-01
F17	Mean	8.47E+03	**2.44E+03**	9.62E+03	2.30E+04	4.34E+07	4.34E+07	1.24E+05	1.56E+05
	Std.	2.86E+03	2.74E+02	4.80E+03	9.06E+03	8.58E+06	0.00E+00	1.21E+05	1.81E+05

Table 1 continued

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F18	Mean	1.90E+03	**1.85E+03**	1.94E+03	2.18E+03	8.89E+06	5.18E+08	1.97E+03	1.98E+03
	Std.	1.84E+01	1.35E+01	9.51E+01	2.55E+02	2.69E+06	0.00E+00	5.91E+01	4.92E+01
F19	Mean	1.93E+03	1.91E+03	**1.91E+03**	1.92E+03	2.09E+03	1.99E+03	1.91E+03	1.93E+03
	Std.	1.11E+01	1.24E+00	1.47E+00	1.09E+01	4.13E+01	0.00E+00	1.73E+00	1.00E+01
F20	Mean	2.10E+03	**2.01E+03**	2.08E+03	4.64E+03	2.02E+05	1.11E+05	2.08E+03	2.11E+03
	Std.	1.17E+01	2.86E+00	3.66E+01	1.28E+03	3.57E+04	0.00E+00	3.39E+01	3.40E+01
F21	Mean	4.28E+03	**2.52E+03**	3.64E+03	2.58E+04	3.02E+07	1.59E+07	6.72E+04	4.59E+04
	Std.	4.36E+02	1.00E+02	9.69E+02	1.14E+04	1.50E+07	0.00E+00	8.50E+04	3.63E+04
F22	Mean	2.63E+03	2.35E+03	2.69E+03	2.91E+03	4.12E+03	5.32E+03	**2.32E+03**	2.36E+03
	Std.	1.44E+02	5.91E+01	1.67E+02	2.58E+02	4.07E+02	0.00E+00	7.56E+01	1.45E+02
F23	Mean	2.64E+03	2.64E+03	2.64E+03	2.64E+03	2.82E+03	2.86E+03	**2.50E+03**	**2.50E+03**
	Std.	1.85E-02	0.00E+00	0.00E+00	5.65E-01	2.50E+01	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.68E+03	2.67E+03	2.66E+03	2.66E+03	2.73E+03	2.72E+03	**2.60E+03**	**2.60E+03**
	Std.	9.74E-01	1.78E+00	5.64E+00	7.31E+00	1.29E+01	0.00E+00	0.00E+00	0.00E+00
F25	Mean	2.71E+03	2.71E+03	2.71E+03	2.71E+03	2.79E+03	2.74E+03	**2.70E+03**	**2.70E+03**
	Std.	8.21E-01	1.17E+00	4.19E+00	9.52E+00	1.52E+01	0.00E+00	0.00E+00	0.00E+00
F26	Mean	**2.70E+03**	2.77E+03	2.71E+03	2.80E+03	2.82E+03	2.81E+03	2.73E+03	2.75E+03
	Std.	2.61E-02	4.70E+01	2.99E+01	1.51E-02	4.48E+00	0.00E+00	4.69E+01	4.99E+01
F27	Mean	3.16E+03	3.00E+03	3.22E+03	3.10E+03	4.31E+03	4.25E+03	**2.90E+03**	**2.90E+03**
	Std.	1.38E+02	1.18E+01	4.85E+01	7.53E+01	1.30E+02	0.00E+00	0.00E+00	0.00E+00
F28	Mean	4.11E+03	4.07E+03	3.96E+03	4.43E+03	9.92E+03	5.99E+03	**3.00E+03**	**3.00E+03**
	Std.	7.45E+01	1.06E+02	2.79E+02	4.77E+02	1.20E+03	0.00E+00	0.00E+00	0.00E+00
F29	Mean	4.41E+03	3.69E+03	1.73E+04	4.15E+03	1.71E+07	7.30E+06	**3.10E+03**	**3.10E+03**
	Std.	2.79E+02	2.46E+01	7.14E+03	2.51E+02	3.11E+07	0.00E+00	0.00E+00	0.00E+00
F30	Mean	1.40E+04	1.26E+04	1.23E+04	4.17E+04	2.82E+05	6.78E+04	4.16E+03	**4.07E+03**
	Std.	6.89E+02	4.26E+02	1.40E+03	1.21E+04	1.24E+05	0.00E+00	2.90E+03	2.60E+03

The bold entries are applied to highlight the best results

Table 2 The significant test and ranking scores on the state-of-the-art algorithms (CEC2014)

Dim.		NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
10-D	+/=/- (AdaGuiDE)	5/6/19	2/8/20	4/3/23	19/5/6	29/1/0	27/3/0	–	13/7/10
	+/=/- (AdaGuiDE-PS)	5/6/19	4/2/24	4/4/22	21/5/4	28/2/0	28/2/0	10/7/13	–
	Ranking score	497	542	**615**	282	152	175	403	401
30-D	+/=/- (AdaGuiDE)	13/4/13	10/3/17	11/5/14	19/3/8	30/0/0	30/0/0	–	3/16/11
	+/=/- (AdaGuiDE-PS)	17/2/11	11/3/16	11/8/11	23/1/6	30/0/0	30/0/0	11/16/3	–
	Ranking score	410	**580**	458	334	150	160	454	516
50-D	+/=/- (AdaGuiDE)	16/1/13	10/4/16	11/2/17	18/3/9	30/0/0	30/0/0	–	5/17/8
	+/=/- (AdaGuiDE-PS)	15/6/9	11/3/16	11/2/17	19/3/8	30/0/0	30/0/0	8/17/5	–
	Ranking score	385	**542**	473	357	148	152	458	477
100-D	+/=/- (AdaGuiDE)	17/2/11	12/1/17	14/2/14	16/4/10	30/0/0	30/0/0	–	6/16/8
	+/=/- (AdaGuiDE-PS)	18/1/11	14/1/15	14/4/12	17/2/11	30/0/0	30/0/0	8/16/6	–
	Ranking score	358	**541**	436	405	120	180	458	477

The bold entries are applied to highlight the best results

this section. They are NL-SHADE-RSP [38], NL-SHADE-LBC [39], EA4EIG [40], DISGSA [43], HEBO [61], and LSSP [62]. More specifically, NL-SHADE-RSP and NL-SHADE-LBC are the top-ranking DE-based algorithms in the IEEE CEC2021 and CEC2022 competitions. EA4EIG is a variant of the Covariance Matrix Adaptation Evolution Strategies (CMA-ES) and achieved first place in the IEEE CEC 2022 competition. DISGSA is a novel gravitational search algorithm that obtains remarkable results on function optimization and practical applications like image segmentation. HEBO is an ensemble-based method for Bayesian optimization that won the NeurIPS 2020 black-box optimization competition while LSSP is one of the top single solver-based algorithms on the same NeurIPS 2020 competition.

To make a fair comparison, all user-controlled parameters of those compared algorithms refer to the literatures [22, 46, 56]. The GA used random tournament selection strategy, two-point crossover strategy and perturbation mutation strategy during the whole evolutionary process while the DE approach used the “DE/Current-to-best/1” strategy for mutation. Meanwhile, all algorithms are examined on each function for 30 times independently where the means and standard deviations of the fitness value $f(x_{best})$ in 30 runs are stored for comparison. In addition, the well-known Wilcoxon rank-sum tests [63] with a significance level 0.05 are vigorously conducted to reveal the statistical significance among algorithms on each dataset. To be more specific, the symbols “+”, “=” and “-” represent that the performance of the AdaGuiDE is significantly better than, similar to or worse than that of the corresponding compared algorithms, respectively. Besides, to conclude the results for the intuitive comparison, the Formula One Criterion (see Appendix B) is adopted to assign award points for each algorithm on each function based on its ranking. The algorithm with higher rankings on more functions will gain a higher score. All experiments are implemented in Python on a desktop computer installed with the Intel i9-7900X processor running at 3.3 GHz and 64 GB of RAM.

In all experiments, the population sizes NP of all algorithms are consistently specified to 50. The error value is set to 10^{-8} which means that the search has reached the global minimum when the difference between the globally best fitness value and the optimal fitness value is less than the error value. For the AdaGuiDE, it just needs to define few parameters in which the domain knowledge is not required a lot before the search. The initial control parameters of each mutation strategy and the reset cycle FP of the proposed contribution scheme follows the settings on [22]. Furthermore, concerning the guided search mechanism, the number of intervals on each dimension is set as $K = 10$ while the penalty factor λ is given at 0.25. The criterion for recognizing local minimum is set to $G_{trap} = 20$ iterations, and the boundary revision scheme is triggered when the search stays at the same local minimum every $G_{trigger} = 200$ iterations. Besides, the control factor ϵ of the neighborhood search is set as 0.05 while the relax factor is assigned to $\beta = 0.01$.

4.1 The CEC2014 benchmark functions

In this section, all algorithms are investigated on 30 benchmark functions of different dimensions including 10, 30, 50 and 100 with the maximum number of function evaluations set to 10^5, 5×10^5, 5×10^5 and 10^6, respectively.

As shown in Tables 1 and 3, the AdaGuiDE and AdaGuiDE-PS framework are carefully compared with both the SOTA optimization algorithms and some popular meta-heuristic algorithms on the 50-dimensional functions of the CEC2014 set as analytical examples. In the comparison of the SOTA algorithms, the AdaGuiDE-PS framework achieves the best results on 10 out of 30 benchmark functions, among which 7 winning functions are the most complicated problems with multiple difficult components (Table 2). Besides, there are other 8 functions that the quality of solutions is very close to that of the best compared algorithms. On the other hands, the AdaGuiDE framework also performs well on the composition type of functions and obtains high-quality solutions on the other types of functions. When compared with the classical yet popular meta-heuristic algorithms, the AdaGuiDE and AdaGuiDE-PS frameworks outperform the compared algorithms on over 20 benchmark functions while the solutions of the remaining functions approach the best performing algorithms, which demonstrates the strong capabilities of the AdaGuiDE-based frameworks to deal with complex tasks (Tables 3 and 4). The detailed analysis in terms of different natures of the functions are described as follows.

- For the uni-modal functions of $F1$-$F3$, the NL-SHADE-RSP framework collects the best results on all three functions while the AdaGuiDE and AdaGuiDE-PS framework obtain quite competitive solutions against the remaining five SOTA algorithms and six popular meta-heuristic algorithms. More specifically, the mean and standard deviation of the AdaGuiDE and its variant on $F2$ are an order of magnitude ahead of some compared algorithms, which can be fairly considered that the AdaGuiDE can obtain such good results in the most runs than others.
- For the multi-modal functions of $F4$-$F16$, except for the NL-SHADE-RSP and EA4EIG methods, the AdaGuiDE-

Table 3 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=50 (CEC2014)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.28E+08	6.93E+08	4.46E+07	6.19E+06	8.98E+06	**1.47E+06**	8.89E+06	2.20E+06
	Std.	1.43E+07	2.99E+08	1.29E+07	2.73E+06	2.50E+06	7.05E+05	2.44E+07	2.34E+06
F2	Mean	6.86E+09	5.05E+10	3.58E+07	1.14E+07	4.16E+03	6.64E+03	9.98E+02	**9.73E+02**
	Std.	4.71E+08	1.91E+10	8.06E+06	1.33E+07	3.47E+03	8.35E+03	1.08E+03	1.42E+03
F3	Mean	2.00E+05	1.38E+05	5.15E+04	2.67E+03	8.17E+02	**3.00E+02**	3.03E+02	3.71E+02
	Std.	2.00E+04	4.36E+04	7.62E+03	1.04E+03	3.10E+02	4.03E-02	9.67E+00	2.08E+02
F4	Mean	9.17E+02	8.93E+03	6.85E+02	6.44E+02	4.97E+02	4.97E+02	4.97E+02	**4.96E+02**
	Std.	2.70E+01	8.08E+03	7.54E+01	6.07E+01	1.56E+01	3.32E+00	3.32E+00	2.44E+00
F5	Mean	5.21E+02	5.20E+02	5.21E+02	5.21E+02	**5.20E+02**	5.20E+02	5.21E+02	5.20E+02
	Std.	4.69E-02	1.46E-01	1.49E-01	4.99E-02	6.93E-02	8.92E-02	9.71E-02	1.95E-01
F6	Mean	6.39E+02	6.57E+02	6.68E+02	6.05E+02	6.09E+02	6.19E+02	**6.05E+02**	6.16E+02
	Std.	9.46E-01	6.15E+00	4.75E+00	2.25E+00	1.21E+01	4.66E+00	2.77E+00	8.29E+00
F7	Mean	7.67E+02	1.20E+03	7.01E+02	7.01E+02	7.00E+02	**7.00E+02**	7.01E+02	**7.00E+02**
	Std.	3.67E+00	1.81E+02	1.05E-01	1.86E-01	1.01E-02	0.00E+00	3.67E-01	0.00E+00
F8	Mean	1.14E+03	1.16E+03	1.16E+03	8.67E+02	8.23E+02	8.27E+02	8.26E+02	**8.17E+02**
	Std.	1.24E+01	5.10E+01	5.24E+01	2.37E+01	6.45E+00	5.22E+00	4.41E+00	4.71E+00
F9	Mean	1.27E+03	1.40E+03	1.33E+03	1.17E+03	1.04E+03	9.67E+02	**9.46E+02**	9.57E+02
	Std.	1.33E+01	7.72E+01	6.36E+01	1.73E+01	5.85E+01	1.58E+01	1.10E+01	1.91E+01
F10	Mean	1.15E+04	9.04E+03	8.93E+03	4.76E+03	**1.34E+03**	2.33E+03	1.54E+03	1.57E+03
	Std.	2.68E+02	1.11E+03	1.55E+03	1.11E+03	2.16E+02	3.42E+02	3.00E+02	2.70E+02
F11	Mean	1.27E+04	9.53E+03	1.11E+04	1.24E+04	8.99E+03	6.65E+03	5.98E+03	**5.70E+03**
	Std.	4.23E+02	1.11E+03	1.30E+03	5.80E+02	1.11E+03	7.78E+02	7.72E+02	6.26E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.20E+03	1.20E+03
	Std.	3.12E-01	3.62E-01	6.19E-01	2.13E-01	4.82E-01	1.14E-01	3.77E-01	2.59E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**
	Std.	4.78E-02	1.37E+00	1.01E-01	9.11E-02	6.74E-02	4.11E-02	4.98E-02	3.16E-02
F14	Mean	1.42E+03	1.55E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	**1.40E+03**
	Std.	1.61E+00	5.62E+01	1.74E-01	4.25E-02	3.67E-02	2.33E-01	1.23E-01	2.58E-02
F15	Mean	1.85E+03	1.33E+06	1.96E+03	1.53E+03	1.51E+03	**1.51E+03**	1.51E+03	1.51E+03
	Std.	6.36E+01	1.92E+06	1.21E+02	6.89E+00	3.81E+00	1.25E+00	1.67E+00	3.52E+00
F16	Mean	1.62E+03	1.62E+03	1.62E+03	1.62E+03	1.62E+03	1.62E+03	1.62E+03	**1.62E+03**
	Std.	2.06E-01	5.22E-01	6.83E-01	2.41E-01	6.06E-01	5.73E-01	4.18E-01	7.75E-01
F17	Mean	7.14E+06	2.98E+07	2.63E+07	1.75E+06	7.51E+05	**7.51E+04**	1.24E+05	1.56E+05
	Std.	9.38E+05	3.46E+07	1.19E+07	7.79E+05	3.75E+05	3.72E+04	1.21E+05	1.81E+05
F18	Mean	1.40E+08	1.61E+09	1.46E+04	3.24E+03	2.45E+03	2.40E+03	**1.97E+03**	1.98E+03
	Std.	2.91E+07	1.50E+09	1.39E+04	1.06E+03	4.24E+02	1.63E+03	5.91E+01	4.92E+01
F19	Mean	1.99E+03	2.36E+03	2.01E+03	1.95E+03	1.95E+03	1.92E+03	**1.91E+03**	1.93E+03
	Std.	4.63E+00	2.52E+02	3.48E+01	1.98E+01	1.87E+01	2.25E+01	1.73E+00	1.00E+01
F20	Mean	6.12E+04	9.53E+04	2.44E+05	2.71E+03	2.78E+03	**2.07E+03**	2.08E+03	2.11E+03
	Std.	1.39E+04	4.96E+04	2.42E+05	1.28E+02	1.76E+02	3.03E+01	3.39E+01	3.40E+01
F21	Mean	2.94E+06	1.62E+07	7.19E+06	1.13E+06	3.86E+05	**2.85E+04**	6.72E+04	4.59E+04
	Std.	5.24E+05	1.75E+07	3.20E+06	5.28E+05	1.94E+05	2.46E+04	8.50E+04	3.63E+04
F22	Mean	3.19E+03	4.19E+03	4.60E+03	2.75E+03	2.73E+03	2.55E+03	**2.32E+03**	2.36E+03
	Std.	1.17E+02	4.81E+02	6.37E+02	1.58E+02	1.52E+02	1.63E+02	7.56E+01	1.45E+02
F23	Mean	2.70E+03	3.02E+03	2.68E+03	2.64E+03	**2.50E+03**	2.64E+03	**2.50E+03**	**2.50E+03**
	Std.	5.42E+00	1.97E+02	7.16E+01	4.34E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 3 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F24	Mean	2.73E+03	2.89E+03	2.60E+03	2.68E+03	**2.60E+03**	2.66E+03	**2.60E+03**	**2.60E+03**
	Std.	1.92E+00	6.16E+01	4.16E-01	2.96E+00	0.00E+00	4.19E+00	0.00E+00	0.00E+00
F25	Mean	2.73E+03	2.79E+03	2.70E+03	2.71E+03	**2.70E+03**	2.71E+03	**2.70E+03**	**2.70E+03**
	Std.	1.77E+00	3.99E+01	5.56E+00	1.99E+00	0.00E+00	1.97E+00	0.00E+00	0.00E+00
F26	Mean	2.71E+03	2.83E+03	2.70E+03	2.76E+03	2.70E+03	**2.70E+03**	2.73E+03	2.75E+03
	Std.	5.31E+01	1.49E+02	9.02E-02	5.01E+01	8.80E-02	4.86E-02	4.69E+01	4.99E+01
F27	Mean	4.01E+03	4.63E+03	4.93E+03	3.26E+03	**2.90E+03**	3.36E+03	**2.90E+03**	**2.90E+03**
	Std.	2.64E+01	1.32E+02	3.15E+02	8.01E+01	0.00E+00	7.43E+01	0.00E+00	0.00E+00
F28	Mean	4.53E+03	7.32E+03	8.92E+03	4.23E+03	**3.00E+03**	3.92E+03	**3.00E+03**	**3.00E+03**
	Std.	6.30E+01	8.61E+02	1.66E+03	2.67E+02	0.00E+00	4.21E+01	0.00E+00	0.00E+00
F29	Mean	1.35E+06	1.74E+08	6.61E+07	1.15E+04	**3.10E+03**	3.53E+07	**3.10E+03**	**3.10E+03**
	Std.	2.15E+05	1.11E+08	4.46E+07	7.05E+03	0.00E+00	9.17E+04	0.00E+00	0.00E+00
F30	Mean	4.04E+04	1.93E+06	2.45E+05	1.64E+04	**3.49E+03**	1.16E+04	4.16E+03	4.07E+03
	Std.	3.57E+03	2.06E+06	3.67E+05	3.25E+03	1.54E+03	6.33E+02	2.90E+03	2.60E+03

The bold entries are applied to highlight the best results

PS attains the outstanding mean value and top rankings against other compared algorithms on the functions such as $F4$, $F6$, $F9$, $F11$ and $F14$ in which the AdaGuiDE shows great potentials on handling the problems full of local minima.

- For the hybrid functions of $F17$-$F22$, the average solution qualities of the AdaGuiDE and AdaGuiDE-PS are very close to the first-ranking approach even though the AdaGuiDE-based frameworks do not take the first place. When compared with the classical algorithms, the AdaGuiDE is ranked first in half of functions including $F18$, $F19$ and $F22$ while it gets the second place for all remaining functions in terms of the mean fitness values.
- For the composition functions of $F23$-$F30$, it is evident that the AdaGuiDE-PS obtains the best performance than those of both the classical and SOTA algorithms on all functions except the $F26$ and $F30$ on which the AdaGuiDE-PS generates the second best result on $F30$. It is worth noting that the proposed frameworks outperform those top-ranking approaches in the recent IEEE competitions on the composition type of benchmark functions that are common in the real-world optimization tasks.
- In general, it clearly reveals that the AdaGuiDE and AdaGuiDE-PS frameworks can better tackle the problems with a diversity of interesting features and different subcomponents where most of the winning functions achieved by the AdaGuiDE and its variant include such features.

In addition, the detailed results for the different dimensions including 10-D, 30-D and 100-D can be referred to the Appendix C. To conclude the performance of the AdaGuiDE on different dimensions, Tables 2 and 4 show a summary of all evaluation results on the CEC2014 set in which the results

Table 4 The significant test and ranking scores on popular meta-heuristic algorithms (CEC2014)

Dim.		GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
10-D	+/ = /−	29/1/0	28/0/2	28/2/0	12/8/10	7/9/14	6/7/17	–	13/7/10
	Ranking score	299	229	225	466	549	**603**	512	–
30-D	+/ = /−	30/0/0	28/0/2	29/0/1	24/1/5	12/10/8	15/4/11	–	3/16/11
	Ranking score	274	227	258	405	540	582	**583**	–
50-D	+/ = /−	29/1/0	28/0/2	27/1/2	26/3/1	13/8/9	13/9/8	–	5/17/8
	Ranking score	260	228	277	372	565	555	**605**	–
100-D	+/ = /−	29/1/0	27/2/1	28/0/2	29/0/1	13/11/6	15/4/11	–	6/16/8
	Ranking score	263	223	326	351	574	543	**608**	–

The bold entries are applied to highlight the best results

Table 5 Comparative results against the state-of-the-art algorithms on functions $F1$-$F10$ with the 'BSR' transformation on 20-D (CEC2021)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	**1.00E+02**	**1.00E+02**	**1.00E+02**	1.08E+03	9.91E+07	6.40E+07	**1.00E+02**	**1.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.46E+03	1.11E+07	0.00E+00	0.00E+00	0.00E+00
F2	Mean	**1.12E+03**	1.23E+03	1.17E+03	1.52E+03	3.44E+03	3.40E+03	1.14E+03	1.14E+03
	Std.	2.89E+01	1.69E+02	7.19E+01	2.37E+02	4.90E+02	0.00E+00	4.47E+01	5.85E+01
F3	Mean	7.23E+02	7.24E+02	7.23E+02	7.39E+02	8.62E+02	8.70E+02	7.23E+02	**7.23E+02**
	Std.	9.25E-01	1.89E+00	1.17E+00	6.28E+00	1.81E+01	0.00E+00	1.28E+00	1.07E+00
F4	Mean	**1.90E+03**	1.90E+03	1.90E+03	1.90E+03	1.92E+03	2.14E+03	1.90E+03	1.90E+03
	Std.	1.63E-01	3.29E-01	1.86E-01	4.42E-01	3.75E+00	0.00E+00	2.69E-01	1.61E-01
F5	Mean	2.11E+03	1.81E+03	1.85E+03	3.38E+03	1.29E+06	5.91E+05	1.88E+03	**1.78E+03**
	Std.	1.55E+02	5.23E+01	9.16E+01	1.27E+03	8.31E+05	0.00E+00	1.13E+02	6.25E+01
F6	Mean	**1.60E+03**	1.60E+03	1.60E+03	1.72E+03	2.14E+03	2.82E+03	1.60E+03	1.60E+03
	Std.	2.97E-01	2.61E-01	2.85E-01	9.40E+01	1.74E+02	0.00E+00	2.80E+00	4.15E-01
F7	Mean	2.21E+03	2.12E+03	2.14E+03	2.32E+03	1.74E+06	9.21E+05	2.14E+03	**2.11E+03**
	Std.	5.64E+01	4.29E+01	5.15E+01	1.22E+02	1.75E+06	0.00E+00	6.94E+01	8.59E+00
F8	Mean	**2.29E+03**	2.30E+03	2.30E+03	2.30E+03	2.45E+03	5.38E+03	2.30E+03	2.30E+03
	Std.	1.54E+01	0.00E+00	2.15E-01	6.09E-01	1.22E+02	0.00E+00	0.00E+00	0.00E+00
F9	Mean	**2.50E+03**	2.79E+03	2.81E+03	2.80E+03	2.93E+03	2.92E+03	2.80E+03	2.80E+03
	Std.	0.00E+00	1.15E+01	5.82E+00	1.34E+01	2.59E+01	0.00E+00	4.36E+00	3.38E+00
F10	Mean	**2.91E+03**	2.91E+03	2.91E+03	2.91E+03	3.01E+03	2.97E+03	2.91E+03	2.91E+03
	Std.	6.67E+00	8.97E-03	1.31E+01	8.39E-01	9.85E+00	0.00E+00	7.87E-01	1.98E+00

The bold entries are applied to highlight the best results

Table 6 The significant test and ranking scores on the state-of-the-art algorithms (CEC2021)

Transformation		NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
B (10 Dim.)	+/ = /− (AdaGuiDE)	6/3/1	8/2/0	10/0/0	10/0/0	10/0/0	10/0/0	–	10/0/0
	+/ = /− (AdaGuiDE-PS)	4/0/6	6/1/3	10/0/0	10/0/0	10/0/0	10/0/0	0/0/10	–
	Ranking score	210	145	172	97	48	52	**250**	**250**
S (10 Dim.)	+/ = /− (AdaGuiDE)	0/1/9	2/5/3	1/1/8	10/0/0	10/0/0	10/0/0	–	3/2/5
	+/ = /− (AdaGuiDE-PS)	0/1/9	4/1/5	0/2/8	10/0/0	10/0/0	10/0/0	5/2/3	–
	Ranking score	**250**	144	195	77	46	54	138	158
BS (10 Dim.)	+/ = /− (AdaGuiDE)	0/1/9	2/6/2	1/1/8	10/0/0	10/0/0	10/0/0	–	3/2/5
	+/ = /− (AdaGuiDE-PS)	0/1/9	4/3/3	0/3/7	10/0/0	10/0/0	10/0/0	5/2/3	–
	Ranking score	**250**	134	198	84	46	54	159	152
SR (10 Dim.)	+/ = /− (AdaGuiDE)	2/1/7	2/2/6	2/3/5	10/0/0	10/0/0	10/0/0	–	5/4/1
	+/ = /− (AdaGuiDE-PS)	2/2/6	1/1/8	0/4/6	9/1/0	10/0/0	10/0/0	1/4/5	–
	Ranking score	**188**	175	184	78	46	56	151	147
BSR (10 Dim.)	+/ = /− (AdaGuiDE)	2/3/5	2/4/4	2/3/5	10/0/0	10/0/0	10/0/0	–	3/6/1
	+/ = /− (AdaGuiDE-PS)	1/2/7	1/2/7	0/4/6	10/0/0	10/0/0	10/0/0	1/6/3	–
	Ranking score	**190**	163	187	78	46	56	161	144
B (20 Dim.)	+/ = /− (AdaGuiDE)	6/3/1	9/1/0	10/0/0	10/0/0	10/0/0	10/0/0	–	10/0/0
	+/ = /− (AdaGuiDE-PS)	4/0/6	7/0/3	10/0/0	10/0/0	10/0/0	10/0/0	0/0/10	–
	Ranking score	210	145	153	103	56	44	236	**250**
S (20 Dim.)	+/ = /− (AdaGuiDE)	0/1/9	3/2/5	1/0/9	9/0/1	10/0/0	10/0/0	–	1/1/8
	+/ = /− (AdaGuiDE-PS)	0/0/10	4/4/2	0/2/8	9/0/1	10/0/0	10/0/0	8/1/1	–
	Ranking score	**250**	134	194	87	52	48	124	152
BS (20 Dim.)	+/ = /− (AdaGuiDE)	0/1/9	2/3/5	1/0/9	8/1/1	10/0/0	10/0/0	–	1/1/8
	+/ = /− (AdaGuiDE-PS)	0/0/10	4/2/4	0/1/9	9/0/1	10/0/0	10/0/0	8/1/1	–
	Ranking score	**250**	137	186	87	52	48	126	149
SR (20 Dim.)	+/ = /− (AdaGuiDE)	2/1/7	1/2/7	3/1/6	9/1/0	10/0/0	10/0/0	–	1/3/6
	+/ = /− (AdaGuiDE-PS)	2/2/6	2/4/4	2/4/4	9/1/0	10/0/0	10/0/0	6/3/1	–
	Ranking score	**213**	151	173	87	56	44	144	166
BSR (20 Dim.)	+/ = /− (AdaGuiDE)	2/2/6	1/2/7	2/4/4	8/2/0	10/0/0	10/0/0	–	1/3/6
	+/ = /− (AdaGuiDE-PS)	2/1/7	2/4/4	2/6/2	9/1/0	10/0/0	10/0/0	6/3/1	–
	Ranking score	**213**	154	151	87	48	52	133	190

The bold entries are applied to highlight the best results

Table 7 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F10$ with the 'BSR' transformation on 20-D (CEC2021)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	4.55E+08	3.76E+09	9.09E+03	**1.00E+02**	**1.00E+02**	**1.00E+02**	**1.00E+02**	**1.00E+02**
	Std.	5.68E+07	2.83E+09	4.59E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F2	Mean	3.25E+03	3.79E+03	3.69E+03	1.24E+03	**1.13E+03**	1.21E+03	1.14E+03	1.14E+03
	Std.	1.81E+02	6.07E+02	4.71E+02	8.49E+01	4.03E+01	1.26E+02	4.47E+01	5.85E+01
F3	Mean	8.47E+02	8.76E+02	9.39E+02	**7.22E+02**	7.22E+02	7.23E+02	7.23E+02	7.23E+02
	Std.	7.58E+00	6.79E+01	5.49E+01	2.17E+00	8.93E-01	3.71E+00	1.28E+00	1.07E+00
F4	Mean	1.91E+03	1.50E+04	1.94E+03	1.90E+03	1.90E+03	1.90E+03	1.90E+03	**1.90E+03**
	Std.	1.06E+00	2.83E+04	1.54E+01	3.83E-01	4.83E-01	2.10E-01	2.69E-01	1.61E-01
F5	Mean	1.84E+05	8.96E+05	2.41E+05	7.58E+03	3.52E+04	**1.77E+03**	1.88E+03	1.78E+03
	Std.	5.21E+04	7.04E+05	2.12E+05	3.24E+03	2.73E+04	7.44E+01	1.13E+02	6.25E+01
F6	Mean	1.74E+03	2.25E+03	2.32E+03	1.63E+03	1.61E+03	1.63E+03	1.60E+03	**1.60E+03**
	Std.	1.79E+01	2.31E+02	2.57E+02	5.81E+01	3.02E+01	5.47E+01	2.80E+00	4.15E-01
F7	Mean	4.79E+04	2.64E+05	2.97E+05	2.35E+03	2.90E+03	**2.10E+03**	2.14E+03	2.11E+03
	Std.	1.62E+04	3.15E+05	1.99E+05	1.06E+02	8.67E+02	5.18E+00	6.94E+01	8.59E+00
F8	Mean	2.82E+03	4.22E+03	3.63E+03	2.30E+03	2.30E+03	2.97E+03	2.30E+03	**2.30E+03**
	Std.	9.61E+02	1.46E+03	1.54E+03	4.01E-01	4.32E-01	6.04E+02	0.00E+00	0.00E+00
F9	Mean	2.88E+03	2.96E+03	3.04E+03	2.82E+03	2.82E+03	2.82E+03	2.80E+03	**2.80E+03**
	Std.	6.26E+00	4.65E+01	6.71E+01	7.38E+00	8.46E+00	5.87E+00	4.36E+00	3.38E+00
F10	Mean	2.93E+03	3.20E+03	3.00E+03	2.93E+03	2.93E+03	2.91E+03	2.91E+03	**2.91E+03**
	Std.	3.66E+00	3.75E+02	3.69E+01	2.14E+01	2.53E+01	7.14E-03	7.87E-01	1.98E+00

The bold entries are applied to highlight the best results

Table 8 The significant test and ranking scores on popular meta-heuristic algorithms (CEC2021)

Transformation		GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
B (10 Dim.)	+/ = /−	10/0/0	10/0/0	3/7/0	7/3/0	0/10/0	6/4/0	–	10/0/0
	Ranking score	68	72	177	152	**250**	173	**250**	–
S (10 Dim.)	+/ = /−	10/0/0/	10/0/0	10/0/0	3/2/5	1/2/7	1/1/8	–	3/2/5
	Ranking score	90	76	74	148	213	**216**	170	–
BS (10 Dim.)	+/ = /−	10/0/0/	10/0/0	10/0/0	2/4/4	1/2/7	1/1/8	–	3/2/5
	Ranking score	88	78	76	153	**206**	**206**	180	–
SR (10 Dim.)	+/ = /−	10/0/0/	10/0/0	10/0/0	2/7/1	2/5/3	3/5/2	–	5/4/1
	Ranking score	94	76	70	154	180	174	**209**	–
BSR (10 Dim.)	+/ = /−	10/0/0	10/0/0	10/0/0	4/5/1	2/6/2	3/6/1	–	3/6/1
	Ranking score	94	74	72	151	186	171	**209**	–
B (20 Dim.)	+/ = /−	10/0/0	10/0/0	4/6/0	8/2/0	0/10/0	7/3/0	–	10/0/0
	Ranking score	70	70	210	134	**250**	142	**250**	–
S (20 Dim.)	+/ = /−	10/0/0	10/0/0	10/0/0	4/3/3	3/1/6	3/4/3	–	1/1/8
	Ranking score	96	86	76	160	199	165	**206**	–
BS (20 Dim.)	+/ = /−	10/0/0	10/0/0	10/0/0	4/2/4	0/4/6	2/5/3	–	1/1/8
	Ranking score	94	68	78	164	**199**	171	196	–
SR (20 Dim.)	+/ = /−	10/0/0	10/0/0	10/0/0	7/2/1	4/3/3	4/2/4	–	1/3/6
	Ranking score	100	68	74	155	183	185	**205**	–
BSR (20 Dim.)	+/ = /−	10/0/0	10/0/0	10/0/0	6/3/1	3/4/3	4/2/4	–	1/3/6
	Ranking score	102	68	74	153	176	185	**212**	–

The bold entries are applied to highlight the best results

of the significant test and ranking score of compared algorithms are given. Except for the NL-SHADE-RSP method, the AdaGuiDE and AdaGuiDE algorithms significantly excel all compared algorithms on 30-D, 50-D and 100-D in which the similar conclusion on 50-D can be drawn on both 30-D and 100-D. More specifically, the search capability of the AdaGuiDE is remarkably exhibited when the dimension increases and the nature of problems tends to be complicated. For the experiment on 10-D, the ranking score of the AdaGuiDE is still mainly contributed by the hybrid and composition functions. Generally speaking, the AdaGuiDE demonstrates a good scalability on higher dimensional tasks with complex components, which implies the possibility to extend the AdaGuiDE to optimize large scale applications such as portfolio optimization and travelling salesman problem.

4.2 The CEC2021 benchmark functions

The CEC2021 set originates from 10 basic functions with different features including uni-modal, multi-modal, hybrid and composition, then respectively being extended by 5 transformations including the Basic (B), Shift (S), Bias and Shift (BS), Shift and Rotation (SR), and Bias, Shift and Rotation (BSR). That is in total 50 benchmark functions are examined on 10 and 20 dimensions with the maximum number of function evaluations set to 2×10^5 and 10^6.

As discussed in previous sections, most real-world optimization problems are complicated and hardly perform as the uni-modal functions. Therefore, the basic function being added transformations such as bias, shift and rotation will be closer to real-life applications. Tables 5 and 7 depict detailed results of all compared algorithms on 20-dimensional benchmark functions with the BSR transformation for which the highlights are summarized as follows.

- For the uni-modal function $F1$, the AdaGuiDE and AdaGuiDE-PS attain the globally optimal solution on all runs.
- For the multi-modal functions of $F2$-$F4$, the AdaGuiDE-PS beats all SOTA algorithms on $F3$ while it gets the second place on $F2$ and $F4$ in which their solutions are very approaching to the best one.
- For the hybrid functions of $F5$-$F7$, the AdaGuiDE-PS is ranked first in terms of the mean value on $F5$ and $F7$ when compared with the SOTA optimization algorithms while the solutions of AdaGuiDE-PS on $F6$ are very competitive against the best algorithm. On the other hand, even though the CSDE ranks first on two functions, the AdaGuiDE-based frameworks are not significantly different from the CSDE by conducting the significant test.
- For the composition functions of $F8$-$F10$, it clearly demonstrates that the AdaGuiDE-PS significantly outperforms other classical algorithms while the solution quality of the AdaGuiDE-PS is very close to the NL-SHADE-RSP that is the winner of IEEE CEC2021 competition, which suggests again that the AdaGuiDE enjoys more advantages to tackling such complicated functions.

For the detailed performance of benchmark functions with the mentioned 5 transformations on 10-D and 20-D, it can be checked in the Appendix D. To compare the performance on the 10-dimensional functions, Table 6 demonstrates that the AdaGuiDE achieves the highest scores on the basic type of benchmarking functions against the SOTA algorithms. Meanwhile, the ranking scores of AdaGuiDE-based frameworks are competitive when compared with the NL-SHADE-LBC and EA4EIG algortihms that are the winners of the IEEE competition. Additionally, Tables 7 and 8 shows that the AdaGuiDE-based framework is ranked first on 3 transformations including the basic set, SR set and BSR set where it maintains the superiority on handling difficult problems on the relatively lower dimension. Furthermore, the experiment results on 20-dimensional functions reveal that the AdaGuiDE outperforms other compared algorithms on all kinds of transformation sets except for the AMPO on the BS set. More importantly, the ranking scores of the AdaGuiDE on complicated function sets including the SR and BSR are significantly higher than that of other algorithms, which still proves the capability of the AdaGuiDE on solving the tasks with a diversity of features.

4.3 The classical benchmark functions

Similar to the CEC2014 set, there are 16 benchmark functions in the classical set being evaluated on 10, 30, 50, and 100 dimensions with the same feature evaluation settings described in the CEC2014, except for the $F16$ on 100 dimensions, in which the first 8 functions $F1$-$F8$ are uni-modal functions while the functions $F9$-$F16$ are multi-modal functions.

Tables 9, 10, 11 and 12 demonstrate the numerical results on all 50-dimensional benchmark functions in which the AdaGuiDE achieves the global minimum on 14 out of the 16 functions except the $F12$ and $F16$ on which the AdaGuiDE still generates competitive solutions when compared with the best algorithm. Also, reveal that the AdaGuiDE keeps competitive ranking scores on all testing dimensions in which it obtains the highest score on relatively lower dimension on the classical set. For the evaluations on other dimensions, the detailed results can be found in the Appendix E.

Table 9 Comparative results against the state-of-the-art algorithms on functions $F1$-$F16$ with D=50 (Classical set)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	4.55E-02	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.48E+04	5.00E+05	**0.00E+00**	**0.00E+00**
	Std.	1.12E-01	0.00E+00	0.00E+00	0.00E+00	5.05E+03	0.00E+00	0.00E+00	0.00E+00
F2	Mean	4.12E-05	**0.00E+00**	**0.00E+00**	**0.00E+00**	5.15E+01	1.12E+01	**0.00E+00**	**0.00E+00**
	Std.	4.86E-05	0.00E+00	0.00E+00	0.00E+00	4.21E+01	0.00E+00	0.00E+00	0.00E+00
F3	Mean	3.75E-02	**0.00E+00**	**0.00E+00**	**0.00E+00**	6.63E+04	7.52E+04	**0.00E+00**	**0.00E+00**
	Std.	5.39E-02	0.00E+00	0.00E+00	0.00E+00	4.86E+04	0.00E+00	0.00E+00	0.00E+00
F4	Mean	1.00E+00	**0.00E+00**	**0.00E+00**	6.22E-02	6.67E+01	6.50E+01	**0.00E+00**	**0.00E+00**
	Std.	3.03E-01	0.00E+00	0.00E+00	4.33E-02	1.74E+01	0.00E+00	0.00E+00	0.00E+00
F5	Mean	2.25E-05	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.18E+01	2.85E+02	**0.00E+00**	**0.00E+00**
	Std.	3.26E-05	0.00E+00	0.00E+00	0.00E+00	2.04E+01	0.00E+00	0.00E+00	0.00E+00
F6	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.67E-06	1.22E-02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.76E-06	0.00E+00	0.00E+00	0.00E+00
F7	Mean	7.86E-04	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.82E+02	6.63E+02	**0.00E+00**	**0.00E+00**
	Std.	5.11E-04	0.00E+00	0.00E+00	0.00E+00	1.26E+02	0.00E+00	0.00E+00	0.00E+00
F8	Mean	1.51E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.37E+04	2.01E+04	**0.00E+00**	**0.00E+00**
	Std.	8.62E-02	0.00E+00	0.00E+00	0.00E+00	5.96E+03	0.00E+00	0.00E+00	0.00E+00
F9	Mean	1.97E+00	1.64E+01	**0.00E+00**	6.11E+01	3.16E+02	2.63E+02	**0.00E+00**	**0.00E+00**
	Std.	1.51E+00	6.15E+00	0.00E+00	1.39E+01	6.57E+01	0.00E+00	0.00E+00	0.00E+00
F10	Mean	3.64E-03	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.02E+01	1.07E+01	**0.00E+00**	**0.00E+00**
	Std.	2.34E-03	0.00E+00	0.00E+00	0.00E+00	5.36E+00	0.00E+00	0.00E+00	0.00E+00
F11	Mean	3.26E-03	**0.00E+00**	**0.00E+00**	1.15E-03	3.44E+00	4.60E+01	**0.00E+00**	**0.00E+00**
	Std.	4.59E-03	0.00E+00	0.00E+00	2.97E-03	5.67E-01	0.00E+00	0.00E+00	0.00E+00
F12	Mean	**−1.96E + 03**	−1.95E+03	**−1.96E + 03**	−1.89E+03	−1.57E+03	−1.59E+03	−1.91E+03	−1.92E+03
	Std.	3.64E-03	8.28E+00	2.29E-03	3.04E+01	2.72E+01	0.00E+00	2.51E+01	4.49E+01
F13	Mean	3.31E-06	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.02E+07	8.88E+11	**0.00E+00**	**0.00E+00**
	Std.	1.92E-06	0.00E+00	0.00E+00	0.00E+00	1.25E+07	1.22E-04	0.00E+00	0.00E+00
F14	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F15	Mean	1.14E-02	2.48E-07	**0.00E+00**	**0.00E+00**	2.14E+01	2.18E+01	**0.00E+00**	**0.00E+00**
	Std.	1.89E-02	8.64E-07	0.00E+00	0.00E+00	7.65E+00	0.00E+00	0.00E+00	0.00E+00
F16	Mean	-4.84E+01	−4.46E+01	**−4.96E + 01**	−4.56E+01	−2.24E+01	−2.31E+01	−3.82E+01	−4.48E+01
	Std.	2.69E-01	1.26E+00	6.59E-03	6.38E-01	1.49E+00	0.00E+00	3.34E+00	1.66E+00

The bold entries are applied to highlight the best results

Table 10 The significant test and ranking scores on the state-of-the-art algorithms (Classical set)

Dim.		NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
10-D	$+/=/-$ (AdaGuiDE)	10/4/2	11/2/3	14/1/1	15/1/0	16/0/0	16/0/0	–	14/1/1
	$+/=/-$ (AdaGuiDE-PS)	1/0/15	1/2/13	14/1/1	15/1/0	16/0/0	16/0/0	1/1/14	–
	Ranking score	**390**	350	370	315	74	105	378	387
30-D	$+/=/-$ (AdaGuiDE)	13/0/3	11/2/3	14/1/1	14/1/1	16/0/0	16/0/0	–	14/1/1
	$+/=/-$ (AdaGuiDE-PS)	1/0/15	2/0/14	14/1/1	16/0/0	15/1/0	15/1/0	1/1/14	–
	Ranking score	376	362	**400**	338	105	95	366	375
50-D	$+/=/-$ (AdaGuiDE)	13/0/3	11/2/3	14/0/2	15/0/1	16/0/0	16/0/0	–	14/0/2
	$+/=/-$ (AdaGuiDE-PS)	12/0/4	1/1/14	14/0/2	15/0/1	16/0/0	16/0/0	2/0/14	–
	Ranking score	193	345	**400**	326	103	97	368	374
100-D	$+/=/-$ (AdaGuiDE)	13/1/1	11/2/2	14/0/1	15/0/0	15/0/0	15/0/0	–	14/0/1
	$+/=/-$ (AdaGuiDE-PS)	12/0/3	3/0/12	14/0/1	15/0/0	15/0/0	15/0/0	1/0/14	–
	Ranking score	163	332	342	281	81	109	360	**362**

The bold entries are applied to highlight the best results

Table 11 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F16$ with D=50 (Classical set)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	4.49E+05	7.76E+05	**0.00E+00**	1.19E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.98E+04	6.38E+05	0.00E+00	1.59E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F2	Mean	4.89E+00	1.44E+02	**0.00E+00**	1.81E-02	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.43E-01	1.50E+02	0.00E+00	2.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	2.12E+05	8.85E+05	**0.00E+00**	1.35E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.16E+04	7.36E+05	0.00E+00	1.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	2.82E+01	3.25E+01	4.12E+01	8.40E+00	**0.00E+00**	3.97E+00	**0.00E+00**	**0.00E+00**
	Std.	1.03E+00	4.66E+00	2.90E+01	2.32E+00	0.00E+00	2.04E+00	0.00E+00	0.00E+00
F5	Mean	2.77E+02	6.48E+02	**0.00E+00**	2.30E-03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.08E+01	4.18E+02	0.00E+00	4.89E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F6	Mean	2.33E-05	1.65E-07	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	9.82E-06	1.91E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F7	Mean	4.24E+02	5.92E+02	7.28E+02	7.98E-07	**0.00E+00**	1.20E-06	**0.00E+00**	**0.00E+00**
	Std.	3.15E+01	1.77E+02	1.22E+02	1.81E-06	0.00E+00	5.96E-06	0.00E+00	0.00E+00
F8	Mean	1.30E+04	2.23E+04	8.34E+01	2.71E+01	**0.00E+00**	2.20E-02	**0.00E+00**	**0.00E+00**
	Std.	9.90E+02	8.63E+03	2.20E+02	2.23E+01	0.00E+00	6.31E-02	0.00E+00	0.00E+00
F9	Mean	3.59E+02	2.50E+02	**0.00E+00**	8.65E+01	**0.00E+00**	2.48E+01	**0.00E+00**	**0.00E+00**
	Std.	1.02E+01	5.34E+01	0.00E+00	1.36E+01	0.00E+00	6.71E+00	0.00E+00	0.00E+00
F10	Mean	1.10E+01	1.62E+01	**0.00E+00**	9.59E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.27E-01	1.93E+00	0.00E+00	6.86E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F11	Mean	4.16E+01	7.26E+01	1.52E-03	5.29E-02	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.07E+00	4.99E+01	5.77E-03	5.81E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F12	Mean	−1.74E+03	−1.56E+03	**−1.96E + 03**	−1.85E+03	−1.93E+03	−1.95E+03	−1.91E+03	−1.92E+03
	Std.	1.29E+01	5.92E+01	8.50E-04	3.96E+01	1.53E+01	9.76E+00	2.51E+01	4.49E+01
F13	Mean	1.40E+09	1.67E+09	**0.00E+00**	2.33E+04	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.76E+08	1.69E+09	0.00E+00	1.99E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F14	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F15	Mean	2.57E+01	2.18E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	8.12E-01	5.68E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F16	Mean	−1.83E+01	−2.62E+01	−2.13E+01	−3.31E+01	**−4.71E + 01**	−4.55E+01	−3.82E+01	−4.48E+01
	Std.	5.64E-01	2.26E+00	3.03E+00	5.18E-01	7.12E-01	8.53E-01	3.34E+00	1.66E+00

The bold entries are applied to highlight the best results

Table 12 The significant test and ranking scores on popular meta-heuristic algorithms (Classical Set)

Dim.		GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
10-D	+/ = /−	16/0/0	12/4/0	6/10/0	0/15/1	0/15/1	2/13/1	–	14/1/1
	Ranking score	106	196	290	370	383	359	**387**	–
30-D	+/ = /−	15/1/0	15/1/0	4/11/1	7/9/0	0/14/2	2/12/2	–	14/1/1
	Ranking score	131	135	323	274	**390**	368	374	–
50-D	+/ = /−	15/1/0	15/1/0	4/11/1	13/3/0	0/14/2	4/10/2	–	14/0/2
	Ranking score	141	129	317	216	**390**	340	377	–
100-D	+/ = /−	14/1/0	14/1/0	3/11/1	13/2/0	0/14/1	4/10/1	–	14/0/1
	Ranking score	133	115	328	189	**368**	319	362	–

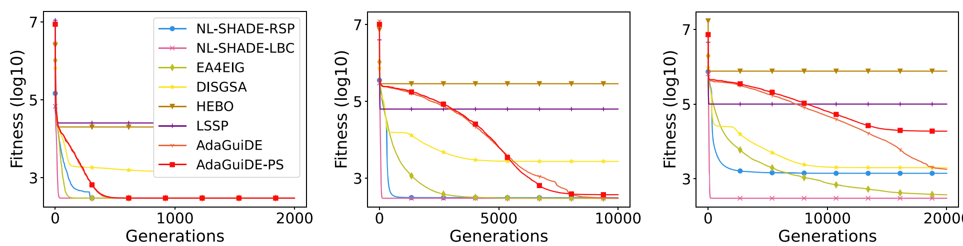
The bold entries are applied to highlight the best results

5 Discussion

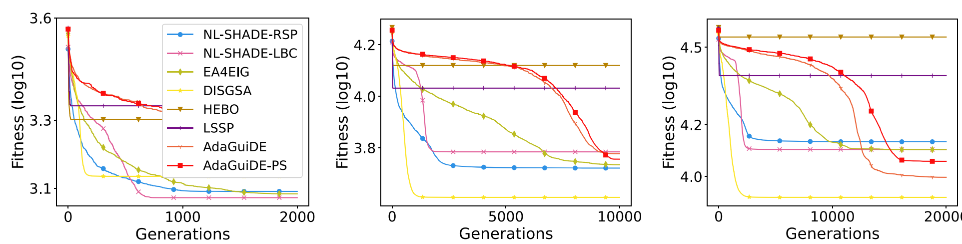
5.1 The analysis of the convergence

Except for the solution quality, the convergence of the search process is analyzed in this section. The mean fitness value of the best solution obtained by the overall evolutionary process on 30 runs is computed for plotting the convergence curve. The x-axis represents the number of generations while the y-axis is $\log(f(x)_{mean})$ with using 10 as its base. Figure 4(a)–(d) and Fig. 5(a)–(d) demonstrate the convergence of 4 functions ($F3$, $F11$, $F22$ and $F27$) sampled from different natures of problems including uni-modal, multi-modal, hybrid and composition. The subgraphs from the left-hand side to the right-hand side represent the dimension of 10, 50, and 100 in turn. As shown in the functions $F3$, $F11$ and $F22$, yet the AdaGuiDE-based framework performs slow speed of the convergence at the early search stage as it probably makes effort on exploring, adjusting and verifying appropriate strategies and control parameters for adapting the corresponding nature of problems. However, it clearly shows that the curve of the AdaGuiDE-based framework will dramatically drop down and ultimately achieve a competitive solution at the middle or the late stage, especially in tackling higher dimensional problems, which depicts the capability of the AdaGuiDE-based framework to recognize and skip local minima whereas other algorithms are still staying at here. Furthermore, it can say that the AdaGuiDE-based framework obtains impressive enhancement for which it selects appropriate mutation strategies and control parameters. Moreover, it is evident that the AdaGuiDE-based framework can better adapt the complicated search environ-

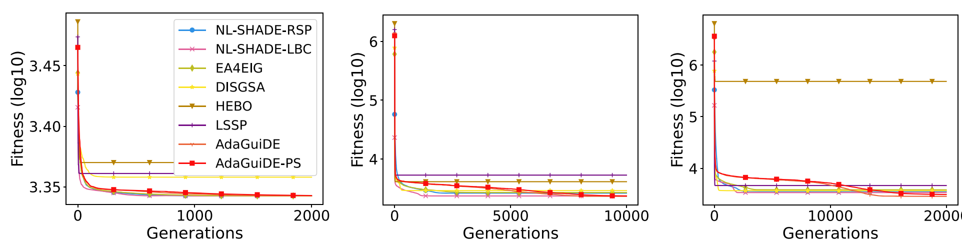
Fig. 4 The convergence comparison against the state-of-the-art algorithms on different dimensions



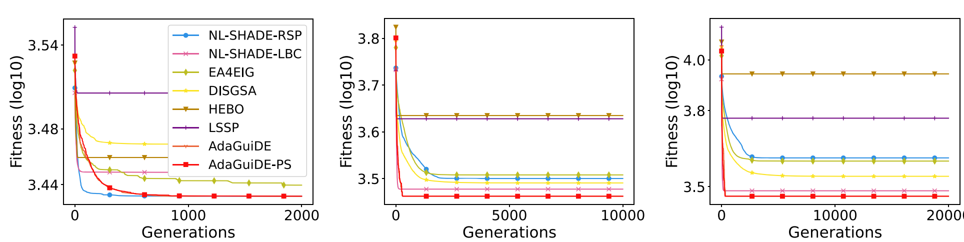
(a) CEC2014-F3 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



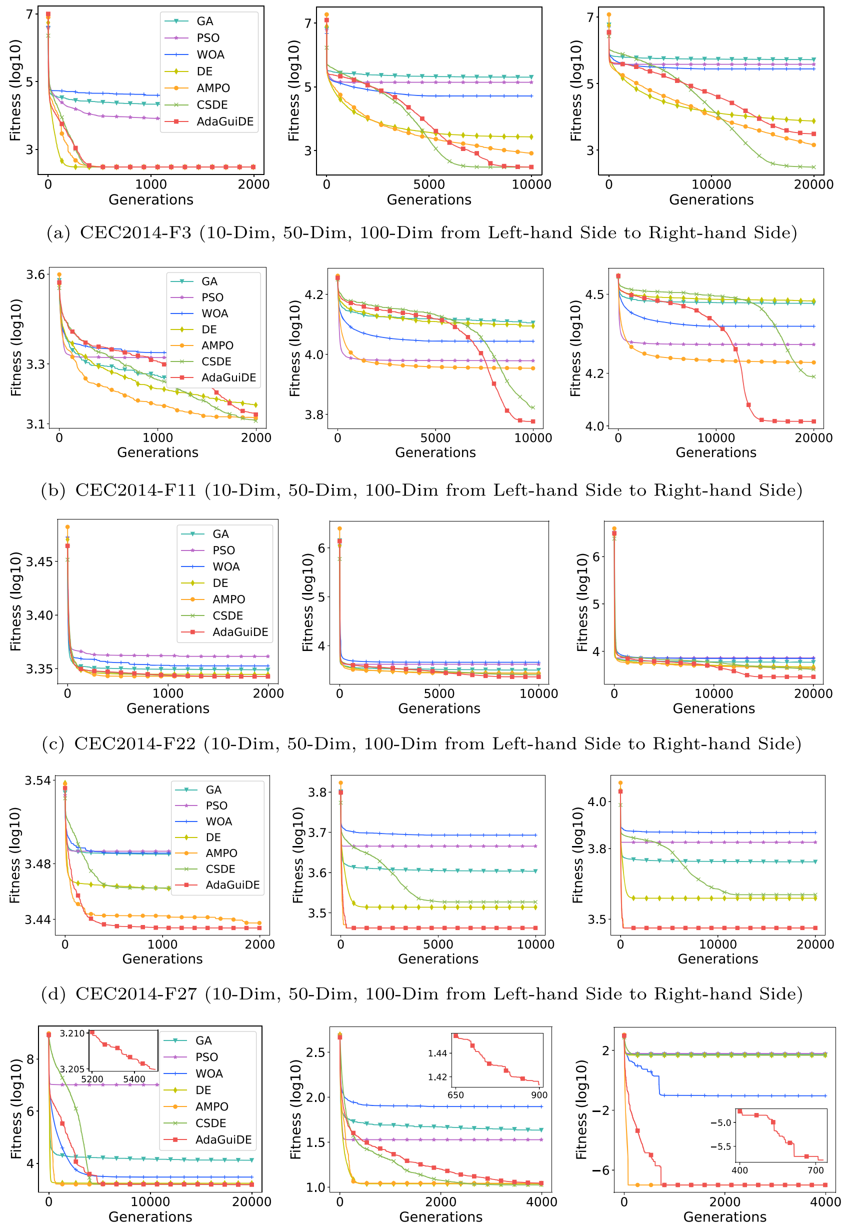
(b) CEC2014-F11 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(c) CEC2014-F22 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(d) CEC2014-F27 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(a) CEC2014-F3 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)

(b) CEC2014-F11 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)

(c) CEC2014-F22 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)

(d) CEC2014-F27 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)

(e) CEC2014-F15 (100-Dim) (f) CEC2021-S3 (10-Dim) (g) CEC2021-B10 (10-Dim)

Fig. 5 The convergence comparison against popular meta-heuristic algorithms on different dimensions

ment on the composition function $F27$ so that it can faster search out a feasible solution when compared with other algorithms. More importantly, the convergence curves of the AdaGuiDE-based framework on $F27$ demonstrate that the proposed method can achieve the solutions with higher resolutions when approaching to the optimal solution against other methods.

To identify the characteristics of the guided search and the boundary revision scheme in the AdaGuiDE framework, Fig. 5(e)–(g) depict three significant cases including the function CEC2014-$F15$ on 100 dimensions, the function CEC2021-$F3$ with the S transformation and the basic function CEC2021-$F10$ both on 10 dimensions for comparison. It can be found that the convergence curve of the AdaGuiDE is very similar to the step function, which means that the AdaGuiDE can continuously escape from local minima through executing the efficiently guided search mechanism and revising boundaries to locate more promising areas once the search cannot achieve progress.

5.2 The analysis of the computational cost

Tables 13 and 14 compare the average time of algorithms to converge finally best solutions. As the AdaGuiDE-based

Table 13 Time and solution comparisons against the state-of-the-art on functions $F1$-$F30$ with D=50 (CEC2014)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	810.18 (3)	247.88 (1)	71.46 (2)	64.16 (4)	177.25 (7)	135.55 (8)	106.88 (6)	96.82 (5)
F2	893.41 (6)	169.41 (1)	64.29 (2)	68.67 (5)	177.07 (7)	114.58 (8)	111.91 (4)	98.76 (3)
F3	820.36 (4)	150.02 (1)	69.03 (2)	67.61 (6)	173.85 (8)	390.33 (7)	105.78 (3)	96.79 (5)
F4	833.63 (6)	277.65 (1)	67.25 (2)	52.98 (5)	174.70 (7)	115.16 (8)	104.87 (4)	95.81 (3)
F5	487.91 (3)	368.39 (2)	67.12 (4)	62.01 (1)	83.31 (7)	127.99 (8)	102.52 (6)	97.07 (5)
F6	668.00 (6)	246.82 (1)	127.69 (4)	126.28 (2)	158.91 (7)	145.00 (8)	101.58 (3)	157.70 (5)
F7	898.58 (5)	106.51 (1)	17.04 (3)	51.51 (4)	166.28 (7)	129.61 (8)	38.09 (6)	42.10 (1)
F8	720.77 (2)	216.94 (5)	34.43 (1)	62.72 (6)	182.31 (8)	145.09 (7)	89.20 (4)	92.75 (3)
F9	628.29 (6)	207.30 (1)	36.91 (5)	62.32 (4)	185.22 (8)	150.28 (7)	87.33 (2)	97.27 (3)
F10	655.73 (2)	336.02 (6)	68.01 (1)	60.77 (5)	171.13 (7)	141.92 (8)	98.43 (3)	95.55 (4)
F11	550.69 (2)	327.53 (6)	67.19 (3)	63.58 (1)	53.32 (8)	172.93 (7)	102.97 (5)	94.82 (4)
F12	516.09 (3)	371.45 (4)	86.83 (2)	80.09 (1)	67.21 (8)	149.16 (7)	118.15 (6)	104.92 (5)
F13	808.03 (3)	219.16 (2)	60.46 (4)	64.43 (5)	172.59 (7)	122.13 (8)	58.83 (6)	91.50 (1)
F14	804.75 (4)	208.34 (5)	55.90 (3)	67.48 (6)	160.69 (7)	117.77 (8)	24.13 (2)	59.15 (1)
F15	800.81 (5)	208.72 (1)	70.13 (4)	67.80 (2)	179.09 (7)	425.54 (8)	98.17 (3)	92.90 (6)
F16	506.93 (3)	331.72 (2)	71.03 (1)	67.63 (5)	100.67 (8)	94.34 (7)	91.95 (6)	90.77 (4)
F17	725.82 (2)	259.79 (1)	72.15 (3)	70.61 (4)	173.85 (7)	251.57 (8)	110.72 (5)	101.16 (6)
F18	796.59 (2)	251.92 (1)	71.45 (3)	66.44 (6)	181.38 (7)	177.80 (8)	112.11 (4)	99.77 (5)
F19	771.50 (5)	258.25 (2)	84.98 (1)	77.89 (4)	175.30 (8)	294.30 (7)	127.15 (3)	109.87 (6)
F20	758.42 (4)	249.44 (1)	68.66 (2)	73.73 (6)	180.44 (8)	330.81 (7)	112.31 (3)	98.76 (5)
F21	780.53 (3)	297.66 (1)	71.66 (2)	69.37 (4)	173.74 (8)	258.13 (7)	110.75 (6)	99.78 (5)
F22	663.06 (4)	275.06 (2)	72.70 (5)	72.26 (6)	154.00 (7)	284.91 (8)	114.22 (1)	99.51 (3)
F23	1174.02 (5)	285.87 (3)	86.01 (3)	160.68 (6)	166.79 (7)	81.17 (8)	37.01 (1)	8.09 (1)
F24	1058.50 (6)	219.77 (5)	124.98 (3)	141.54 (4)	161.16 (8)	72.96 (7)	55.60 (1)	5.59 (1)
F25	844.43 (4)	462.50 (3)	121.83 (5)	135.23 (6)	152.17 (8)	153.25 (7)	15.01 (1)	6.02 (1)
F26	1074.13 (1)	449.04 (5)	227.47 (2)	289.17 (6)	156.38 (8)	268.36 (7)	168.24 (3)	128.40 (4)
F27	1084.83 (5)	458.32 (3)	261.29 (6)	258.91 (4)	181.26 (8)	154.83 (7)	32.75 (1)	15.14 (1)
F28	1040.08 (5)	475.88 (4)	197.01 (3)	218.38 (6)	183.21 (8)	208.81 (7)	26.68 (1)	14.26 (1)
F29	1060.29 (5)	522.66 (3)	91.97 (6)	161.63 (4)	181.70 (8)	168.91 (7)	30.53 (1)	17.20 (1)
F30	1103.53 (5)	474.18 (4)	144.40 (3)	162.23 (6)	181.06 (8)	311.69 (7)	50.23 (2)	35.92 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

framework has to put more efforts to collect and analyze historical data to adapt search environment and adjust strategies, it unavoidably spends extra time to explore solutions than classical meta-heuritic algorithms. Nevertheless, when comparing the quality of solutions (i.e., the ranking in the brackets), the AdaGuiDE-based framework still demonstrate the potential benefit in the computational overheads since it requires fewer generations to escape from local minima and achieves relatively good solutions. Furthermore, the AdaGuiDE framework shows great ability to balance the trade-off between execution time and solution quality when compared with the SOTA algorithms as the AdaGuiDE can obtain a competitive solution within a shorter period of time. More results on other datasets can be referred to Appendix F.

5.3 The analysis of the stability

As meta-heuristic algorithms are not the exact search method, it cannot surely achieve the same performance due to the design of meta-heuristic algorithms. Thus, it is necessary to analyze the stability of algorithms to learn whether it can generate the similar solution on each run. Figures 6 and 7 demonstrate the stability of the 4 functions (i.e., $F3$, $F11$, $F22$, and $F27$) on 30 runs. Also, the subgraphs from the left-hand side to the right-hand side represent the dimension of 10, 50, and 100 in turn. It is evident that the AdaGuiDE-based framework has a good stability on all kinds of problems of different dimensions. There is almost no outlier point generated by the AdaGuiDE-based framework, and it maintains lower

Table 14 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=50 (CEC2014)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	13.46 (6)	1.60 (7)	22.63 (5)	47.93 (2)	30.51 (4)	86.35 (1)	106.88 (3)
F2	11.93 (6)	2.20 (7)	21.55 (5)	31.30 (4)	28.57 (2)	88.48 (3)	111.91 (1)
F3	9.72 (7)	1.94 (6)	21.36 (5)	47.46 (4)	27.97 (3)	82.87 (1)	105.78 (2)
F4	12.74 (6)	1.57 (7)	23.81 (5)	30.86 (4)	29.47 (2)	77.78 (3)	104.87 (1)
F5	13.19 (7)	10.53 (2)	24.36 (4)	27.56 (6)	29.67 (1)	86.53 (3)	102.52 (5)
F6	56.56 (5)	13.03 (6)	88.53 (7)	108.52 (2)	102.53 (3)	152.41 (4)	101.58 (1)
F7	10.24 (6)	0.97 (7)	21.92 (5)	18.83 (4)	22.99 (2)	27.72 (1)	38.09 (3)
F8	9.75 (5)	0.90 (7)	20.50 (6)	46.19 (4)	23.83 (1)	80.56 (3)	89.20 (2)
F9	11.03 (5)	1.08 (7)	22.30 (6)	38.64 (4)	25.14 (3)	78.60 (2)	87.33 (1)
F10	13.65 (7)	1.93 (6)	24.24 (5)	47.73 (4)	28.81 (1)	87.96 (3)	98.43 (2)
F11	15.52 (7)	6.56 (4)	25.82 (5)	29.07 (6)	31.00 (3)	88.20 (2)	102.97 (1)
F12	21.68 (7)	26.47 (2)	41.92 (6)	49.73 (5)	51.52 (3)	105.32 (1)	118.15 (4)
F13	11.46 (6)	0.78 (7)	19.38 (5)	32.26 (3)	9.55 (2)	85.92 (1)	58.83 (4)
F14	10.49 (6)	0.94 (7)	20.34 (5)	26.36 (3)	8.55 (2)	83.78 (4)	24.13 (1)
F15	9.57 (5)	1.74 (7)	21.68 (6)	33.15 (4)	26.67 (3)	82.50 (1)	98.17 (2)
F16	10.83 (7)	7.96 (5)	24.91 (6)	36.46 (3)	29.13 (2)	86.61 (1)	91.95 (4)
F17	12.86 (5)	4.08 (7)	29.79 (6)	45.17 (4)	36.27 (3)	90.79 (1)	110.72 (2)
F18	15.09 (6)	2.57 (7)	25.70 (5)	49.84 (4)	33.04 (3)	88.01 (2)	112.11 (1)
F19	21.37 (5)	3.95 (7)	39.87 (6)	62.86 (4)	49.36 (3)	106.43 (2)	127.15 (1)
F20	10.24 (5)	6.03 (6)	26.29 (7)	51.08 (3)	32.94 (4)	88.51 (1)	112.31 (2)
F21	13.14 (5)	3.89 (7)	25.59 (6)	51.08 (4)	37.24 (3)	92.54 (1)	110.75 (2)
F22	19.09 (5)	3.48 (6)	26.85 (7)	52.51 (4)	37.12 (3)	93.50 (2)	114.22 (1)
F23	18.79 (6)	2.98 (7)	37.58 (5)	100.00 (4)	1.41 (1)	35.22 (3)	37.01 (1)
F24	38.81 (6)	6.32 (7)	70.24 (3)	158.70 (5)	0.92 (1)	74.92 (4)	55.60 (1)
F25	20.64 (6)	2.62 (7)	35.13 (3)	154.74 (5)	0.53 (1)	109.77 (4)	15.01 (1)
F26	74.58 (4)	12.00 (7)	111.75 (3)	135.85 (6)	86.25 (2)	276.46 (1)	168.24 (5)
F27	104.23 (5)	13.67 (6)	119.47 (7)	146.72 (3)	3.49 (1)	298.05 (4)	32.75 (1)
F28	34.45 (5)	10.05 (6)	66.43 (7)	88.92 (4)	1.84 (1)	300.43 (3)	26.68 (1)
F29	28.75 (4)	5.79 (7)	27.27 (6)	97.54 (3)	0.99 (1)	193.48 (5)	30.53 (1)
F30	20.26 (5)	17.00 (7)	87.98 (6)	168.43 (4)	7.87 (1)	264.71 (3)	50.23 (2)

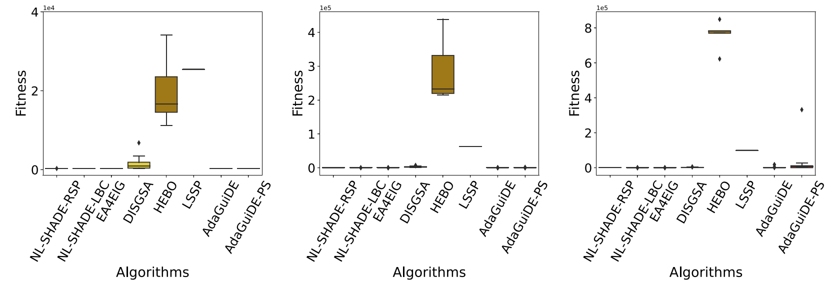
- Data format: Average time (Ranking of solution quality)
- Average time unit: CPU second(s)

deviation on each run, which strengthens the confidence of the AdaGuiDE-based framework to generate more reliable results on real-world applications in the future investigation. The detailed numerical results can be referred to Appendix C, D, and E.

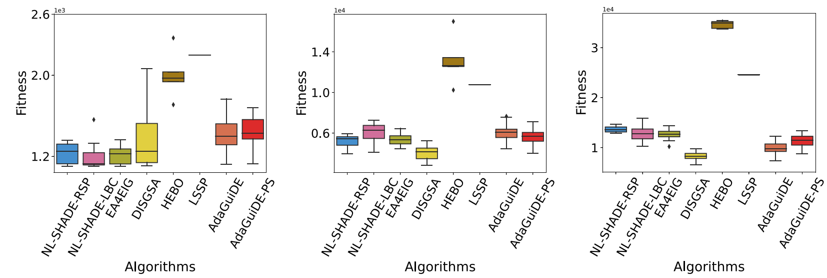
5.4 The analysis of the ablation study

To investigate the effectiveness of key components of the AdaGuiDE and AdaGuiDE-PS including the Boundary Revision (BR), Dynamic contribution mechanism (DYN), and Guided DE search (GUIDED), an ablation study is conducted in this section. The AdaGuiDE-WO does not involve the mentioned three key components. The AdaGuiDE-BR, AdaGuiDE-DYN, AdaGuiDE-GUIDED, and AdaGuiDE-PS-GUIDED only involve one of the key components. More specifically, the AdaGuiDE-GUIDED is the AdaGuiDE with the guided scheme only while the AdaGuiDE-PS-GUIDED is the AdaGuiDE-PS with the guided scheme only. Moreover, the AdaGuiDE-DYN-BR, AdaGuiDE-DYN-GUIDED, AdaGuiDE-PS-DYN-GUIDED, AdaGuiDE-GUIDED-BR. and AdaGuiDE-PS-GUIDED-BR are considering two of the three key components. Lastly, the AdaGuiDE and AdaGuiDE-PS are the versions including all three key components. As shown in Table 15, when including the guided search scheme, the AdaGuiDE-PS can achieve improvements on the uni-modal type of functions. Moreover, the boundary revision mechanism of the AdaGuiDE-PS may effectively help the search escaping from the local minima when solving the multi-modal problems and the composition problems with different natures. Meanwhile, through dynamically adjusting the parameters at different search stages, the

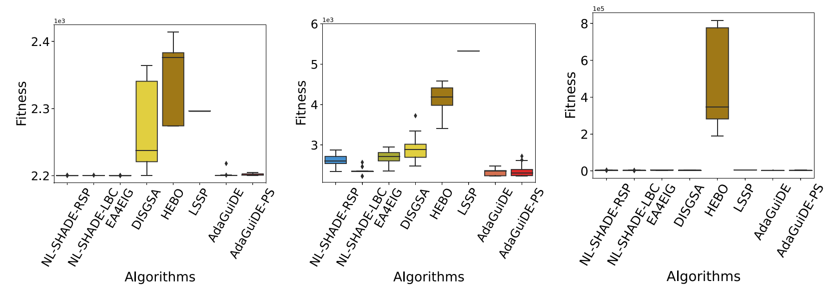
Fig. 6 The stability comparison against the state-of-the-art algorithms on different dimensions



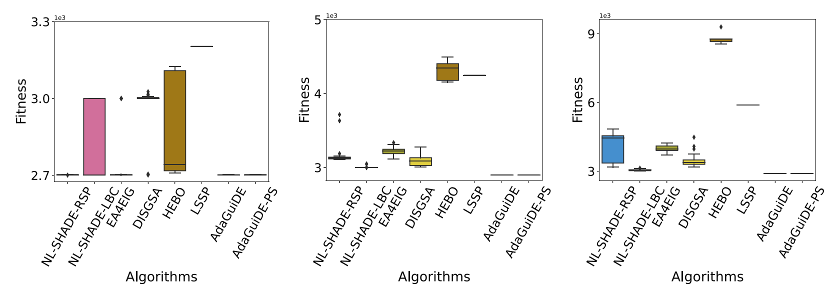
(a) CEC2014-F3 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(b) CEC2014-F11 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(c) CEC2014-F22 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



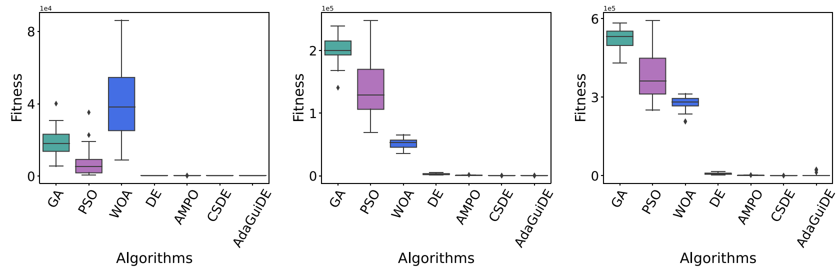
(d) CEC2014-F27 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)

AdaGuiDE-PS can better adapt to the current search environment when adopting the dynamic contribution-based mechanism to handle the problems with different natures. More detailed numerical results can be referred to Appendix G.

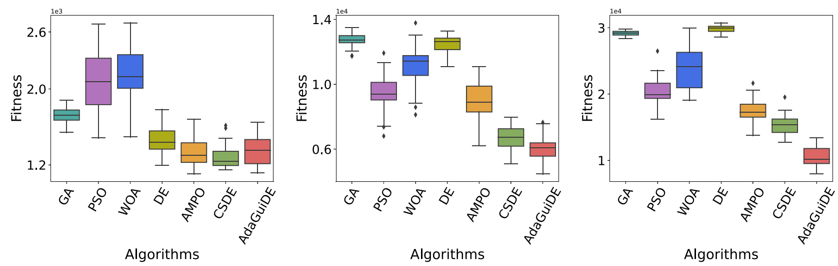
5.5 The analysis of the key hyper-parameters

To study the impact of key hyper-parameters on the AdaGuiDE-PS framework, the orthogonal experimental design method is applied to set the different combinations of hyper-parameters as shown in Table 16. The summarized results are shown in Table 17. From the ranking scores, a larger population size is not suggested to solve the multi-modal and hybrid functions as more efforts should be put into the local search for escaping from the local minima. However, when trying to deal with the problems with different unknown natures, a larger population size may help to explore more regions of the search space for enhancing the overall performance. Besides, a higher K is recommended to use when solving multi-modal problems as it can penalize the local minima

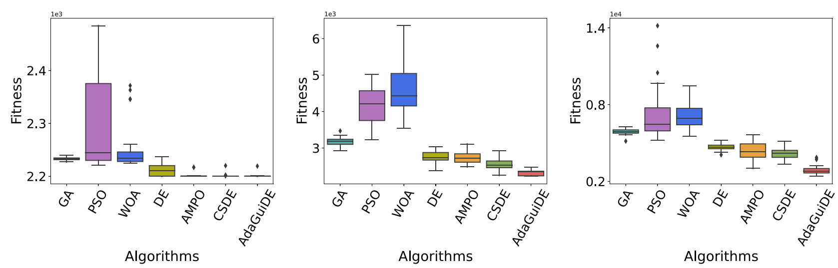
Fig. 7 The stability comparison against popular meta-heuristic algorithms on different dimensions



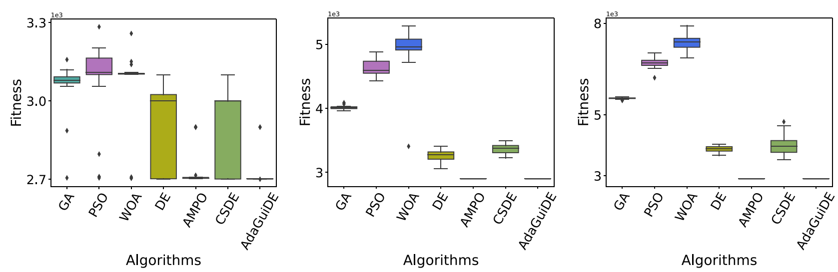
(a) CEC2014-F3 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(b) CEC2014-F11 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(c) CEC2014-F22 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)



(d) CEC2014-F27 (10-Dim, 50-Dim, 100-Dim from Left-hand Side to Right-hand Side)

with higher resolution, especially when the global optimum is close to the local minima yet difficult to approach. On the other hand, the FP, G_{trap}, and $G_{trigger}$ may not be sensitive to the overall search, which can be set within an appropriate range for the problems in different scenarios. More detailed numerical results can be referred to Appendix G.

6 Conclusion

To tackle the challenging problems with difficult features such as non-differentiable, non-convex and multi-model, meta-heuristic algorithms originating from evolution theory or swarm behaviors have been proven to well solve such problems. However, the algorithm to be solved a particular problem typically is tuned by using the trial-and-error scheme, which is no doubt that more efforts will be needed, and it hardly generalizes to other scenarios. Although some self-adaptive algorithms have achieved progress, those adaptive mechanisms mostly focus on selecting mutation strategies and tuning control parameters only. Besides, Escaping from local minima is also a bothersome problem for such self-adaptive algorithms. Therefore, an Adaptive and Guided Differential Evolution (AdaGuiDE)

Table 15 The ranking score of different types of functions on CEC2014 in ablation study

Variants	Total	Uni-modal	Multi-modal	Hybrid	Composition
AdaGuiDE-WO	428	62	135	63	**168**
AdaGuiDE-BR	**464**	54	**202**	68	140
AdaGuiDE-DYN	391	58	125	**73**	135
AdaGuiDE-GUIDED	162	25	30	33	74
AdaGuiDE-PS-GUIDED	293	**65**	45	18	165
AdaGuiDE-DYN-BR	**486**	51	**219**	48	**168**
AdaGuiDE-DYN-GUIDED	194	10	29	21	134
AdaGuiDE-PS-DYN-GUIDED	325	**68**	67	37	153
AdaGuiDE-GUIDED-BR	375	56	101	67	151
AdaGuiDE-PS-GUIDED-BR	437	50	172	50	165
AdaGuiDE	323	50	86	53	134
AdaGuiDE-PS	432	52	164	**75**	141

The bold entries are applied to highlight the best results

framework is proposed in this work in which the adaptive mechanism monitors the search process and adjusts the search behavior from three aspects including the adaptively objective function, dynamic boundary revision techniques and a flexible scheme to adjust appropriate search strategies. Also, as a critical part of the AdaGuiDE, a penalty-based guided DE search is proposed to encourage the search toward to other promising areas so as to escape from local minima, allocating search efforts to ROIs. To carefully evaluate the search effectiveness of the proposed framework on more possible scenarios, the AdaGuiDE algorithm is compared against other meta-heuristic algorithms on three well-known datasets of different dimensions in which those benchmark functions cover various characteristics such as uni-modal, multi-modal, shift, rotation, etc. For the classical set and the CEC 2014 set, the AdaGuiDE algorithm has achieved impressive results on solving the complicated benchmark functions (i.e., multi-modal, hybrid functions and composition functions), especially when applying on the relatively higher dimensions like 50-D or 100-D. Meanwhile, the AdaGuiDE framework also performed remarkable convergence speed on uni-modal functions. For the CEC2021 set, except for achieving outstanding results on basic functions, the AdaGuiDE framework outperforms than other algorithms on the functions with the most complex transformation (i.e., Bias, shift and rotation) in which the performance of the hybrid or composition functions in the AdaGuiDE framework is significant when compared with other algorithms. Besides, although the AdaGuiDE framework may spend extra time on analyzing and adjusting the search strategies for adapting environments on each generation, it still maintains competitive total running time by achieving high-quality solutions with fewer generations.

Table 16 The settings of key hyper-parameters based on the orthogonal experimental design method

Experiment No.	NP	FP	G_{trap}	K	$G_{trigger}$
HYPER-1	25	50	10	2	100
HYPER-2	25	100	20	5	200
HYPER-3	25	200	50	10	300
HYPER-4	25	400	100	20	400
HYPER-5	50	50	20	10	400
HYPER-6	50	100	10	20	300
HYPER-7	50	200	100	2	200
HYPER-8	50	400	50	5	100
HYPER-9	75	50	50	20	200
HYPER-10	75	100	100	10	100
HYPER-11	75	200	10	5	400
HYPER-12	75	400	20	2	300
HYPER-13	100	50	100	5	300
HYPER-14	100	100	50	2	400
HYPER-15	100	200	20	20	100
HYPER-16	100	400	10	10	200

There are some possible directions worth studying in the future. First, the strength of the penalty factor may affect the speed and capacity to skip local minima. Besides, it is interesting to explore a more flexible scheme to revise the boundaries for effectively locating the regions of interest. Lastly, it is worthwhile to consider the correlation among different features and utilize such information to cluster the features for better adapting to solve higher dimensional problems. More importantly, the AdaGuiDE framework sheds

Table 17 The ranking score of different types of functions on CEC2014 in hyper-parameter analysis

Variants	Total	Uni-modal	Multi-modal	Hybrid	Composition
HYPER-1	321	33	132	31	125
HYPER-2	379	25	154	**65**	135
HYPER-3	392	50	**177**	40	125
HYPER-4	389	50	152	62	125
HYPER-5	315	68	33	64	150
HYPER-6	290	**75**	45	27	143
HYPER-7	414	50	168	47	149
HYPER-8	362	51	136	34	141
HYPER-9	321	62	75	51	133
HYPER-10	**438**	56	163	47	172
HYPER-11	250	65	8	41	136
HYPER-12	271	60	27	37	147
HYPER-13	297	50	48	25	**174**
HYPER-14	249	50	52	10	137
HYPER-15	232	52	5	11	164
HYPER-16	215	54	0	14	147

The bold entries are applied to highlight the best results

light on solving more complex and high dimensional real-world problems such as large-scale portfolio optimization problems, deep neural network architecture optimization problems, delivery scheduling optimization problems, etc.

Appendix A: The benchmark functions of the classical set

In this sections, the definition of all 16 benchmark functions on the classical set is listed as below.

F1: Sphere Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} x_i^2 \quad \text{s.t.} \quad x_i \in [-1000, 1000] \tag{A1}$$

F2 ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D-1} x_i^{2x_{i+1}^2+2} + x_{i+1}^{2x_i^2+2} \quad \text{s.t.} \quad x_i \in [-1, 4] \tag{A2}$$

F3: High Conditioned Elliptic Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} \left(10^6\right)^{\frac{i-1}{D-1}} x_i^2 \quad \text{s.t.} \quad x_i \in [-5.12, 5.12] \tag{A3}$$

F4: Schwefel 2.21 Function ($f_{opt} = 0$)

$$f(x) = \max |x_i| \quad \text{s.t.} \quad x_i \in [-100, 100] \tag{A4}$$

F5: Axis Parallel Hyper-ellipsoid Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} i x_i^2 \quad \text{s.t.} \quad x_i \in [-5.12, 5.12] \tag{A5}$$

F6: Sum of Different Power Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} |x_i|^{i+1} \quad \text{s.t.} \quad x_i \in [-1, 1] \tag{A6}$$

F7: Zakharov Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} x_i^2 + \left(\sum_{i=1}^{D} 0.5 i x_i\right)^2 + \left(\sum_{i=1}^{D} 0.5 i x_i\right)^4 \quad \text{s.t.} \quad x_i \in [-5, 10] \tag{A7}$$

F8: Rotated Hyper-ellipsoid Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} \sum_{j=1}^{i} x_j^2 \quad \text{s.t.} \quad x_i \in [-65.536, 65.536] \tag{A8}$$

F9: Rastrigin ($f_{opt} = 0$)

$$f(x) = 10D + \sum_{i=1}^{D} \left[x_i^2 - 10\cos(2\pi x_i)\right] \quad \text{s.t.} \quad x_i \in [-5.12, 5.12] \tag{A9}$$

F10: Ackley Function ($f_{opt} = 0$)

$$f(x) = -20e^{-b\sqrt{\frac{1}{D}\sum_{i=1}^{D} x_i^2}} - e^{\frac{1}{D}\sum_{i=1}^{D}\cos(2\pi x_i)} + 20 + e \quad \text{s.t.} \quad x_i \in [-32.768, 32.768] \tag{A10}$$

F11: Griewank Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} \frac{x_i^2}{4000} - \prod_{i=1}^{D} \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1 \quad \text{s.t.} \quad x_i \in [-600, 600] \tag{A11}$$

F12: Styblinski-Tang Function ($f_{opt} = -39.16599 \times D$)

$$f(x) = \frac{1}{2}\sum_{i=1}^{D}\left(x_i^4 - 16x_i^2 + 5x_i\right) \quad \text{s.t.} \quad x_i \in [-5, 5] \tag{A12}$$

F13: Csendes Function ($f_{opt} = 0$)

$$f(x) = \begin{cases} \sum_{i=1}^{D} x_i^6 \left[\sin\left(\frac{1}{x_i}\right) + 2\right], & \text{if } \prod_{i=1}^{D} x_i \neq 0 \\ 0, & \text{otherwise} \end{cases} \quad \text{s.t.} \quad x_i \in [-100, 100] \tag{A13}$$

F14: Xin-She Yang-2 Function ($f_{opt} = 0$)

$$f(x) = \left(\sum_{i=1}^{D} |x_i|\right) e^{-\sum_{i=1}^{D}\sin(x_i^2)} \quad \text{s.t.} \quad x_i \in [-2\pi, 2\pi] \tag{A14}$$

F15: Alpine 1 Function ($f_{opt} = 0$)

$$f(x) = \sum_{i=1}^{D} |x_i \sin(x_i) + 0.1x_i| \quad \text{s.t.} \quad x_i \in [-10, 10] \tag{A15}$$

F16: Michalewicz Function

$$f_{opt} = \begin{cases} -9.66015, & D = 10 \\ -29.6308839, & D = 30 \\ -49.6248323, & D = 50 \end{cases}$$
$$f(x) = -\sum_{i=1}^{D} \sin(x_i)\left(\sin\left(\frac{i x_i^2}{\pi}\right)\right)^{2m} \quad \text{s.t.} \quad x_i \in [0, \pi] \tag{A16}$$

Appendix B: The formula one criterion

To comprehensively evaluate the performance of algorithms on each dataset of different dimensions, a popular scoring system shown in Table 18 is introduced to count the ranking of compared methods. Higher cumulative score means the better performance achieved by the method.

Table 18 The formula one criterion for comprehensively evaluating algorithms

Ranking	Score
1^{st}	25
2^{nd}	18
3^{rd}	15
4^{th}	12
5^{th}	10
6^{th}	8
7^{th}	6
8^{th}	4
9^{th}	2
10^{th}	1
$> 10^{th}$	No score

Source: https://en.wikipedia.org/wiki/Formula_One_regulations

Appendix C: The comparative results on the CEC2014 set

C.1 10 Dimensions

Table 19 Comparative results against the state-of-the-art algorithms on functions $F1$-$F30$ with D=10 (CEC2014)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.00E+02	**1.00E+02**	**1.00E+02**	8.26E+03	5.65E+06	9.45E+06	1.00E+02	1.03E+02
	Std.	1.12E-06	0.00E+00	0.00E+00	1.24E+04	3.64E+06	0.00E+00	2.36E-03	1.13E+01
F2	Mean	**2.00E+02**	**2.00E+02**	**2.00E+02**	1.45E+03	6.08E+06	9.31E+05	**2.00E+02**	**2.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.60E+03	2.55E+06	0.00E+00	0.00E+00	0.00E+00
F3	Mean	**3.00E+02**	**3.00E+02**	**3.00E+02**	1.43E+03	2.00E+04	2.55E+04	**3.00E+02**	**3.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.43E+03	8.11E+03	0.00E+00	0.00E+00	0.00E+00
F4	Mean	**4.00E+02**	4.28E+02	4.00E+02	4.33E+02	4.40E+02	4.01E+02	4.11E+02	4.02E+02
	Std.	0.00E+00	1.39E+01	7.51E-01	8.24E+00	2.06E+00	0.00E+00	1.56E+01	6.24E+00
F5	Mean	5.16E+02	5.17E+02	**5.16E+02**	5.20E+02	5.21E+02	5.20E+02	5.20E+02	5.19E+02
	Std.	7.26E+00	7.46E+00	8.01E+00	8.65E-04	1.27E-01	0.00E+00	1.24E+00	3.13E+00
F6	Mean	6.00E+02	**6.00E+02**	**6.00E+02**	6.00E+02	6.03E+02	6.07E+02	6.01E+02	6.02E+02
	Std.	3.12E-02	0.00E+00	0.00E+00	7.36E-04	1.12E+00	0.00E+00	9.12E-01	1.09E+00
F7	Mean	7.00E+02	**7.00E+02**	7.00E+02	7.00E+02	7.01E+02	7.01E+02	7.00E+02	7.00E+02
	Std.	7.47E-03	1.84E-03	1.30E-02	5.40E-02	9.29E-02	0.00E+00	5.65E-02	5.12E-02
F8	Mean	**8.00E+02**	8.01E+02	8.00E+02	8.07E+02	8.37E+02	8.17E+02	8.01E+02	8.02E+02
	Std.	0.00E+00	1.06E+00	0.00E+00	3.11E+00	7.78E+00	0.00E+00	8.14E-01	1.26E+00
F9	Mean	9.04E+02	**9.03E+02**	9.04E+02	9.08E+02	9.49E+02	9.26E+02	9.04E+02	9.07E+02
	Std.	1.33E+00	1.78E+00	1.29E+00	4.72E+00	7.06E+00	0.00E+00	1.71E+00	2.07E+00
F10	Mean	**1.00E+03**	1.02E+03	1.00E+03	1.31E+03	1.88E+03	2.36E+03	1.01E+03	1.03E+03
	Std.	3.09E-02	3.91E+01	3.46E-02	1.58E+02	2.69E+02	0.00E+00	5.51E+00	1.25E+01
F11	Mean	1.23E+03	**1.18E+03**	1.21E+03	1.36E+03	2.00E+03	2.20E+03	1.41E+03	1.44E+03
	Std.	9.08E+01	1.03E+02	8.75E+01	2.48E+02	2.12E+02	0.00E+00	1.54E+02	1.41E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	4.96E-02	9.00E-02	4.75E-02	3.47E-02	4.77E-01	0.00E+00	1.13E-01	5.24E-02
F13	Mean	1.30E+03	**1.30E+03**	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03
	Std.	1.83E-02	2.86E-02	1.93E-02	6.01E-02	1.30E-01	0.00E+00	5.36E-02	1.57E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	**1.40E+03**
	Std.	4.09E-02	5.15E-02	2.66E-02	9.29E-02	8.30E-02	0.00E+00	4.90E-02	2.92E-02
F15	Mean	1.50E+03	1.50E+03	**1.50E+03**	1.50E+03	1.51E+03	1.51E+03	1.50E+03	1.50E+03
	Std.	1.64E-01	1.71E-01	1.12E-01	2.83E-01	8.91E-01	0.00E+00	2.26E-01	3.11E-01
F16	Mean	1.60E+03	**1.60E+03**	1.60E+03	1.60E+03	1.60E+03	1.60E+03	1.60E+03	1.60E+03
	Std.	3.07E-01	4.69E-01	3.54E-01	5.02E-01	5.45E-02	0.00E+00	3.28E-01	2.96E-01
F17	Mean	1.81E+03	1.71E+03	**1.70E+03**	3.01E+03	5.38E+05	6.58E+05	1.71E+03	1.72E+03
	Std.	9.33E+01	2.42E+01	2.77E+00	1.02E+03	7.09E+05	0.00E+00	4.64E+00	1.04E+01
F18	Mean	1.80E+03	1.80E+03	**1.80E+03**	7.59E+03	9.52E+03	2.84E+03	1.80E+03	1.80E+03
	Std.	1.46E+00	1.24E-01	9.99E-02	3.70E+03	6.68E+03	0.00E+00	3.49E-01	5.40E-01
F19	Mean	1.90E+03	1.90E+03	**1.90E+03**	1.90E+03	1.91E+03	1.90E+03	1.90E+03	1.90E+03
	Std.	4.61E-02	2.60E-02	2.65E-02	4.85E-01	1.21E+00	0.00E+00	3.93E-01	2.03E-01
F20	Mean	2.00E+03	2.00E+03	**2.00E+03**	5.03E+03	7.26E+03	3.09E+03	2.00E+03	2.00E+03
	Std.	7.10E-01	2.09E-01	8.96E-02	2.44E+03	5.46E+03	0.00E+00	2.42E-01	2.63E-01
F21	Mean	2.11E+03	2.10E+03	**2.10E+03**	2.82E+03	1.28E+05	3.36E+04	2.10E+03	2.10E+03
	Std.	8.05E+00	3.04E+00	1.95E-01	7.27E+02	2.35E+05	0.00E+00	7.63E-01	5.61E-01
F22	Mean	2.20E+03	2.20E+03	**2.20E+03**	2.28E+03	2.34E+03	2.30E+03	2.20E+03	2.20E+03
	Std.	1.58E-01	1.86E-01	8.04E-02	6.05E+01	5.87E+01	0.00E+00	3.20E+00	1.34E+00

Table 19 (Continued)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F23	Mean	**2.48E+03**	2.63E+03	2.63E+03	2.63E+03	2.63E+03	2.63E+03	2.50E+03	2.50E+03
	Std.	1.64E+02	0.00E+00	0.00E+00	0.00E+00	8.80E-01	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.51E+03	**2.51E+03**	2.51E+03	2.51E+03	2.55E+03	2.55E+03	2.51E+03	2.51E+03
	Std.	2.54E+00	4.03E+00	2.78E+00	3.73E+00	1.58E+01	0.00E+00	3.20E+00	4.49E+00
F25	Mean	**2.62E+03**	2.62E+03	2.62E+03	2.67E+03	2.67E+03	2.67E+03	2.68E+03	2.68E+03
	Std.	4.32E+00	1.08E+01	9.81E+00	3.33E+01	1.93E+01	0.00E+00	2.73E+01	2.52E+01
F26	Mean	2.70E+03	**2.70E+03**	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	2.23E-02	3.68E-02	2.39E-02	3.93E-02	3.89E-01	0.00E+00	6.11E-02	1.14E-02
F27	Mean	2.70E+03	2.81E+03	2.74E+03	2.94E+03	2.88E+03	3.20E+03	**2.70E+03**	2.70E+03
	Std.	5.60E-01	1.44E+02	1.01E+02	1.21E+02	1.93E+02	0.00E+00	3.68E-01	5.47E-01
F28	Mean	3.15E+03	3.22E+03	3.10E+03	3.15E+03	3.19E+03	3.32E+03	**3.00E+03**	**3.00E+03**
	Std.	6.50E+01	5.71E+01	6.83E+01	1.90E+02	3.44E+00	0.00E+00	0.00E+00	0.00E+00
F29	Mean	3.12E+03	3.12E+03	**3.11E+03**	3.24E+03	3.99E+03	5.05E+03	3.12E+03	3.12E+03
	Std.	1.26E+00	3.80E-01	5.71E+00	7.36E+01	6.50E+02	0.00E+00	6.53E+00	1.68E+01
F30	Mean	3.47E+03	3.47E+03	**3.30E+03**	3.99E+03	4.44E+03	4.93E+03	3.48E+03	3.51E+03
	Std.	9.35E+00	1.61E+01	4.45E+01	2.35E+02	5.18E+02	0.00E+00	1.58E+01	1.85E+01

The bold entries are applied to highlight the best results

Table 20 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=10 (CEC2014)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	8.21E+05	4.74E+06	6.50E+06	1.77E+02	2.15E+03	**1.00E+02**	1.00E+02	1.03E+02
	Std.	2.56E+05	9.54E+06	5.26E+06	1.00E+02	2.00E+03	2.81E-06	2.36E-03	1.13E+01
F2	Mean	4.45E+07	1.03E+08	1.69E+05	**2.00E+02**	2.10E+02	**2.00E+02**	**2.00E+02**	**2.00E+02**
	Std.	1.29E+07	4.01E+08	8.45E+04	0.00E+00	5.43E+01	0.00E+00	0.00E+00	0.00E+00
F3	Mean	1.74E+04	3.46E+03	4.27E+04	**3.00E+02**	**3.00E+02**	**3.00E+02**	**3.00E+02**	**3.00E+02**
	Std.	6.80E+03	3.86E+03	1.47E+04	0.00E+00	1.29E-07	0.00E+00	0.00E+00	0.00E+00
F4	Mean	4.36E+02	4.48E+02	4.35E+02	4.24E+02	4.07E+02	4.26E+02	4.11E+02	**4.02E+02**
	Std.	2.21E+00	3.82E+01	2.23E+01	1.52E+01	1.27E+01	1.49E+01	1.56E+01	6.24E+00
F5	Mean	**5.16E+02**	5.20E+02	5.20E+02	5.19E+02	5.18E+02	5.20E+02	5.20E+02	5.19E+02
	Std.	4.82E+00	4.42E-02	9.17E-02	3.01E+00	4.76E+00	3.35E-02	1.24E+00	3.13E+00
F6	Mean	6.03E+02	6.06E+02	6.09E+02	6.00E+02	**6.00E+02**	6.01E+02	6.01E+02	6.02E+02
	Std.	5.61E-01	2.07E+00	1.20E+00	3.73E-01	5.62E-02	1.01E+00	9.12E-01	1.09E+00
F7	Mean	7.02E+02	7.11E+02	7.02E+02	**7.00E+02**	7.00E+02	7.00E+02	7.00E+02	7.00E+02
	Std.	1.61E-01	1.15E+01	7.09E-01	1.62E-02	2.06E-02	3.04E-02	5.65E-02	5.12E-02
F8	Mean	8.22E+02	8.20E+02	8.42E+02	8.00E+02	**8.00E+02**	8.00E+02	8.01E+02	8.02E+02
	Std.	3.49E+00	7.79E+00	1.31E+01	2.98E-01	2.98E-01	7.14E-01	8.14E-01	1.26E+00
F9	Mean	9.25E+02	9.30E+02	9.44E+02	9.04E+02	9.05E+02	**9.03E+02**	9.04E+02	9.07E+02
	Std.	3.37E+00	1.30E+01	1.63E+01	1.13E+00	1.51E+00	1.27E+00	1.71E+00	2.07E+00
F10	Mean	1.35E+03	1.48E+03	1.57E+03	1.03E+03	**1.01E+03**	1.03E+03	1.01E+03	1.03E+03
	Std.	1.06E+02	2.00E+02	2.60E+02	4.71E+01	2.18E+01	1.08E+01	5.51E+00	1.25E+01
F11	Mean	1.68E+03	2.03E+03	2.18E+03	1.47E+03	1.28E+03	**1.24E+03**	1.41E+03	1.44E+03
	Std.	1.24E+02	3.29E+02	3.58E+02	1.10E+02	1.30E+02	9.62E+01	1.54E+02	1.41E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**
	Std.	2.08E-01	1.90E-01	2.83E-01	7.39E-02	1.11E-01	5.71E-02	1.13E-01	5.24E-02
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**
	Std.	3.72E-02	5.26E-01	1.83E-01	2.14E-02	4.44E-02	2.41E-02	5.36E-02	1.57E-02

Table 20 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	**1.40E+03**	1.40E+03	1.40E+03
	Std.	4.01E-02	2.64E+00	1.85E-01	6.10E-02	7.59E-02	2.06E-02	4.90E-02	2.92E-02
F15	Mean	1.50E+03	1.57E+03	1.51E+03	1.50E+03	1.50E+03	**1.50E+03**	1.50E+03	1.50E+03
	Std.	5.11E-01	3.15E+02	5.02E+00	1.76E-01	2.86E-01	1.68E-01	2.26E-01	3.11E-01
F16	Mean	1.60E+03	1.60E+03	1.60E+03	1.60E+03	**1.60E+03**	1.60E+03	1.60E+03	1.60E+03
	Std.	1.43E-01	3.65E-01	3.88E-01	3.20E-01	3.49E-01	3.64E-01	3.28E-01	2.96E-01
F17	Mean	9.33E+03	1.02E+04	1.27E+05	1.79E+03	1.97E+03	**1.71E+03**	1.71E+03	1.72E+03
	Std.	2.92E+03	1.05E+04	1.77E+05	7.63E+01	3.95E+02	2.41E+00	4.64E+00	1.04E+01
F18	Mean	8.32E+03	1.24E+04	1.24E+04	1.80E+03	1.80E+03	**1.80E+03**	1.80E+03	1.80E+03
	Std.	5.61E+03	1.08E+04	1.00E+04	6.01E+00	2.17E+00	2.47E-01	3.49E-01	5.40E-01
F19	Mean	1.90E+03	1.91E+03	1.91E+03	1.90E+03	**1.90E+03**	1.90E+03	1.90E+03	1.90E+03
	Std.	4.82E-01	1.98E+00	1.52E+00	8.68E-01	3.79E-02	1.82E-01	3.93E-01	2.03E-01
F20	Mean	4.59E+03	8.24E+03	6.31E+03	2.00E+03	2.00E+03	**2.00E+03**	2.00E+03	2.00E+03
	Std.	3.73E+03	7.58E+03	3.85E+03	5.52E+00	4.21E-01	2.00E-01	2.42E-01	2.63E-01
F21	Mean	4.47E+03	3.19E+03	3.75E+04	2.11E+03	2.12E+03	**2.10E+03**	2.10E+03	2.10E+03
	Std.	1.73E+03	8.24E+02	4.00E+04	3.08E+01	5.54E+01	1.00E+00	7.63E-01	5.61E-01
F22	Mean	2.23E+03	2.28E+03	2.26E+03	2.21E+03	2.20E+03	2.20E+03	**2.20E+03**	2.20E+03
	Std.	3.45E+00	7.08E+01	4.52E+01	1.07E+01	4.94E+00	6.12E+00	3.20E+00	1.34E+00
F23	Mean	2.63E+03	2.65E+03	2.63E+03	2.63E+03	**2.50E+03**	2.63E+03	**2.50E+03**	**2.50E+03**
	Std.	3.66E-01	1.63E+01	2.34E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.55E+03	2.55E+03	2.58E+03	2.51E+03	2.51E+03	2.51E+03	**2.51E+03**	2.51E+03
	Std.	3.05E+01	3.16E+01	2.94E+01	2.59E+00	4.19E+00	1.72E+00	3.20E+00	4.49E+00
F25	Mean	2.69E+03	2.70E+03	2.68E+03	2.65E+03	**2.64E+03**	2.70E+03	2.68E+03	2.68E+03
	Std.	1.94E+01	1.01E+01	1.93E+01	3.57E+01	1.71E+01	2.06E+01	2.73E+01	2.52E+01
F26	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	**2.70E+03**
	Std.	4.07E-02	2.79E-01	1.82E-01	2.52E-02	4.66E-02	1.88E-02	6.11E-02	1.14E-02
F27	Mean	3.04E+03	3.09E+03	3.04E+03	2.90E+03	2.73E+03	2.92E+03	**2.70E+03**	2.70E+03
	Std.	9.31E+01	1.56E+02	1.52E+02	1.67E+02	6.63E+01	1.49E+02	3.68E-01	5.47E-01
F28	Mean	3.22E+03	3.29E+03	3.37E+03	3.21E+03	**3.00E+03**	3.18E+03	**3.00E+03**	**3.00E+03**
	Std.	6.29E+01	8.18E+01	1.36E+02	5.88E+01	0.00E+00	3.56E+00	0.00E+00	0.00E+00
F29	Mean	2.66E+05	2.74E+05	4.29E+03	3.17E+03	3.20E+03	**3.12E+03**	3.12E+03	3.12E+03
	Std.	6.72E+05	6.90E+05	1.63E+03	3.03E+01	7.41E+01	6.41E-01	6.53E+00	1.68E+01
F30	Mean	3.67E+03	4.48E+03	5.09E+03	3.54E+03	3.53E+03	**3.47E+03**	3.48E+03	3.51E+03
	Std.	6.21E+01	9.14E+02	7.08E+02	6.77E+01	1.03E+02	1.15E+01	1.58E+01	1.85E+01

The bold entries are applied to highlight the best results

C.2 30 Dimensions

Table 21 Comparative results against the state-of-the-art algorithms on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	4.02E+03	**1.00E+02**	1.77E+03	7.91E+04	9.16E+07	1.09E+08	6.43E+05	5.76E+05
	Std.	3.28E+03	0.00E+00	1.74E+03	1.23E+05	3.75E+07	0.00E+00	8.78E+05	9.38E+05
F2	Mean	2.00E+02	**2.00E+02**	**2.00E+02**	8.14E+03	2.76E+08	1.31E+09	**2.00E+02**	**2.00E+02**
	Std.	5.45E-05	0.00E+00	0.00E+00	5.79E+03	6.82E+07	0.00E+00	0.00E+00	0.00E+00
F3	Mean	3.00E+02	**3.00E+02**	**3.00E+02**	3.15E+02	1.10E+05	3.92E+04	**3.00E+02**	**3.00E+02**
	Std.	1.06E-05	0.00E+00	0.00E+00	2.37E+01	3.25E+04	0.00E+00	0.00E+00	0.00E+00
F4	Mean	4.00E+02	**4.00E+02**	4.02E+02	4.78E+02	6.74E+02	7.94E+02	4.50E+02	4.25E+02
	Std.	2.33E-01	0.00E+00	1.14E+01	5.12E+01	1.69E+01	0.00E+00	4.21E+01	3.69E+01
F5	Mean	5.20E+02	5.20E+02	5.20E+02	**5.20E+02**	5.21E+02	5.21E+02	5.21E+02	5.20E+02
	Std.	4.71E-02	5.21E-03	1.02E-01	2.73E-04	9.27E-02	0.00E+00	1.17E-01	1.62E-01
F6	Mean	6.10E+02	**6.00E+02**	6.01E+02	6.01E+02	6.21E+02	6.28E+02	6.02E+02	6.05E+02
	Std.	1.43E+00	0.00E+00	1.16E+00	1.14E+00	2.41E+00	0.00E+00	1.65E+00	2.97E+00
F7	Mean	**7.00E+02**	**7.00E+02**	7.00E+02	7.00E+02	7.13E+02	8.05E+02	7.00E+02	**7.00E+02**
	Std.	0.00E+00	0.00E+00	3.16E-03	1.27E-02	2.28E+00	0.00E+00	4.24E-01	0.00E+00
F8	Mean	**8.00E+02**	8.11E+02	**8.00E+02**	8.29E+02	9.64E+02	8.65E+02	8.08E+02	8.04E+02
	Std.	0.00E+00	4.20E+00	0.00E+00	6.57E+00	2.19E+01	0.00E+00	2.56E+00	3.04E+00
F9	Mean	9.58E+02	**9.12E+02**	9.33E+02	9.32E+02	1.09E+03	1.07E+03	9.19E+02	9.21E+02
	Std.	9.81E+00	3.09E+00	9.12E+00	8.39E+00	2.19E+01	0.00E+00	4.67E+00	5.22E+00
F10	Mean	1.00E+03	1.41E+03	**1.00E+03**	1.77E+03	4.09E+03	4.96E+03	1.07E+03	1.03E+03
	Std.	3.48E-01	2.02E+02	2.92E-02	2.25E+02	6.65E+02	0.00E+00	7.19E+01	3.07E+01
F11	Mean	**2.66E+03**	3.30E+03	2.90E+03	2.75E+03	5.98E+03	7.04E+03	2.78E+03	2.89E+03
	Std.	2.19E+02	4.02E+02	3.78E+02	4.96E+02	8.37E+02	0.00E+00	5.01E+02	4.90E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	3.65E-02	1.03E-01	3.78E-02	8.44E-03	5.83E-01	0.00E+00	1.49E-01	1.38E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**
	Std.	2.52E-02	2.52E-02	3.44E-02	5.55E-02	1.62E-01	0.00E+00	5.88E-02	1.52E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.41E+03	1.40E+03	**1.40E+03**
	Std.	2.08E-02	3.57E-02	5.22E-02	5.25E-02	3.29E+00	0.00E+00	2.65E-02	3.26E-02
F15	Mean	1.50E+03	**1.50E+03**	1.50E+03	1.50E+03	1.54E+03	1.53E+03	1.50E+03	1.50E+03
	Std.	4.62E-01	5.89E-01	7.28E-01	6.78E-01	9.67E+00	0.00E+00	8.72E-01	1.12E+00
F16	Mean	1.61E+03	**1.61E+03**	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03
	Std.	5.21E-01	6.89E-01	6.48E-01	7.53E-01	4.12E-01	0.00E+00	3.85E-01	6.65E-01
F17	Mean	3.07E+03	**1.90E+03**	2.18E+03	7.82E+03	2.25E+07	1.93E+07	3.92E+04	2.58E+04
	Std.	3.33E+02	9.40E+01	2.44E+02	4.78E+03	4.01E+06	0.00E+00	8.89E+04	5.69E+04
F18	Mean	1.84E+03	**1.81E+03**	1.82E+03	2.20E+03	1.83E+06	1.02E+04	1.82E+03	1.82E+03
	Std.	8.17E+00	2.75E+00	9.78E+00	4.25E+02	3.98E+05	0.00E+00	8.93E+00	1.14E+01
F19	Mean	1.90E+03	1.90E+03	**1.90E+03**	1.91E+03	2.00E+03	1.98E+03	1.91E+03	1.90E+03
	Std.	5.15E-01	7.09E-01	6.51E-01	2.86E+00	7.14E+00	0.00E+00	8.47E-01	5.15E-01
F20	Mean	2.02E+03	**2.00E+03**	2.01E+03	4.75E+03	5.77E+04	2.48E+04	2.01E+03	2.01E+03
	Std.	5.48E+00	8.13E-01	4.50E+00	1.54E+03	1.19E+04	0.00E+00	1.94E+00	3.41E+00
F21	Mean	2.57E+03	**2.21E+03**	2.25E+03	6.51E+03	2.63E+06	3.48E+06	3.88E+03	2.38E+03
	Std.	1.87E+02	7.53E+01	1.11E+02	2.78E+03	1.47E+06	0.00E+00	6.23E+03	1.85E+02
F22	Mean	2.31E+03	2.29E+03	2.29E+03	2.51E+03	3.21E+03	2.94E+03	2.24E+03	**2.23E+03**
	Std.	5.72E+01	5.82E+01	8.97E+01	1.28E+02	1.95E+02	0.00E+00	3.13E+01	1.04E+01
F23	Mean	2.62E+03	2.62E+03	2.62E+03	2.62E+03	2.67E+03	2.62E+03	**2.50E+03**	**2.50E+03**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E+01	0.00E+00	0.00E+00	0.00E+00

Table 21 Continued

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F24	Mean	2.62E+03	2.62E+03	2.62E+03	2.60E+03	2.66E+03	2.66E+03	**2.60E+03**	**2.60E+03**
	Std.	3.64E-01	8.24E-01	4.47E+00	5.59E+00	1.96E+00	0.00E+00	0.00E+00	0.00E+00
F25	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.73E+03	2.72E+03	**2.70E+03**	**2.70E+03**
	Std.	2.06E-01	1.37E-01	9.56E-01	3.66E+00	5.99E+00	0.00E+00	0.00E+00	0.00E+00
F26	Mean	2.70E+03	**2.70E+03**	2.70E+03	2.78E+03	2.70E+03	2.70E+03	2.70E+03	2.71E+03
	Std.	2.91E-02	2.93E-02	3.94E-02	3.77E+01	6.72E-01	0.00E+00	1.79E+01	2.49E+01
F27	Mean	3.09E+03	3.00E+03	3.07E+03	3.03E+03	3.57E+03	3.73E+03	**2.90E+03**	**2.90E+03**
	Std.	7.09E+01	0.00E+00	4.37E+01	3.91E+01	1.37E+02	0.00E+00	0.00E+00	0.00E+00
F28	Mean	3.72E+03	3.44E+03	3.55E+03	3.43E+03	4.81E+03	7.08E+03	**3.00E+03**	**3.00E+03**
	Std.	3.09E+01	2.59E+02	8.64E+01	2.88E+02	1.04E+03	0.00E+00	0.00E+00	0.00E+00
F29	Mean	3.66E+03	3.62E+03	5.18E+03	3.90E+03	8.74E+04	1.99E+04	**3.31E+03**	3.31E+03
	Std.	2.73E+01	3.28E+00	1.63E+03	2.03E+02	3.54E+04	0.00E+00	3.60E+02	3.28E+02
F30	Mean	4.35E+03	**3.70E+03**	4.08E+03	5.46E+03	7.00E+04	2.32E+04	4.36E+03	3.97E+03
	Std.	3.62E+02	2.24E+02	4.80E+02	1.31E+03	2.59E+04	0.00E+00	1.21E+03	1.08E+03

The bold entries are applied to highlight the best results

Table 22 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	3.77E+07	1.67E+08	2.65E+07	3.04E+06	3.92E+06	**1.91E+05**	6.43E+05	5.76E+05
	Std.	5.48E+06	1.34E+08	1.18E+07	1.40E+06	1.33E+06	1.04E+05	8.78E+05	9.38E+05
F2	Mean	2.02E+09	1.37E+10	2.00E+06	6.86E+03	2.63E+02	**2.00E+02**	**2.00E+02**	**2.00E+02**
	Std.	1.78E+08	9.30E+09	5.80E+05	1.31E+04	3.38E+02	0.00E+00	0.00E+00	0.00E+00
F3	Mean	9.47E+04	8.23E+04	5.19E+04	3.00E+02	**3.00E+02**	**3.00E+02**	**3.00E+02**	**3.00E+02**
	Std.	1.03E+04	3.64E+04	1.39E+04	8.84E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	6.30E+02	1.86E+03	5.68E+02	5.11E+02	4.73E+02	**4.03E+02**	4.50E+02	4.25E+02
	Std.	1.05E+01	1.52E+03	4.32E+01	2.70E+01	2.30E+01	1.22E+01	4.21E+01	3.69E+01
F5	Mean	5.21E+02	5.20E+02	5.20E+02	5.21E+02	**5.20E+02**	5.20E+02	5.21E+02	5.20E+02
	Std.	7.91E-02	1.37E-01	1.83E-01	5.85E-02	1.23E-01	7.18E-02	1.17E-01	1.62E-01
F6	Mean	6.19E+02	6.28E+02	6.38E+02	**6.01E+02**	6.06E+02	6.08E+02	6.02E+02	6.05E+02
	Std.	1.11E+00	3.64E+00	2.62E+00	1.18E+00	5.24E+00	2.19E+00	1.65E+00	2.97E+00
F7	Mean	7.19E+02	8.50E+02	7.01E+02	7.00E+02	7.00E+02	**7.00E+02**	7.00E+02	**7.00E+02**
	Std.	1.49E+00	9.31E+01	5.16E-02	2.60E-02	2.22E-03	0.00E+00	4.24E-01	0.00E+00
F8	Mean	9.60E+02	9.62E+02	9.95E+02	**8.03E+02**	8.05E+02	8.07E+02	8.08E+02	8.04E+02
	Std.	9.27E+00	4.09E+01	4.24E+01	2.04E+00	2.41E+00	2.24E+00	2.56E+00	3.04E+00
F9	Mean	1.07E+03	1.11E+03	1.13E+03	1.00E+03	9.53E+02	9.37E+02	**9.19E+02**	9.21E+02
	Std.	7.48E+00	4.59E+01	6.12E+01	8.46E+00	2.19E+01	1.09E+01	4.67E+00	5.22E+00
F10	Mean	5.59E+03	5.30E+03	5.10E+03	1.36E+03	1.08E+03	1.17E+03	1.07E+03	**1.03E+03**
	Std.	2.91E+02	7.89E+02	6.65E+02	2.39E+02	7.72E+01	1.15E+02	7.19E+01	3.07E+01
F11	Mean	6.75E+03	5.63E+03	6.63E+03	5.98E+03	5.09E+03	3.51E+03	**2.78E+03**	2.89E+03
	Std.	2.97E+02	9.32E+02	9.26E+02	4.10E+02	6.86E+02	4.67E+02	5.01E+02	4.90E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.20E+03	1.20E+03
	Std.	2.56E-01	2.36E-01	4.84E-01	1.61E-01	2.73E-01	9.78E-02	1.49E-01	1.38E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**	1.30E+03	**1.30E+03**
	Std.	5.04E-02	1.35E+00	1.11E-01	4.92E-02	5.60E-02	3.77E-02	5.88E-02	1.52E-02

Table 22 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F14	Mean	1.40E+03	1.47E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	**1.40E+03**
	Std.	6.07E-01	4.02E+01	3.88E-02	4.28E-02	3.09E-02	1.50E-01	2.65E-02	3.26E-02
F15	Mean	1.55E+03	1.36E+05	1.63E+03	1.51E+03	1.51E+03	**1.50E+03**	1.50E+03	1.50E+03
	Std.	3.44E+00	3.06E+05	4.18E+01	1.13E+00	2.32E+00	5.86E-01	8.72E-01	1.12E+00
F16	Mean	1.61E+03	1.61E+03	1.61E+03	1.61E+03	**1.61E+03**	1.61E+03	1.61E+03	1.61E+03
	Std.	1.89E-01	5.86E-01	5.53E-01	3.85E-01	6.29E-01	5.80E-01	3.85E-01	6.65E-01
F17	Mean	1.18E+06	5.63E+06	3.70E+06	3.16E+05	1.57E+05	**4.24E+03**	3.92E+04	2.58E+04
	Std.	2.82E+05	5.16E+06	2.37E+06	1.85E+05	9.20E+04	2.60E+03	8.89E+04	5.69E+04
F18	Mean	1.53E+07	7.90E+07	7.34E+03	2.58E+03	2.16E+03	1.82E+03	**1.82E+03**	1.82E+03
	Std.	4.77E+06	2.18E+08	4.51E+03	9.73E+02	2.98E+02	2.11E+01	8.93E+00	1.14E+01
F19	Mean	1.92E+03	2.04E+03	1.95E+03	1.91E+03	1.91E+03	1.90E+03	1.91E+03	**1.90E+03**
	Std.	1.50E+00	1.11E+02	3.48E+01	1.11E+00	8.69E-01	9.47E-01	8.47E-01	5.15E-01
F20	Mean	1.64E+04	2.82E+04	2.52E+04	2.09E+03	2.15E+03	2.01E+03	**2.01E+03**	2.01E+03
	Std.	5.61E+03	2.34E+04	1.53E+04	2.79E+01	8.30E+01	3.24E+00	1.94E+00	3.41E+00
F21	Mean	3.19E+05	9.87E+05	2.16E+06	3.05E+04	5.49E+04	**2.33E+03**	3.88E+03	2.38E+03
	Std.	8.25E+04	6.77E+05	1.69E+06	1.46E+04	4.57E+04	1.70E+02	6.23E+03	1.85E+02
F22	Mean	2.33E+03	3.03E+03	3.01E+03	2.38E+03	2.36E+03	2.29E+03	2.24E+03	**2.23E+03**
	Std.	2.70E+01	2.17E+02	2.49E+02	8.96E+01	6.98E+01	1.13E+02	3.13E+01	1.04E+01
F23	Mean	2.63E+03	2.71E+03	2.64E+03	2.62E+03	**2.50E+03**	2.62E+03	**2.50E+03**	**2.50E+03**
	Std.	2.29E+00	9.47E+01	1.40E+01	6.57E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.66E+03	2.70E+03	2.61E+03	2.63E+03	**2.60E+03**	2.61E+03	**2.60E+03**	**2.60E+03**
	Std.	1.08E+00	2.93E+01	5.74E+00	5.40E+00	0.00E+00	1.11E+01	0.00E+00	0.00E+00
F25	Mean	2.71E+03	2.73E+03	2.72E+03	2.70E+03	**2.70E+03**	2.70E+03	**2.70E+03**	**2.70E+03**
	Std.	8.51E-01	1.32E+01	1.75E+01	6.45E-01	0.00E+00	7.76E-01	0.00E+00	0.00E+00
F26	Mean	2.71E+03	2.73E+03	2.70E+03	2.71E+03	2.70E+03	**2.70E+03**	2.70E+03	2.71E+03
	Std.	4.40E+01	7.17E+01	1.14E-01	3.00E+01	4.32E-02	2.75E-02	1.79E+01	2.49E+01
F27	Mean	3.47E+03	3.75E+03	3.71E+03	3.10E+03	**2.90E+03**	3.22E+03	**2.90E+03**	**2.90E+03**
	Std.	2.69E+01	2.68E+02	4.22E+02	4.79E+01	0.00E+00	8.82E+01	0.00E+00	0.00E+00
F28	Mean	3.87E+03	5.02E+03	5.27E+03	3.62E+03	**3.00E+03**	3.61E+03	**3.00E+03**	**3.00E+03**
	Std.	2.61E+01	5.94E+02	8.00E+02	5.59E+01	0.00E+00	2.66E+01	0.00E+00	0.00E+00
F29	Mean	4.64E+05	2.23E+07	9.87E+06	4.65E+03	**3.29E+03**	3.68E+03	3.31E+03	3.31E+03
	Std.	2.08E+06	1.61E+07	5.02E+06	4.59E+02	4.33E+02	6.07E+01	3.60E+02	3.28E+02
F30	Mean	1.82E+04	1.98E+05	1.71E+05	5.23E+03	**3.60E+03**	5.87E+03	4.36E+03	3.97E+03
	Std.	1.93E+03	1.76E+05	1.64E+05	1.04E+03	8.20E+02	6.85E+02	1.21E+03	1.08E+03

The bold entries are applied to highlight the best results

C.3 100 Dimensions

Table 23 Comparative results against the state-of-the-art algorithms on functions $F1$-$F30$ with D=100 (CEC2014)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.32E+07	**3.31E+05**	4.95E+05	5.45E+06	1.61E+10	5.40E+08	5.22E+07	5.64E+07
	Std.	2.62E+06	8.23E+04	1.73E+05	6.67E+06	1.07E+09	0.00E+00	6.65E+07	1.14E+08
F2	Mean	2.23E+08	**2.00E+02**	2.00E+02	1.67E+04	5.69E+11	3.18E+10	3.36E+08	1.03E+08
	Std.	1.29E+08	0.00E+00	1.86E-02	1.24E+04	1.65E+10	3.81E-06	7.58E+08	5.51E+08
F3	Mean	1.40E+03	**3.00E+02**	3.10E+02	1.98E+03	7.62E+05	9.98E+04	1.79E+03	1.88E+04
	Std.	3.40E+02	0.00E+00	2.17E+01	1.20E+03	7.48E+04	0.00E+00	4.35E+03	5.87E+04
F4	Mean	8.55E+02	**5.30E+02**	5.45E+02	6.65E+02	2.13E+05	3.48E+03	6.13E+02	6.23E+02
	Std.	5.60E+01	3.64E+01	4.79E+01	4.22E+01	2.17E+04	0.00E+00	5.30E+01	6.70E+01
F5	Mean	5.21E+02	5.20E+02	5.20E+02	**5.20E+02**	5.21E+02	5.21E+02	5.21E+02	5.21E+02
	Std.	4.97E-02	1.64E-01	2.01E-01	9.83E-05	2.40E-02	0.00E+00	1.59E-01	2.25E-01
F6	Mean	6.86E+02	**6.04E+02**	6.44E+02	6.18E+02	7.72E+02	7.11E+02	6.18E+02	6.35E+02
	Std.	2.17E+00	2.00E+00	7.15E+00	4.98E+00	2.78E-01	0.00E+00	4.81E+00	1.40E+01
F7	Mean	7.04E+02	**7.00E+02**	7.00E+02	7.00E+02	5.63E+03	1.06E+03	7.01E+02	**7.00E+02**
	Std.	1.55E+00	0.00E+00	7.11E-03	4.12E-03	1.80E+02	0.00E+00	4.44E-01	0.00E+00
F8	Mean	8.35E+02	8.56E+02	**8.00E+02**	9.94E+02	2.74E+03	1.50E+03	8.67E+02	8.46E+02
	Std.	7.15E+00	9.80E+00	0.00E+00	2.50E+01	3.58E+01	0.00E+00	1.02E+01	8.06E+00
F9	Mean	1.14E+03	**9.52E+02**	1.15E+03	1.10E+03	3.13E+03	2.15E+03	1.02E+03	1.02E+03
	Std.	2.01E+01	8.75E+00	3.06E+01	2.90E+01	8.74E+01	0.00E+00	1.74E+01	2.01E+01
F10	Mean	1.94E+03	9.84E+03	**1.00E+03**	6.67E+03	3.43E+04	1.80E+04	4.77E+03	5.01E+03
	Std.	2.72E+02	8.91E+02	3.80E-01	6.34E+02	5.62E+02	0.00E+00	1.04E+03	9.12E+02
F11	Mean	1.36E+04	1.27E+04	1.27E+04	**8.30E+03**	3.46E+04	2.45E+04	9.93E+03	1.14E+04
	Std.	5.64E+02	1.23E+03	9.22E+02	7.26E+02	6.95E+02	0.00E+00	1.12E+03	1.11E+03
F12	Mean	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.21E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	7.12E-02	2.25E-01	6.39E-02	5.94E-03	3.76E-01	0.00E+00	7.88E-01	5.82E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.31E+03	1.30E+03	1.30E+03	**1.30E+03**
	Std.	3.76E-02	3.77E-02	4.49E-02	6.85E-02	3.58E-01	0.00E+00	5.24E-02	3.61E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	2.82E+03	1.52E+03	1.40E+03	**1.40E+03**
	Std.	2.56E-02	2.90E-02	3.28E-02	2.93E-02	8.74E+01	0.00E+00	1.35E-02	1.80E-02
F15	Mean	1.61E+03	**1.51E+03**	1.53E+03	1.51E+03	3.14E+08	3.67E+04	1.51E+03	1.54E+03
	Std.	2.56E+01	2.38E+00	6.02E+00	2.68E+00	5.05E+07	0.00E+00	2.60E+00	1.57E+01
F16	Mean	1.64E+03	1.64E+03	**1.64E+03**	1.64E+03	1.65E+03	1.65E+03	1.64E+03	1.64E+03
	Std.	4.99E-01	1.26E+00	8.56E-01	9.64E-01	2.73E-01	0.00E+00	8.90E-01	1.36E+00
F17	Mean	2.78E+05	**5.89E+03**	1.27E+05	1.99E+05	2.30E+09	9.57E+07	2.00E+06	8.53E+06
	Std.	1.23E+05	6.46E+02	5.29E+04	8.17E+04	3.98E+08	0.00E+00	3.69E+06	3.58E+07
F18	Mean	2.51E+03	**2.03E+03**	2.76E+03	2.39E+03	6.24E+10	6.86E+09	2.45E+03	2.60E+03
	Std.	3.50E+02	1.73E+01	9.33E+02	3.65E+02	8.51E+09	0.00E+00	2.99E+02	3.81E+02
F19	Mean	2.00E+03	1.98E+03	1.99E+03	**1.96E+03**	1.65E+04	2.32E+03	2.00E+03	1.99E+03
	Std.	1.93E+01	2.22E+01	2.30E+01	1.98E+01	1.50E+03	0.00E+00	2.84E+00	2.54E+00
F20	Mean	2.37E+03	**2.06E+03**	2.32E+03	8.10E+03	1.37E+07	1.42E+05	2.78E+03	3.04E+03
	Std.	5.36E+01	1.27E+01	1.15E+02	3.15E+03	6.64E+06	0.00E+00	4.14E+02	1.25E+03
F21	Mean	4.94E+04	**3.40E+03**	5.12E+04	6.71E+04	1.00E+09	1.40E+08	8.93E+05	2.80E+06
	Std.	2.16E+04	3.92E+02	2.69E+04	4.23E+04	1.00E+08	0.00E+00	7.93E+05	7.69E+06
F22	Mean	3.61E+03	3.41E+03	3.86E+03	3.72E+03	4.82E+05	4.67E+03	**2.88E+03**	3.13E+03
	Std.	2.08E+02	3.63E+02	2.54E+02	4.22E+02	2.62E+05	0.00E+00	3.26E+02	3.18E+02
F23	Mean	2.66E+03	2.65E+03	2.65E+03	2.65E+03	9.16E+03	3.07E+03	**2.50E+03**	**2.50E+03**
	Std.	3.21E+00	0.00E+00	0.00E+00	3.79E+00	6.39E+02	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.80E+03	2.78E+03	2.75E+03	2.77E+03	4.15E+03	2.96E+03	2.60E+03	**2.60E+03**
	Std.	3.31E+00	3.08E+00	9.12E+00	4.53E+00	1.11E+02	0.00E+00	0.00E+00	0.00E+00

Table 23 (Continued)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F25	Mean	2.72E+03	2.70E+03	2.73E+03	2.70E+03	3.96E+03	2.85E+03	**2.70E+03**	**2.70E+03**
	Std.	7.99E+00	0.00E+00	2.70E+01	0.00E+00	7.23E+01	0.00E+00	0.00E+00	0.00E+00
F26	Mean	**2.72E+03**	2.80E+03	2.79E+03	2.80E+03	3.83E+03	2.83E+03	2.80E+03	2.80E+03
	Std.	3.98E+01	0.00E+00	2.49E+01	2.86E-02	1.05E+02	0.00E+00	0.00E+00	1.79E+01
F27	Mean	4.11E+03	3.05E+03	3.99E+03	3.47E+03	8.81E+03	5.89E+03	**2.90E+03**	2.90E+03
	Std.	6.28E+02	3.37E+01	1.26E+02	2.76E+02	2.56E+02	0.00E+00	0.00E+00	0.00E+00
F28	Mean	6.93E+03	4.87E+03	5.65E+03	9.83E+03	3.76E+04	1.58E+04	**3.00E+03**	3.00E+03
	Std.	1.36E+03	4.12E+02	4.71E+02	1.77E+03	1.00E+03	0.00E+00	0.00E+00	0.00E+00
F29	Mean	7.31E+03	3.65E+03	3.41E+04	5.13E+03	6.21E+09	8.47E+06	**3.10E+03**	**3.10E+03**
	Std.	7.09E+02	3.32E+01	1.99E+04	4.01E+02	6.70E+08	0.00E+00	0.00E+00	0.00E+00
F30	Mean	2.15E+04	8.89E+03	1.03E+04	3.34E+05	2.04E+08	8.85E+05	**3.20E+03**	**3.20E+03**
	Std.	2.80E+03	3.20E+02	1.56E+03	9.86E+04	2.47E+07	0.00E+00	0.00E+00	0.00E+00

The bold entries are applied to highlight the best results

Table 24 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=100 (CEC2014)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	7.71E+08	2.75E+09	2.38E+08	5.02E+07	3.48E+07	**6.22E+06**	5.22E+07	5.64E+07
	Std.	5.23E+07	1.08E+09	4.54E+07	1.44E+07	5.49E+06	1.86E+06	6.65E+07	1.14E+08
F2	Mean	2.97E+10	2.05E+11	1.38E+08	3.03E+09	**1.37E+04**	2.92E+04	3.36E+08	1.03E+08
	Std.	1.25E+09	4.64E+10	2.27E+07	1.33E+09	1.27E+04	3.72E+04	7.58E+08	5.51E+08
F3	Mean	5.21E+05	3.67E+05	2.74E+05	7.61E+03	1.43E+03	**3.07E+02**	1.79E+03	1.88E+04
	Std.	3.05E+04	9.15E+04	3.10E+04	2.61E+03	3.47E+02	8.17E+00	4.35E+03	5.87E+04
F4	Mean	2.54E+03	4.44E+04	1.06E+03	1.18E+03	**5.83E+02**	5.94E+02	6.13E+02	6.23E+02
	Std.	8.14E+01	1.29E+04	9.52E+01	1.34E+02	4.15E+01	2.99E+01	5.30E+01	6.70E+01
F5	Mean	5.21E+02	5.20E+02	5.21E+02	5.21E+02	**5.20E+02**	5.20E+02	5.21E+02	5.21E+02
	Std.	2.38E-02	1.40E-01	1.38E-01	1.79E-02	1.12E-01	8.42E-02	1.59E-01	2.25E-01
F6	Mean	6.98E+02	7.35E+02	7.52E+02	6.28E+02	6.22E+02	6.64E+02	**6.18E+02**	6.35E+02
	Std.	1.62E+00	7.19E+00	5.68E+00	3.97E+00	4.15E+00	8.87E+00	4.81E+00	1.40E+01
F7	Mean	9.52E+02	2.69E+03	7.02E+02	7.33E+02	7.00E+02	**7.00E+02**	7.01E+02	**7.00E+02**
	Std.	9.85E+00	3.68E+02	1.35E-01	7.09E+00	8.79E-02	0.00E+00	4.44E-01	0.00E+00
F8	Mean	1.66E+03	1.86E+03	1.46E+03	9.15E+02	9.11E+02	8.89E+02	8.67E+02	**8.46E+02**
	Std.	1.83E+01	9.46E+01	6.40E+01	2.05E+01	2.05E+01	1.40E+01	1.02E+01	8.06E+00
F9	Mean	1.81E+03	2.17E+03	1.67E+03	1.67E+03	1.42E+03	1.05E+03	1.02E+03	**1.02E+03**
	Std.	1.70E+01	1.37E+02	1.07E+02	3.40E+01	2.15E+02	2.33E+01	1.74E+01	2.01E+01
F10	Mean	2.72E+04	2.05E+04	1.99E+04	1.25E+04	**2.96E+03**	6.92E+03	4.77E+03	5.01E+03
	Std.	4.90E+02	1.75E+03	3.27E+03	4.62E+03	6.46E+02	9.99E+02	1.04E+03	9.12E+02
F11	Mean	2.93E+04	1.99E+04	2.46E+04	2.99E+04	1.72E+04	1.54E+04	**9.93E+03**	1.14E+04
	Std.	5.44E+02	1.60E+03	3.06E+03	4.74E+02	1.86E+03	1.35E+03	1.12E+03	1.11E+03
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	**1.20E+03**	1.20E+03	1.20E+03
	Std.	2.33E-01	3.87E-01	4.58E-01	2.20E-01	3.87E-01	1.37E-01	7.88E-01	5.82E-01
F13	Mean	1.30E+03	1.31E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	**1.30E+03**
	Std.	5.73E-02	8.43E-01	6.04E-02	5.52E-02	5.68E-02	5.14E-02	5.24E-02	3.61E-02
F14	Mean	1.47E+03	1.96E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	**1.40E+03**
	Std.	1.98E+00	1.20E+02	1.25E-01	2.59E-02	2.32E-02	3.09E-01	1.35E-02	1.80E-02
F15	Mean	1.28E+04	9.88E+06	2.94E+03	1.70E+03	1.55E+03	1.52E+03	**1.51E+03**	1.54E+03
	Std.	1.82E+03	8.74E+06	3.83E+02	9.36E+01	1.07E+01	2.48E+00	2.60E+00	1.57E+01

Table 24 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F16	Mean	1.65E+03	1.65E+03	1.65E+03	1.65E+03	1.65E+03	**1.64E+03**	1.64E+03	1.64E+03
	Std.	2.34E-01	7.73E-01	9.27E-01	3.17E-01	9.30E-01	1.01E+00	8.90E-01	1.36E+00
F17	Mean	5.23E+07	2.00E+08	1.20E+07	8.54E+06	2.17E+06	**1.01E+06**	2.00E+06	8.53E+06
	Std.	5.98E+06	1.03E+08	4.40E+06	3.11E+06	7.33E+05	4.75E+05	3.69E+06	3.58E+07
F18	Mean	1.11E+09	7.04E+09	3.45E+05	3.25E+05	2.71E+03	1.06E+04	**2.45E+03**	2.60E+03
	Std.	1.26E+08	5.22E+09	1.04E+06	1.67E+06	8.31E+02	7.85E+03	2.99E+02	3.81E+02
F19	Mean	2.17E+03	3.85E+03	2.17E+03	2.05E+03	2.00E+03	1.99E+03	2.00E+03	**1.99E+03**
	Std.	8.12E+00	6.06E+02	5.09E+01	2.84E+01	2.02E+01	2.64E+00	2.84E+00	2.54E+00
F20	Mean	2.48E+05	4.30E+05	9.22E+04	3.41E+03	3.62E+03	**2.47E+03**	2.78E+03	3.04E+03
	Std.	3.83E+04	1.91E+05	1.99E+04	2.96E+02	2.39E+02	8.93E+01	4.14E+02	1.25E+03
F21	Mean	2.62E+07	7.42E+07	1.15E+07	6.48E+06	1.59E+06	**3.40E+05**	8.93E+05	2.80E+06
	Std.	2.34E+06	4.07E+07	4.26E+06	1.37E+06	5.28E+05	1.63E+05	7.93E+05	7.69E+06
F22	Mean	5.98E+03	6.75E+03	7.19E+03	4.58E+03	4.59E+03	4.09E+03	**2.88E+03**	3.13E+03
	Std.	1.64E+02	1.46E+03	1.05E+03	3.23E+02	6.68E+02	3.55E+02	3.26E+02	3.18E+02
F23	Mean	2.95E+03	3.86E+03	2.57E+03	2.67E+03	**2.50E+03**	2.65E+03	**2.50E+03**	**2.50E+03**
	Std.	1.75E+01	4.67E+02	1.22E+02	7.24E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.96E+03	3.52E+03	2.60E+03	2.81E+03	**2.60E+03**	2.77E+03	**2.60E+03**	**2.60E+03**
	Std.	4.01E+00	1.35E+02	8.52E-01	7.13E+00	0.00E+00	3.19E+00	0.00E+00	0.00E+00
F25	Mean	2.83E+03	2.98E+03	**2.70E+03**	2.76E+03	**2.70E+03**	2.73E+03	**2.70E+03**	**2.70E+03**
	Std.	5.28E+00	7.31E+01	0.00E+00	8.02E+00	0.00E+00	8.16E+00	0.00E+00	0.00E+00
F26	Mean	**2.79E+03**	2.93E+03	2.80E+03	2.80E+03	2.80E+03	2.87E+03	2.80E+03	2.80E+03
	Std.	8.52E+01	6.37E+01	0.00E+00	5.10E-01	0.00E+00	1.43E+02	0.00E+00	1.79E+01
F27	Mean	5.54E+03	6.71E+03	7.34E+03	3.86E+03	**2.90E+03**	4.02E+03	**2.90E+03**	2.90E+03
	Std.	4.03E+01	1.94E+02	2.15E+02	1.16E+02	0.00E+00	2.53E+02	0.00E+00	0.00E+00
F28	Mean	6.65E+03	1.36E+04	2.16E+04	6.43E+03	**3.00E+03**	4.98E+03	**3.00E+03**	3.00E+03
	Std.	1.15E+02	2.24E+03	3.52E+03	5.17E+02	0.00E+00	4.87E+01	0.00E+00	0.00E+00
F29	Mean	1.61E+07	9.22E+08	4.67E+08	2.02E+05	**3.10E+03**	8.34E+07	**3.10E+03**	**3.10E+03**
	Std.	1.91E+06	2.69E+08	2.71E+08	4.62E+05	0.00E+00	4.23E+05	0.00E+00	0.00E+00
F30	Mean	6.36E+05	1.93E+07	2.18E+06	7.72E+04	**3.20E+03**	1.22E+04	**3.20E+03**	**3.20E+03**
	Std.	6.81E+04	9.95E+06	1.35E+06	4.52E+04	0.00E+00	9.28E+02	0.00E+00	0.00E+00

The bold entries are applied to highlight the best results

Appendix D: The comparative results on the CEC2021 set

D.1 10 Dimensions

Table 25 Comparative results against the state-of-the-art algorithms on functions $F1$-$F10$ with D=10 (CEC2021)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
B-F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.09E-04	7.19E+06	6.64E+05	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.44E-04	3.29E+06	0.00E+00	0.00E+00	0.00E+00
B-F2	Mean	**0.00E+00**	6.29E-01	6.25E-03	3.63E+01	6.22E+02	8.91E+02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	9.75E-01	1.87E-02	7.27E+01	2.35E+02	0.00E+00	0.00E+00	0.00E+00
B-F3	Mean	**0.00E+00**	1.14E+01	9.79E+00	1.73E+01	5.46E+01	8.46E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	5.75E-01	3.26E+00	2.84E+00	9.05E+00	0.00E+00	0.00E+00	0.00E+00
B-F4	Mean	2.34E-02	4.59E-01	2.96E-01	7.78E-01	3.74E+00	3.38E+00	**0.00E+00**	**0.00E+00**
	Std.	1.78E-02	1.19E-01	7.21E-02	2.91E-01	9.33E-01	0.00E+00	0.00E+00	0.00E+00
B-F5	Mean	**0.00E+00**	1.32E-01	0.00E+00	1.40E+01	1.61E+03	1.30E+03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	1.37E-01	0.00E+00	2.16E+01	5.62E+02	0.00E+00	0.00E+00	0.00E+00
B-F6	Mean	2.00E-02	4.52E-01	2.50E-02	1.08E+00	1.93E+02	2.35E+02	**0.00E+00**	**0.00E+00**
	Std.	9.52E-03	2.35E-01	3.96E-02	2.16E+00	5.88E+01	0.00E+00	0.00E+00	0.00E+00
B-F7	Mean	1.24E-03	1.52E-01	1.74E-02	6.79E+00	7.12E+02	9.85E+02	**0.00E+00**	**0.00E+00**
	Std.	1.99E-03	2.21E-01	5.90E-02	2.16E+01	2.99E+02	0.00E+00	0.00E+00	0.00E+00
B-F8	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.88E+01	8.17E+02	2.58E+02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.24E+01	1.60E+02	0.00E+00	0.00E+00	0.00E+00
B-F9	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.29E+01	1.33E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.26E+00	0.00E+00	0.00E+00	0.00E+00
B-F10	Mean	5.94E-05	4.80E+01	4.64E+01	4.82E+01	5.28E+01	5.11E+01	**0.00E+00**	**0.00E+00**
	Std.	6.21E-05	3.15E-02	8.61E+00	1.26E-01	1.30E+00	0.00E+00	0.00E+00	0.00E+00
S-F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.23E-04	6.31E+06	8.26E+05	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	2.55E-04	1.79E+06	0.00E+00	0.00E+00	0.00E+00
S-F2	Mean	**0.00E+00**	7.90E+00	1.46E-02	1.12E+02	5.69E+02	9.28E+02	9.30E+00	1.19E+01
	Std.	0.00E+00	2.27E+01	3.09E-02	6.71E+01	2.43E+02	0.00E+00	8.85E+00	8.04E+00
S-F3	Mean	**1.09E+01**	1.13E+01	1.09E+01	1.69E+01	5.08E+01	6.52E+01	1.11E+01	1.14E+01
	Std.	0.00E+00	3.29E-01	0.00E+00	3.53E+00	7.78E+00	0.00E+00	2.24E-01	4.79E-01
S-F4	Mean	**1.09E-01**	5.07E-01	3.14E-01	7.56E-01	5.04E+00	4.68E+00	6.43E-01	3.96E-01
	Std.	5.97E-02	1.02E-01	6.72E-02	1.98E-01	5.47E-01	0.00E+00	1.32E-01	7.13E-02
S-F5	Mean	**0.00E+00**	9.29E+00	6.94E-03	1.07E+02	2.10E+03	1.21E+03	1.28E-01	3.47E-02
	Std.	0.00E+00	2.96E+01	3.74E-02	5.80E+01	8.59E+02	0.00E+00	1.13E-01	7.76E-02
S-F6	Mean	**2.43E-02**	8.02E-01	2.94E-02	1.79E+01	2.82E+02	5.63E+01	5.91E-01	2.42E-01
	Std.	7.46E-03	1.13E+00	7.28E-02	3.03E+01	6.99E+01	0.00E+00	3.12E-01	1.78E-01
S-F7	Mean	**1.85E-03**	3.22E-01	2.03E-02	4.12E+01	1.27E+03	1.04E+03	2.17E-01	1.72E-02
	Std.	2.47E-03	2.54E-01	7.46E-02	5.26E+01	5.52E+02	0.00E+00	1.66E-01	5.62E-02
S-F8	Mean	**7.78E+00**	1.00E+02	9.00E+01	1.02E+02	1.13E+02	1.07E+02	8.70E+01	8.73E+01
	Std.	2.49E+01	0.00E+00	3.00E+01	6.12E-01	1.32E+00	0.00E+00	3.41E+01	3.26E+01
S-F9	Mean	**9.33E+01**	3.03E+02	2.45E+02	3.32E+02	3.52E+02	3.56E+02	3.16E+02	3.25E+02
	Std.	2.49E+01	6.96E+01	9.52E+01	7.05E+00	2.71E+00	0.00E+00	4.09E+01	6.91E+00
S-F10	Mean	**4.00E+02**	**4.00E+02**	**4.00E+02**	4.00E+02	4.70E+02	4.03E+02	4.00E+02	**4.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.82E+01	0.00E+00	0.00E+00	0.00E+00
BS-F1	Mean	**1.00E+02**	**1.00E+02**	**1.00E+02**	1.00E+02	6.73E+06	8.26E+05	**1.00E+02**	**1.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	2.32E-04	2.38E+06	0.00E+00	0.00E+00	0.00E+00
BS-F2	Mean	**1.10E+03**	1.11E+03	1.10E+03	1.21E+03	1.51E+03	2.03E+03	1.11E+03	1.11E+03
	Std.	0.00E+00	2.08E+01	1.56E-02	6.79E+01	1.45E+02	0.00E+00	6.92E+00	5.98E+00

Table 25 Continued

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
BS-F3	Mean	**7.11E+02**	7.11E+02	**7.11E+02**	7.18E+02	7.49E+02	7.65E+02	7.11E+02	7.11E+02
	Std.	0.00E+00	4.24E-01	0.00E+00	3.75E+00	6.93E+00	0.00E+00	1.59E-01	3.67E-01
BS-F4	Mean	**1.90E+03**	1.90E+03	1.90E+03	1.90E+03	1.91E+03	1.90E+03	1.90E+03	1.90E+03
	Std.	5.94E-02	1.17E-01	7.82E-02	2.09E-01	8.67E-01	0.00E+00	1.91E-01	7.15E-02
BS-F5	Mean	**1.70E+03**	1.71E+03	1.70E+03	1.79E+03	5.30E+03	2.91E+03	1.70E+03	1.70E+03
	Std.	0.00E+00	2.30E+01	3.74E-02	5.68E+01	4.16E+03	0.00E+00	1.14E-01	1.22E-01
BS-F6	Mean	**1.60E+03**	1.60E+03	1.60E+03	1.62E+03	1.71E+03	1.66E+03	1.60E+03	1.60E+03
	Std.	1.13E-02	1.50E+00	8.89E-02	2.45E+01	1.11E+02	0.00E+00	1.98E-01	1.81E-01
BS-F7	Mean	**2.10E+03**	2.10E+03	2.10E+03	2.12E+03	3.13E+03	3.14E+03	2.10E+03	2.10E+03
	Std.	2.72E-02	4.14E+00	2.18E-02	3.96E+01	4.62E+02	0.00E+00	1.71E-01	5.97E-02
BS-F8	Mean	**2.20E+03**	2.30E+03	2.29E+03	2.30E+03	2.32E+03	2.31E+03	2.29E+03	2.29E+03
	Std.	1.80E+01	0.00E+00	2.49E+01	6.30E-01	2.54E+00	0.00E+00	2.51E+01	2.28E+01
BS-F9	Mean	**2.48E+03**	2.72E+03	2.64E+03	2.72E+03	2.76E+03	2.76E+03	2.72E+03	2.73E+03
	Std.	3.63E+01	7.14E+00	9.80E+01	4.21E+01	5.90E+00	0.00E+00	8.39E+00	5.01E+00
BS-F10	Mean	**2.90E+03**	**2.90E+03**	**2.90E+03**	2.90E+03	2.99E+03	2.90E+03	**2.90E+03**	**2.90E+03**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E+01	0.00E+00	4.71E-06	0.00E+00

The bold entries are applied to highlight the best results

Table 26 (Cont'd) Comparative results against the state-of-the-art algorithms on functions $F1$-$F10$ with D=10 (CEC2021)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
SR-F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	9.76E+02	7.91E+06	1.53E+06	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.53E+03	4.42E+06	0.00E+00	0.00E+00	0.00E+00
SR-F2	Mean	4.11E+01	**3.18E+01**	4.34E+01	1.69E+02	7.79E+02	1.41E+03	3.75E+01	5.78E+01
	Std.	4.51E+01	5.43E+01	4.86E+01	1.40E+02	4.79E+02	0.00E+00	3.61E+01	6.27E+01
SR-F3	Mean	1.39E+01	**1.26E+01**	1.33E+01	1.94E+01	5.59E+01	7.06E+01	1.27E+01	1.36E+01
	Std.	2.60E+00	9.14E-01	1.66E+00	4.32E+00	8.38E+00	0.00E+00	1.11E+00	1.42E+00
SR-F4	Mean	**1.68E-01**	4.73E-01	4.83E-01	9.01E-01	4.82E+00	3.16E+00	6.57E-01	5.71E-01
	Std.	1.05E-01	1.32E-01	1.44E-01	3.48E-01	5.91E-01	0.00E+00	3.55E-01	1.24E-01
SR-F5	Mean	6.45E+01	1.84E+01	**3.23E-01**	9.71E+02	7.05E+05	2.49E+05	2.63E+00	4.82E+00
	Std.	6.37E+01	2.98E+01	3.20E-01	7.37E+02	8.60E+05	0.00E+00	8.96E+00	2.13E+00
SR-F6	Mean	2.37E-01	2.75E-01	**1.58E-01**	7.62E+01	1.82E+02	2.24E+01	1.22E+00	6.65E-01
	Std.	1.52E-01	2.05E-01	1.49E-01	8.92E+01	8.78E+01	0.00E+00	1.97E+00	2.97E-01
SR-F7	Mean	3.50E+00	7.23E-01	**1.38E-01**	1.24E+02	4.44E+04	1.30E+04	1.64E+00	3.21E-01
	Std.	6.68E+00	2.99E+00	1.57E-01	9.17E+01	4.37E+04	0.00E+00	4.16E+00	3.45E-01
SR-F8	Mean	**2.98E+01**	1.00E+02	1.00E+02	1.02E+02	1.14E+02	1.10E+02	1.01E+02	8.91E+01
	Std.	2.85E+01	0.00E+00	1.23E-01	6.31E-01	1.13E+00	0.00E+00	4.09E-01	2.70E+01
SR-F9	Mean	**7.33E+01**	3.04E+02	2.39E+02	3.34E+02	3.59E+02	3.64E+02	3.29E+02	3.32E+02
	Std.	4.42E+01	6.81E+01	1.13E+02	4.24E+00	9.28E+00	0.00E+00	6.12E+00	2.01E+00
SR-F10	Mean	**3.98E+02**	4.27E+02	4.13E+02	4.39E+02	4.54E+02	4.49E+02	4.00E+02	4.01E+02
	Std.	5.03E-04	2.17E+01	2.16E+01	1.63E+01	2.88E+00	0.00E+00	8.18E+00	8.22E+00
BSR-F1	Mean	**1.00E+02**	**1.00E+02**	**1.00E+02**	1.14E+03	1.20E+07	1.53E+06	**1.00E+02**	**1.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.57E+03	5.88E+06	0.00E+00	0.00E+00	0.00E+00
BSR-F2	Mean	1.13E+03	**1.11E+03**	1.14E+03	1.31E+03	2.25E+03	2.51E+03	1.13E+03	1.16E+03
	Std.	3.55E+01	5.96E+00	4.70E+01	1.47E+02	1.96E+02	0.00E+00	1.82E+01	5.47E+01
BSR-F3	Mean	7.14E+02	7.13E+02	7.13E+02	7.20E+02	7.64E+02	7.71E+02	**7.12E+02**	7.13E+02
	Std.	1.26E+00	9.72E-01	2.35E+00	4.25E+00	4.62E+00	0.00E+00	7.09E-01	8.88E-01

Table 26 continued

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
BSR-F4	Mean	**1.90E+03**	1.90E+03	1.90E+03	1.90E+03	1.91E+03	1.90E+03	1.90E+03	1.90E+03
	Std.	1.46E-01	1.38E-01	1.11E-01	2.97E-01	1.27E+00	0.00E+00	2.88E-01	1.25E-01
BSR-F5	Mean	1.78E+03	1.73E+03	**1.70E+03**	2.94E+03	8.86E+05	2.51E+05	1.70E+03	1.70E+03
	Std.	7.14E+01	4.37E+01	2.07E+00	9.17E+02	1.26E+06	0.00E+00	8.33E-01	6.36E+00
BSR-F6	Mean	1.60E+03	1.60E+03	**1.60E+03**	1.65E+03	1.73E+03	1.62E+03	1.60E+03	1.60E+03
	Std.	2.51E-01	1.87E-01	2.27E-01	7.91E+01	4.47E+01	0.00E+00	3.74E-01	2.61E-01
BSR-F7	Mean	2.10E+03	2.10E+03	**2.10E+03**	2.23E+03	2.65E+04	1.51E+04	2.10E+03	2.10E+03
	Std.	6.67E+00	2.97E+00	1.59E-01	1.12E+02	1.41E+04	0.00E+00	6.71E-01	2.89E-01
BSR-F8	Mean	**2.22E+03**	2.30E+03	2.30E+03	2.30E+03	2.31E+03	2.31E+03	2.30E+03	2.30E+03
	Std.	1.37E+01	0.00E+00	1.80E+01	8.36E-01	2.30E+01	0.00E+00	2.17E+01	1.46E+01
BSR-F9	Mean	**2.48E+03**	2.69E+03	2.65E+03	2.73E+03	2.76E+03	2.76E+03	2.71E+03	2.72E+03
	Std.	4.23E+01	7.63E+01	1.11E+02	4.26E+01	4.62E+00	0.00E+00	6.88E+01	5.76E+01
BSR-F10	Mean	**2.89E+03**	2.93E+03	2.92E+03	2.94E+03	2.96E+03	2.95E+03	2.90E+03	2.90E+03
	Std.	5.34E+01	2.21E+01	2.27E+01	1.87E+01	2.88E+00	0.00E+00	1.59E+01	8.35E+00

The bold entries are applied to highlight the best results

Table 27 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F10$ with D=10 (CEC2021)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
B-F1	Mean	2.91E+07	4.00E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	7.67E+06	4.90E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F2	Mean	3.86E+02	6.01E+02	**0.00E+00**	1.50E-01	**0.00E+00**	1.62E-01	**0.00E+00**	**0.00E+00**
	Std.	9.53E+01	2.41E+02	0.00E+00	8.00E-02	0.00E+00	7.69E-02	0.00E+00	0.00E+00
B-F3	Mean	4.40E+01	3.52E+01	**0.00E+00**	9.06E+00	**0.00E+00**	1.09E+01	**0.00E+00**	**0.00E+00**
	Std.	4.46E+00	2.30E+01	0.00E+00	4.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F4	Mean	2.80E+00	1.16E+00	5.72E-03	4.42E-01	**0.00E+00**	3.27E-01	**0.00E+00**	**0.00E+00**
	Std.	3.97E-01	4.81E-01	3.08E-02	7.04E-02	0.00E+00	5.87E-02	0.00E+00	0.00E+00
B-F5	Mean	5.38E+03	1.94E+03	**0.00E+00**	4.23E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.80E+03	2.92E+03	0.00E+00	5.25E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F6	Mean	1.28E+01	3.75E+01	1.39E-01	3.16E-01	**0.00E+00**	3.71E-02	**0.00E+00**	**0.00E+00**
	Std.	2.56E+00	5.46E+01	3.22E-01	3.70E-01	0.00E+00	4.06E-02	0.00E+00	0.00E+00
B-F7	Mean	1.54E+03	5.17E+02	2.27E-02	2.27E+01	**0.00E+00**	1.19E-02	**0.00E+00**	**0.00E+00**
	Std.	4.73E+02	7.62E+02	5.64E-02	4.33E+01	0.00E+00	5.62E-02	0.00E+00	0.00E+00
B-F8	Mean	1.66E+02	4.60E+02	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.62E+01	2.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F9	Mean	3.56E+01	9.15E-01	3.31E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.41E+00	1.89E+00	1.24E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F10	Mean	5.30E+01	6.19E+01	7.67E-02	4.81E+01	**0.00E+00**	4.80E+01	**0.00E+00**	**0.00E+00**
	Std.	5.08E-01	1.62E+01	2.83E-02	2.91E-01	0.00E+00	2.66E-03	0.00E+00	0.00E+00
S-F1	Mean	3.42E+07	3.44E+08	6.56E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	7.67E+06	5.05E+08	5.46E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S-F2	Mean	3.52E+02	6.67E+02	8.43E+02	**2.01E+00**	4.91E+00	6.96E+00	9.30E+00	1.19E+01
	Std.	8.68E+01	2.91E+02	2.89E+02	2.56E+00	4.86E+00	2.39E+01	8.85E+00	8.04E+00
S-F3	Mean	4.32E+01	3.45E+01	7.79E+01	**1.05E+01**	1.10E+01	1.09E+01	1.11E+01	1.14E+01
	Std.	3.39E+00	1.76E+01	2.19E+01	1.95E+00	1.75E-01	0.00E+00	2.24E-01	4.79E-01
S-F4	Mean	2.96E+00	3.81E+01	5.46E+00	4.63E-01	**2.99E-01**	3.36E-01	6.43E-01	3.96E-01
	Std.	4.14E-01	1.10E+02	3.71E+00	6.43E-02	7.97E-02	5.71E-02	1.32E-01	7.13E-02

Table 27 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
S-F5	Mean	5.89E+03	9.07E+02	1.19E+04	1.04E+02	5.71E+00	**6.94E-03**	1.28E-01	3.47E-02
	Std.	2.31E+03	5.02E+02	1.40E+04	5.97E+01	2.13E+01	3.74E-02	1.13E-01	7.76E-02
S-F6	Mean	1.36E+01	8.68E+01	1.11E+02	6.89E-01	7.52E-01	**7.50E-02**	5.91E-01	2.42E-01
	Std.	4.24E+00	7.72E+01	6.83E+01	8.68E-01	2.06E+00	7.11E-02	3.12E-01	1.78E-01
S-F7	Mean	1.45E+03	6.05E+02	6.47E+03	6.06E+01	4.74E+00	4.31E-02	2.17E-01	**1.72E-02**
	Std.	5.17E+02	4.04E+02	7.72E+03	7.63E+01	2.13E+01	1.06E-01	1.66E-01	5.62E-02
S-F8	Mean	1.16E+02	1.53E+02	1.08E+02	9.67E+01	**8.45E+01**	1.00E+02	8.70E+01	8.73E+01
	Std.	1.25E+00	5.92E+01	1.43E+01	1.80E+01	3.50E+01	5.30E-02	3.41E+01	3.26E+01
S-F9	Mean	3.50E+02	3.67E+02	3.51E+02	2.66E+02	**2.17E+02**	3.27E+02	3.16E+02	3.25E+02
	Std.	2.56E+00	1.30E+01	1.03E+02	1.00E+02	1.11E+02	9.64E+00	4.09E+01	6.91E+00
S-F10	Mean	4.31E+02	4.89E+02	4.66E+02	4.05E+02	4.00E+02	4.00E+02	**4.00E+02**	**4.00E+02**
	Std.	5.06E+00	7.18E+01	7.70E+01	1.68E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BS-F1	Mean	3.54E+07	4.15E+08	1.08E+04	**1.00E+02**	**1.00E+02**	**1.00E+02**	**1.00E+02**	**1.00E+02**
	Std.	7.90E+06	5.67E+08	8.09E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BS-F2	Mean	1.49E+03	1.69E+03	1.97E+03	**1.10E+03**	1.10E+03	1.10E+03	1.11E+03	1.11E+03
	Std.	7.93E+01	2.82E+02	3.04E+02	1.46E+00	3.38E+00	5.21E+00	6.92E+00	5.98E+00
BS-F3	Mean	7.43E+02	7.29E+02	7.84E+02	7.11E+02	**7.11E+02**	7.11E+02	7.11E+02	7.11E+02
	Std.	4.87E+00	9.04E+00	2.15E+01	2.94E-02	1.63E+00	0.00E+00	1.59E-01	3.67E-01
BS-F4	Mean	1.90E+03	1.93E+03	1.91E+03	1.90E+03	**1.90E+03**	1.90E+03	1.90E+03	1.90E+03
	Std.	3.54E-01	9.15E+01	3.95E+00	7.00E-02	9.22E-02	6.08E-02	1.91E-01	7.15E-02
BS-F5	Mean	7.52E+03	2.62E+03	2.83E+04	1.80E+03	1.71E+03	**1.70E+03**	1.70E+03	1.70E+03
	Std.	2.45E+03	3.51E+02	3.54E+04	5.63E+01	2.23E+01	3.74E-02	1.14E-01	1.22E-01
BS-F6	Mean	1.62E+03	1.67E+03	1.72E+03	1.60E+03	1.60E+03	**1.60E+03**	1.60E+03	1.60E+03
	Std.	2.28E+01	5.84E+01	7.23E+01	1.29E+00	2.08E+00	5.55E-02	1.98E-01	1.81E-01
BS-F7	Mean	3.56E+03	2.67E+03	9.91E+03	2.12E+03	2.10E+03	**2.10E+03**	2.10E+03	2.10E+03
	Std.	5.04E+02	3.28E+02	7.75E+03	4.01E+01	2.68E-01	7.75E-02	1.71E-01	5.97E-02
BS-F8	Mean	2.31E+03	2.38E+03	2.31E+03	2.29E+03	2.28E+03	**2.28E+03**	2.29E+03	2.29E+03
	Std.	1.35E+01	1.01E+02	1.60E+01	2.50E+01	3.52E+01	3.73E+01	2.51E+01	2.28E+01
BS-F9	Mean	2.75E+03	2.77E+03	2.78E+03	2.69E+03	**2.63E+03**	2.72E+03	2.72E+03	2.73E+03
	Std.	2.74E+00	1.28E+01	8.02E+01	8.43E+01	1.12E+02	2.50E+01	8.39E+00	5.01E+00
BS-F10	Mean	2.93E+03	2.98E+03	2.96E+03	2.90E+03	2.90E+03	**2.90E+03**	2.90E+03	**2.90E+03**
	Std.	4.21E+00	9.64E+01	9.00E+01	4.42E+00	0.00E+00	0.00E+00	4.71E-06	0.00E+00

The bold entries are applied to highlight the best results

Table 28 (Cont'd) Comparative results against popular meta-heuristic algorithms on functions $F1$-$F10$ with D=10 (CEC2021)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
SR-F1	Mean	4.61E+07	1.07E+09	8.57E+04	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.07E+07	8.59E+08	1.60E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-F2	Mean	4.78E+02	8.00E+02	1.07E+03	1.08E+02	**2.85E+01**	1.14E+02	3.75E+01	5.78E+01
	Std.	8.03E+01	3.08E+02	3.56E+02	6.62E+01	3.84E+01	8.93E+01	3.61E+01	6.27E+01
SR-F3	Mean	4.39E+01	3.61E+01	7.87E+01	1.28E+01	1.28E+01	**1.26E+01**	1.27E+01	1.36E+01
	Std.	3.97E+00	1.95E+01	2.37E+01	1.30E+00	1.49E+00	6.31E-01	1.11E+00	1.42E+00
SR-F4	Mean	3.14E+00	4.69E+01	5.88E+00	7.89E-01	5.83E-01	5.94E-01	6.57E-01	**5.71E-01**
	Std.	3.82E-01	8.37E+01	3.44E+00	2.86E-01	2.67E-01	1.40E-01	3.55E-01	1.24E-01
SR-F5	Mean	5.99E+03	8.50E+03	6.19E+04	9.54E+01	1.62E+02	**2.11E+00**	2.63E+00	4.82E+00
	Std.	2.71E+03	1.05E+04	1.47E+05	8.51E+01	3.34E+02	1.15E+00	8.96E+00	2.13E+00

Table 28 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
SR-F6	Mean	3.82E+01	1.72E+02	2.01E+02	2.07E+01	5.56E+00	1.81E+01	1.22E+00	**6.65E-01**
	Std.	6.24E+01	1.28E+02	1.06E+02	4.43E+01	2.15E+01	4.02E+01	1.97E+00	2.97E-01
SR-F7	Mean	1.75E+03	1.13E+03	2.16E+04	2.23E+01	2.79E+00	**3.10E-01**	1.64E+00	3.21E-01
	Std.	9.60E+02	7.52E+02	1.92E+04	4.04E+01	5.57E+00	1.79E-01	4.16E+00	3.45E-01
SR-F8	Mean	1.14E+02	1.24E+02	1.65E+02	1.00E+02	9.32E+01	9.48E+01	1.01E+02	**8.91E+01**
	Std.	1.57E+01	2.28E+01	2.11E+02	2.38E-01	1.83E+01	2.15E+01	4.09E-01	2.70E+01
SR-F9	Mean	3.48E+02	3.77E+02	3.60E+02	2.37E+02	**1.58E+02**	3.35E+02	3.29E+02	3.32E+02
	Std.	1.49E+01	1.40E+01	9.52E+01	1.12E+02	9.93E+01	2.34E+00	6.12E+00	2.01E+00
SR-F10	Mean	4.32E+02	4.92E+02	4.36E+02	4.22E+02	**3.96E+02**	4.14E+02	4.00E+02	4.01E+02
	Std.	1.58E+01	8.53E+01	7.09E+01	2.25E+01	5.75E+01	2.23E+01	8.18E+00	8.22E+00
BSR-F1	Mean	4.21E+07	5.54E+08	3.02E+04	**1.00E+02**	1.00E+02	**1.00E+02**	**1.00E+02**	**1.00E+02**
	Std.	1.36E+07	6.82E+08	1.37E+04	0.00E+00	2.22E+00	0.00E+00	0.00E+00	0.00E+00
BSR-F2	Mean	1.53E+03	1.88E+03	2.12E+03	1.21E+03	1.13E+03	1.23E+03	**1.13E+03**	1.16E+03
	Std.	1.06E+02	2.72E+02	2.79E+02	6.87E+01	3.31E+01	1.14E+02	1.82E+01	5.47E+01
BSR-F3	Mean	7.45E+02	7.33E+02	7.79E+02	7.13E+02	7.13E+02	7.13E+02	**7.12E+02**	7.13E+02
	Std.	5.13E+00	1.95E+01	2.57E+01	7.78E-01	1.11E+00	1.10E+00	7.09E-01	8.88E-01
BSR-F4	Mean	1.90E+03	1.95E+03	1.91E+03	1.90E+03	1.90E+03	**1.90E+03**	1.90E+03	1.90E+03
	Std.	3.68E-01	7.96E+01	6.98E+00	1.63E-01	2.64E-01	1.43E-01	2.88E-01	1.25E-01
BSR-F5	Mean	7.66E+03	8.73E+03	8.43E+04	1.80E+03	1.87E+03	1.70E+03	**1.70E+03**	1.70E+03
	Std.	2.04E+03	5.46E+03	1.36E+05	6.54E+01	5.22E+02	1.15E+00	8.33E-01	6.36E+00
BSR-F6	Mean	1.64E+03	1.80E+03	1.80E+03	1.60E+03	**1.60E+03**	1.61E+03	1.60E+03	1.60E+03
	Std.	5.87E+01	1.08E+02	9.26E+01	2.13E+01	4.19E-01	2.97E+01	3.74E-01	2.61E-01
BSR-F7	Mean	3.53E+03	3.16E+03	1.59E+04	2.14E+03	2.10E+03	**2.10E+03**	2.10E+03	2.10E+03
	Std.	5.22E+02	5.80E+02	9.95E+03	5.26E+01	2.96E+00	2.15E-01	6.71E-01	2.89E-01
BSR-F8	Mean	2.32E+03	2.44E+03	2.32E+03	2.30E+03	**2.29E+03**	2.29E+03	2.30E+03	2.30E+03
	Std.	1.33E+00	3.21E+02	3.14E+01	1.80E+01	2.26E+01	2.51E+01	2.17E+01	1.46E+01
BSR-F9	Mean	2.75E+03	2.77E+03	2.77E+03	2.64E+03	**2.57E+03**	2.73E+03	2.71E+03	2.72E+03
	Std.	3.46E+00	1.20E+01	7.95E+01	1.11E+02	1.02E+02	4.22E+01	6.88E+01	5.76E+01
BSR-F10	Mean	2.93E+03	2.96E+03	2.94E+03	2.92E+03	**2.89E+03**	2.91E+03	2.90E+03	2.90E+03
	Std.	1.70E+01	3.32E+01	3.14E+01	2.26E+01	3.68E+01	1.88E+01	1.59E+01	8.35E+00

The bold entries are applied to highlight the best results

D.2 20 Dimensions

Table 29 Comparative results against the state-of-the-art algorithms on functions $F1$-$F10$ with D=20 (CEC2021)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
B-F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.88E-07	4.38E+07	2.25E+08	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.98E-07	1.11E+07	0.00E+00	0.00E+00	0.00E+00
B-F2	Mean	**0.00E+00**	3.44E-01	1.77E-02	6.65E+01	2.14E+03	3.89E+03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	6.65E-02	2.51E-02	9.47E+01	2.18E+02	0.00E+00	0.00E+00	0.00E+00
B-F3	Mean	**0.00E+00**	2.07E+01	1.81E+01	1.34E+01	1.41E+02	2.09E+02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	5.02E+00	6.05E+00	3.51E+00	1.32E+01	0.00E+00	0.00E+00	0.00E+00
B-F4	Mean	7.60E-02	1.11E+00	7.13E-01	1.76E+00	1.40E+01	2.07E+01	**0.00E+00**	**0.00E+00**
	Std.	2.98E-02	2.59E-01	1.46E-01	4.24E-01	1.56E+00	0.00E+00	0.00E+00	0.00E+00
B-F5	Mean	**0.00E+00**	5.86E-01	3.47E-03	9.54E+00	5.13E+04	2.15E+03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	6.83E-01	1.87E-02	4.82E+00	3.19E+04	0.00E+00	0.00E+00	0.00E+00
B-F6	Mean	7.08E-02	7.13E-01	2.18E-01	1.06E+00	3.23E+02	4.97E+02	1.08E-07	**0.00E+00**
	Std.	2.49E-02	1.34E-01	1.14E-01	4.02E-01	1.25E+02	0.00E+00	5.47E-07	0.00E+00
B-F7	Mean	3.90E-02	6.69E-01	1.10E-01	7.65E-01	7.87E+03	1.08E+03	2.91E-05	**0.00E+00**
	Std.	1.57E-02	1.37E-01	1.10E-01	2.70E-01	2.34E+03	0.00E+00	1.57E-04	0.00E+00
B-F8	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.08E+01	2.07E+03	3.54E+03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	2.06E+01	6.40E+02	0.00E+00	0.00E+00	0.00E+00
B-F9	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.23E+01	7.49E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E+00	0.00E+00	0.00E+00	0.00E+00
B-F10	Mean	5.47E-04	4.88E+01	4.92E+01	4.90E+01	5.78E+01	7.63E+01	**0.00E+00**	**0.00E+00**
	Std.	4.32E-04	3.24E-02	2.30E+00	1.04E-01	1.53E+00	0.00E+00	0.00E+00	0.00E+00
S-F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.29E-01	3.75E+07	2.66E+08	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.19E+00	9.16E+06	0.00E+00	0.00E+00	0.00E+00
S-F2	Mean	**0.00E+00**	6.00E+01	1.25E-02	4.48E+02	2.17E+03	3.54E+03	2.46E+01	1.62E+01
	Std.	0.00E+00	6.69E+01	2.07E-02	1.33E+02	5.33E+02	0.00E+00	2.89E+01	8.20E+00
S-F3	Mean	**2.02E+01**	2.20E+01	**2.02E+01**	3.50E+01	1.35E+02	2.24E+02	2.12E+01	2.04E+01
	Std.	0.00E+00	1.39E+00	0.00E+00	4.63E+00	1.94E+01	0.00E+00	8.19E-01	4.41E-01
S-F4	Mean	**1.90E-01**	1.13E+00	6.92E-01	1.73E+00	1.39E+01	4.46E+01	1.57E+00	8.38E-01
	Std.	8.40E-02	2.71E-01	1.31E-01	3.08E-01	1.10E+00	0.00E+00	3.19E-01	1.25E-01
S-F5	Mean	**0.00E+00**	3.90E+01	2.43E-02	1.02E+02	7.47E+04	1.80E+03	3.20E+00	1.70E+00
	Std.	0.00E+00	5.46E+01	5.16E-02	5.25E+01	7.07E+04	0.00E+00	4.99E+00	3.89E+00
S-F6	Mean	**7.98E-02**	6.81E-01	1.42E-01	1.25E+02	6.88E+02	1.19E+03	1.83E+00	8.33E-01
	Std.	3.80E-02	1.08E-01	7.53E-02	5.71E+01	2.88E+02	0.00E+00	3.75E+00	1.00E+00
S-F7	Mean	**6.11E-02**	3.34E+01	7.99E-02	8.21E+01	4.60E+04	1.61E+04	8.91E-01	3.34E+00
	Std.	2.38E-02	5.26E+01	6.61E-02	5.72E+01	5.78E+03	0.00E+00	1.50E+00	8.71E+00
S-F8	Mean	**4.08E+01**	1.00E+02	1.00E+02	1.01E+02	1.38E+02	2.88E+03	1.00E+02	1.00E+02
	Std.	4.85E+01	0.00E+00	0.00E+00	1.00E+00	6.49E+00	0.00E+00	0.00E+00	0.00E+00
S-F9	Mean	**1.89E+02**	3.91E+02	3.00E+02	3.80E+02	4.95E+02	4.56E+02	4.02E+02	4.01E+02
	Std.	1.27E+02	3.85E+00	0.00E+00	3.68E+01	1.72E+01	0.00E+00	1.26E+00	7.88E-01
S-F10	Mean	**4.00E+02**	4.63E+02	4.59E+02	4.87E+02	5.57E+02	5.46E+02	4.80E+02	4.60E+02
	Std.	0.00E+00	3.79E+01	3.25E+01	3.10E+01	1.45E+01	0.00E+00	2.15E+01	3.93E+01
BS-F1	Mean	**1.00E+02**	**1.00E+02**	**1.00E+02**	1.00E+02	5.28E+07	2.66E+08	**1.00E+02**	**1.00E+02**
	Std.	0.00E+00	0.00E+00	0.00E+00	6.04E-03	1.67E+07	0.00E+00	0.00E+00	0.00E+00
BS-F2	Mean	**1.10E+03**	1.13E+03	1.10E+03	1.54E+03	3.13E+03	4.64E+03	1.12E+03	1.12E+03
	Std.	0.00E+00	4.79E+01	1.68E-02	1.24E+02	3.09E+02	0.00E+00	7.54E+00	6.67E+00
BS-F3	Mean	**7.20E+02**	7.22E+02	**7.20E+02**	7.35E+02	8.48E+02	9.24E+02	7.21E+02	7.20E+02
	Std.	0.00E+00	1.63E+00	0.00E+00	5.05E+00	2.14E+01	0.00E+00	6.40E-01	3.42E-01
BS-F4	Mean	**1.90E+03**	1.90E+03	1.90E+03	1.90E+03	1.92E+03	1.94E+03	1.90E+03	1.90E+03
	Std.	9.71E-02	2.47E-01	1.39E-01	4.06E-01	1.14E+00	0.00E+00	3.59E-01	1.57E-01

Table 29 (Continued)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
BS-F5	Mean	**1.70E+03**	1.72E+03	1.70E+03	1.80E+03	9.35E+04	3.50E+03	1.70E+03	1.70E+03
	Std.	0.00E+00	4.05E+01	6.66E-02	5.83E+01	4.41E+04	0.00E+00	8.53E+00	2.18E+00
BS-F6	Mean	**1.60E+03**	1.60E+03	1.60E+03	1.70E+03	2.54E+03	2.79E+03	1.60E+03	1.60E+03
	Std.	3.17E-02	1.24E-01	7.60E-02	8.12E+01	3.32E+02	0.00E+00	3.57E+00	1.02E+00
BS-F7	Mean	**2.10E+03**	2.13E+03	2.10E+03	2.19E+03	3.55E+04	1.82E+04	2.10E+03	2.10E+03
	Std.	3.07E-02	4.86E+01	1.17E-01	5.60E+01	1.88E+04	0.00E+00	7.42E+00	9.85E+00
BS-F8	Mean	**2.25E+03**	2.30E+03	2.30E+03	2.30E+03	2.37E+03	5.08E+03	2.30E+03	2.30E+03
	Std.	4.86E+01	0.00E+00	2.28E-01	7.71E-01	5.38E+00	0.00E+00	2.64E-06	0.00E+00
BS-F9	Mean	**2.56E+03**	2.79E+03	2.71E+03	2.78E+03	2.91E+03	2.86E+03	2.80E+03	2.80E+03
	Std.	1.15E+02	3.31E+00	2.99E+01	3.26E+01	1.02E+01	0.00E+00	1.45E+00	6.60E-01
BS-F10	Mean	**2.90E+03**	2.96E+03	2.95E+03	3.00E+03	3.10E+03	3.05E+03	2.98E+03	2.97E+03
	Std.	0.00E+00	3.79E+01	3.75E+01	2.12E+01	2.78E+01	0.00E+00	1.55E+01	3.63E+01
SR-F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.06E+03	5.65E+07	6.40E+07	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.36E+03	1.15E+07	0.00E+00	0.00E+00	0.00E+00
SR-F2	Mean	**1.24E+01**	1.27E+02	5.03E+01	4.24E+02	2.26E+03	2.30E+03	3.38E+01	2.24E+01
	Std.	2.23E+01	1.57E+02	7.06E+01	1.76E+02	3.96E+02	0.00E+00	3.46E+01	1.10E+01
SR-F3	Mean	**2.27E+01**	2.41E+01	2.38E+01	3.80E+01	1.43E+02	1.70E+02	2.33E+01	2.27E+01
	Std.	7.73E-01	2.35E+00	1.47E+00	4.96E+00	1.52E+01	0.00E+00	1.13E+00	1.24E+00
SR-F4	Mean	**6.24E-01**	1.21E+00	8.56E-01	1.82E+00	1.47E+01	2.42E+02	1.59E+00	9.61E-01
	Std.	1.21E-01	3.17E-01	2.08E-01	4.85E-01	1.54E+00	0.00E+00	4.32E-01	1.51E-01
SR-F5	Mean	3.72E+02	1.14E+02	**1.12E+02**	1.52E+03	2.36E+06	5.90E+05	1.82E+02	1.28E+02
	Std.	1.78E+02	7.87E+01	8.57E+01	9.59E+02	2.11E+06	0.00E+00	1.16E+02	1.04E+02
SR-F6	Mean	**3.88E-01**	7.58E-01	5.19E-01	9.73E+01	7.23E+02	1.22E+03	1.95E+00	1.48E+00
	Std.	1.93E-01	2.80E-01	3.33E-01	8.34E+01	1.83E+02	0.00E+00	1.04E+00	5.40E-01
SR-F7	Mean	1.00E+02	3.34E+01	4.43E+01	1.77E+02	5.18E+05	9.19E+05	**2.02E+01**	2.72E+01
	Std.	6.16E+01	4.89E+01	6.24E+01	9.14E+01	1.95E+05	0.00E+00	5.21E+01	4.11E+01
SR-F8	Mean	**9.16E+01**	1.00E+02	1.00E+02	1.01E+02	9.53E+02	3.18E+03	1.00E+02	1.00E+02
	Std.	1.41E+01	0.00E+00	0.00E+00	7.53E-01	1.22E+03	0.00E+00	0.00E+00	0.00E+00
SR-F9	Mean	**1.03E+02**	3.93E+02	4.14E+02	3.98E+02	5.20E+02	5.17E+02	4.04E+02	4.02E+02
	Std.	3.15E+01	8.80E+00	4.82E+00	2.31E+01	2.03E+01	0.00E+00	4.02E+00	2.81E+00
SR-F10	Mean	4.09E+02	4.14E+02	**4.07E+02**	4.17E+02	4.59E+02	4.66E+02	4.14E+02	4.13E+02
	Std.	6.01E+00	9.79E-03	3.59E+00	9.50E+00	2.50E+01	0.00E+00	5.89E-01	8.04E-01

The bold entries are applied to highlight the best results

Table 30 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F10$ with D=20 (CEC2021)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
B-F1	Mean	3.62E+08	1.55E+07	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	4.97E+07	8.16E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F2	Mean	2.23E+03	2.10E+03	**0.00E+00**	4.87E+00	**0.00E+00**	2.34E+00	**0.00E+00**	**0.00E+00**
	Std.	1.70E+02	5.18E+02	0.00E+00	2.11E+01	0.00E+00	2.20E+00	0.00E+00	0.00E+00
B-F3	Mean	1.46E+02	2.27E+02	**0.00E+00**	1.58E+01	**0.00E+00**	2.02E+01	**0.00E+00**	**0.00E+00**
	Std.	7.78E+00	1.17E+02	0.00E+00	8.72E+00	0.00E+00	1.53E-01	0.00E+00	0.00E+00
B-F4	Mean	1.28E+01	9.06E+00	**0.00E+00**	1.72E+00	**0.00E+00**	8.08E-01	**0.00E+00**	**0.00E+00**
	Std.	7.95E-01	5.48E+00	0.00E+00	2.31E-01	0.00E+00	1.71E-01	0.00E+00	0.00E+00
B-F5	Mean	1.31E+05	2.73E+05	**0.00E+00**	1.87E+02	**0.00E+00**	2.62E+01	**0.00E+00**	**0.00E+00**
	Std.	3.84E+04	9.25E+05	0.00E+00	1.38E+02	0.00E+00	9.80E+01	0.00E+00	0.00E+00

Table 30 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
B-F6	Mean	1.10E+02	5.05E+02	1.03E-01	2.83E+00	**0.00E+00**	1.12E+00	1.08E-07	**0.00E+00**
	Std.	1.96E+01	2.47E+02	6.75E-02	1.49E+00	0.00E+00	3.26E-01	5.47E-07	0.00E+00
B-F7	Mean	2.98E+04	1.19E+05	3.58E-02	8.09E+01	**0.00E+00**	5.15E+00	2.91E-05	**0.00E+00**
	Std.	1.12E+04	4.51E+05	4.02E-02	1.02E+02	0.00E+00	2.12E+01	1.57E-04	0.00E+00
B-F8	Mean	8.15E+02	1.83E+03	**0.00E+00**	4.46E+00	**0.00E+00**	6.87E-01	**0.00E+00**	**0.00E+00**
	Std.	8.86E+01	5.52E+02	0.00E+00	6.82E+00	0.00E+00	2.57E+00	0.00E+00	0.00E+00
B-F9	Mean	8.61E+01	6.98E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	5.00E+00	5.91E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
B-F10	Mean	6.44E+01	1.39E+02	1.12E-01	5.20E+01	**0.00E+00**	4.88E+01	**0.00E+00**	**0.00E+00**
	Std.	1.46E+00	7.80E+01	3.75E-02	7.37E+00	0.00E+00	1.10E-02	0.00E+00	0.00E+00
S-F1	Mean	3.50E+08	4.35E+09	6.35E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	5.64E+07	3.33E+09	5.98E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
S-F2	Mean	2.12E+03	2.23E+03	2.58E+03	4.80E+01	3.82E+01	4.11E+01	2.46E+01	**1.62E+01**
	Std.	1.84E+02	5.71E+02	5.50E+02	6.56E+01	5.91E+01	4.26E+01	2.89E+01	8.20E+00
S-F3	Mean	1.47E+02	1.79E+02	2.45E+02	2.04E+01	2.20E+01	**2.02E+01**	2.12E+01	2.04E+01
	Std.	6.13E+00	8.39E+01	4.47E+01	4.29E-01	9.75E-01	1.10E-01	8.19E-01	4.41E-01
S-F4	Mean	1.21E+01	1.69E+04	2.81E+01	1.84E+00	1.03E+00	8.65E-01	1.57E+00	**8.38E-01**
	Std.	9.84E-01	3.00E+04	1.04E+01	2.60E-01	2.27E-01	1.71E-01	3.19E-01	1.25E-01
S-F5	Mean	1.09E+05	3.13E+05	1.42E+05	2.10E+02	1.13E+01	1.12E+02	3.20E+00	**1.70E+00**
	Std.	4.24E+04	5.63E+05	8.73E+04	1.51E+02	2.99E+01	1.28E+02	4.99E+00	3.89E+00
S-F6	Mean	1.37E+02	7.02E+02	6.64E+02	2.22E+01	1.31E+00	2.66E+01	1.83E+00	**8.33E-01**
	Std.	1.70E+01	2.20E+02	2.69E+02	4.36E+01	2.15E+00	4.98E+01	3.75E+00	1.00E+00
S-F7	Mean	3.66E+04	4.43E+04	4.12E+04	1.29E+02	1.44E+01	3.12E+01	**8.91E-01**	3.34E+00
	Std.	9.97E+03	9.01E+04	3.33E+04	1.06E+02	3.52E+01	1.83E+01	1.50E+00	8.71E+00
S-F8	Mean	1.73E+02	9.97E+02	7.53E+02	1.00E+02	**1.00E+02**	1.50E+02	1.00E+02	**1.00E+02**
	Std.	7.09E+00	9.95E+02	1.19E+03	3.17E-01	0.00E+00	7.71E+01	0.00E+00	0.00E+00
S-F9	Mean	4.73E+02	5.76E+02	6.27E+02	4.02E+02	**4.01E+02**	4.04E+02	4.02E+02	4.01E+02
	Std.	5.58E+00	4.50E+01	8.00E+01	4.20E+00	2.05E+00	2.57E+00	1.26E+00	7.88E-01
S-F10	Mean	5.16E+02	7.80E+02	4.98E+02	4.47E+02	**4.37E+02**	4.86E+02	4.80E+02	4.60E+02
	Std.	4.02E+00	3.23E+02	3.31E+01	3.73E+01	4.21E+01	2.42E-02	2.15E+01	3.93E+01
BS-F1	Mean	3.47E+08	3.56E+09	6.59E+03	**1.00E+02**	**1.00E+02**	**1.00E+02**	**1.00E+02**	**1.00E+02**
	Std.	4.81E+07	2.96E+09	5.89E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BS-F2	Mean	3.11E+03	3.40E+03	3.65E+03	1.17E+03	**1.12E+03**	1.15E+03	1.12E+03	1.12E+03
	Std.	1.59E+02	5.16E+02	5.78E+02	8.06E+01	3.03E+01	5.15E+01	7.54E+00	6.67E+00
BS-F3	Mean	8.46E+02	8.97E+02	9.43E+02	7.21E+02	7.22E+02	**7.20E+02**	7.21E+02	7.20E+02
	Std.	9.30E+00	8.57E+01	4.34E+01	9.15E-01	1.43E+00	1.10E-01	6.40E-01	3.42E-01
BS-F4	Mean	1.91E+03	7.68E+03	1.92E+03	1.90E+03	1.90E+03	**1.90E+03**	1.90E+03	1.90E+03
	Std.	6.32E-01	9.32E+03	1.19E+01	2.77E-01	2.86E-01	1.35E-01	3.59E-01	1.57E-01
BS-F5	Mean	1.25E+05	8.39E+05	1.64E+05	1.98E+03	1.71E+03	1.79E+03	1.70E+03	**1.70E+03**
	Std.	2.76E+04	2.79E+06	7.96E+04	1.35E+02	2.99E+01	1.28E+02	8.53E+00	2.18E+00
BS-F6	Mean	1.74E+03	2.30E+03	2.26E+03	1.64E+03	**1.60E+03**	1.62E+03	1.60E+03	1.60E+03
	Std.	1.45E+01	2.41E+02	1.62E+02	6.25E+01	1.02E+00	5.34E+01	3.57E+00	1.02E+00

Table 30 continued

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
BS-F7	Mean	3.70E+04	8.94E+04	4.03E+04	2.22E+03	2.11E+03	2.15E+03	**2.10E+03**	2.10E+03
	Std.	1.08E+04	1.78E+05	3.26E+04	7.02E+01	3.52E+01	8.96E+01	7.42E+00	9.85E+00
BS-F8	Mean	2.37E+03	3.12E+03	3.42E+03	2.30E+03	**2.30E+03**	2.37E+03	2.30E+03	**2.30E+03**
	Std.	5.97E+00	8.89E+02	1.38E+03	0.00E+00	0.00E+00	8.91E+01	2.64E-06	0.00E+00
BS-F9	Mean	2.87E+03	2.97E+03	3.05E+03	2.80E+03	**2.80E+03**	2.81E+03	2.80E+03	2.80E+03
	Std.	6.31E+00	3.59E+01	7.22E+01	2.55E+00	1.01E+00	7.58E+00	1.45E+00	6.60E-01
BS-F10	Mean	3.02E+03	3.22E+03	3.00E+03	2.97E+03	**2.93E+03**	2.99E+03	2.98E+03	2.97E+03
	Std.	4.05E+00	3.01E+02	3.87E+01	3.65E+01	4.21E+01	2.56E-02	1.55E+01	3.63E+01
SR-F1	Mean	4.20E+08	2.49E+09	9.53E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	5.92E+07	2.62E+09	4.11E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-F2	Mean	2.17E+03	2.42E+03	2.50E+03	1.80E+02	2.73E+01	1.06E+02	3.38E+01	**2.24E+01**
	Std.	1.70E+02	5.77E+02	4.89E+02	1.29E+02	4.11E+01	1.17E+02	3.46E+01	1.10E+01
SR-F3	Mean	1.49E+02	2.07E+02	2.42E+02	**2.17E+01**	2.18E+01	2.42E+01	2.33E+01	2.27E+01
	Std.	6.48E+00	8.73E+01	3.82E+01	9.31E-01	9.45E-01	1.41E+00	1.13E+00	1.24E+00
SR-F4	Mean	1.34E+01	3.12E+03	4.26E+01	2.40E+00	1.70E+00	1.13E+00	1.59E+00	**9.61E-01**
	Std.	1.11E+00	4.57E+03	1.73E+01	4.22E-01	4.35E-01	2.79E-01	4.32E-01	1.51E-01
SR-F5	Mean	1.90E+05	1.24E+06	2.67E+05	4.90E+03	3.21E+04	**1.04E+02**	1.82E+02	1.28E+02
	Std.	4.98E+04	1.37E+06	2.27E+05	3.20E+03	1.83E+04	7.98E+01	1.16E+02	1.04E+02
SR-F6	Mean	1.46E+02	6.05E+02	7.89E+02	2.20E+01	5.37E+00	1.20E+01	1.95E+00	**1.48E+00**
	Std.	1.27E+01	2.30E+02	2.29E+02	4.41E+01	2.23E+01	9.49E+00	1.04E+00	5.40E-01
SR-F7	Mean	4.11E+04	3.82E+05	1.73E+05	2.76E+02	7.22E+02	**3.66E+00**	2.02E+01	2.72E+01
	Std.	1.46E+04	3.17E+05	1.39E+05	1.04E+02	1.32E+03	2.78E+00	5.21E+01	4.11E+01
SR-F8	Mean	5.16E+02	1.91E+03	1.06E+03	1.00E+02	**1.00E+02**	9.56E+02	1.00E+02	**1.00E+02**
	Std.	8.49E+02	1.28E+03	1.49E+03	1.60E-07	0.00E+00	6.46E+02	0.00E+00	0.00E+00
SR-F9	Mean	4.76E+02	5.70E+02	6.46E+02	4.24E+02	4.19E+02	4.19E+02	4.04E+02	**4.02E+02**
	Std.	7.22E+00	4.57E+01	7.64E+01	5.44E+00	7.85E+00	6.75E+00	4.02E+00	2.81E+00
SR-F10	Mean	4.34E+02	6.47E+02	5.11E+02	4.31E+02	4.15E+02	4.14E+02	4.14E+02	**4.13E+02**
	Std.	2.60E+00	1.87E+02	3.31E+01	2.55E+01	9.67E+00	8.06E-03	5.89E-01	8.04E-01

The bold entries are applied to highlight the best results

Appendix E: The comparative results on the classical set

E.1 10 Dimensions

Table 31 Comparative results against the state-of-the-art algorithms on functions $F1$-$F16$ with D=10 (Classical Set)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.16E+03	5.15E+02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.07E+02	0.00E+00	0.00E+00	0.00E+00
F2	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.85E-02	6.66E-03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.05E-02	0.00E+00	0.00E+00	0.00E+00
F3	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.38E+02	1.30E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E+02	0.00E+00	0.00E+00	0.00E+00
F4	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.73E+00	4.16E+00	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.44E-01	0.00E+00	0.00E+00	0.00E+00
F5	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.53E-01	2.73E-02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.73E-02	0.00E+00	0.00E+00	0.00E+00
F6	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.09E-07	0.00E+00	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-07	0.00E+00	0.00E+00	0.00E+00
F7	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.52E+01	2.09E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E+01	0.00E+00	0.00E+00	0.00E+00
F8	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.46E+02	5.58E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E+02	0.00E+00	0.00E+00	0.00E+00
F9	Mean	**0.00E+00**	9.29E-01	**0.00E+00**	7.03E+00	2.51E+01	2.95E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	1.15E+00	0.00E+00	3.14E+00	6.66E+00	0.00E+00	0.00E+00	0.00E+00
F10	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.73E+00	1.85E+00	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.27E-01	0.00E+00	0.00E+00	0.00E+00
F11	Mean	**0.00E+00**	5.75E-04	2.47E-04	8.09E-02	1.13E+00	8.70E-01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	2.18E-03	1.33E-03	4.66E-02	2.99E-02	0.00E+00	0.00E+00	0.00E+00
F12	Mean	**−3.92E+02**	**−3.92E+02**	**−3.92E+02**	−3.90E+02	−3.67E+02	−3.35E+02	**−3.92E+02**	**−3.92E+02**
	Std.	0.00E+00	0.00E+00	2.50E-04	4.81E+00	1.34E+01	0.00E+00	0.00E+00	3.03E-04
F13	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.39E+02	2.02E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.04E+01	0.00E+00	0.00E+00	0.00E+00
F14	Mean	5.66E-04	5.66E-04	5.66E-04	6.98E-04	1.14E-03	1.34E-03	2.52E-04	**7.64E-05**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.98E-04	2.62E-04	0.00E+00	3.26E-04	1.95E-04
F15	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.46E-01	2.02E-01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.31E-02	0.00E+00	0.00E+00	0.00E+00
F16	Mean	**−9.66E+00**	−9.60E+00	−9.66E+00	−9.20E+00	−8.12E+00	−5.74E+00	−9.23E+00	−9.57E+00
	Std.	0.00E+00	5.16E-02	8.81E-04	2.29E-01	3.26E-01	0.00E+00	3.02E-01	7.60E-02

The bold entries are applied to highlight the best results

Table 32 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F16$ with D=10 (Classical set)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	5.77E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.43E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F2	Mean	6.57E-02	1.20E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.39E-02	1.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	1.68E+03	1.25E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	4.73E+02	2.30E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	5.93E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.36E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F5	Mean	7.77E-01	2.62E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.56E-01	7.86E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F6	Mean	4.54E-06	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F7	Mean	2.53E+00	9.65E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	6.52E-01	5.13E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F8	Mean	7.56E+01	2.19E+00	2.22E-05	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.93E+01	1.14E+01	7.72E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F9	Mean	2.33E+01	2.06E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.27E+00	1.05E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F10	Mean	4.43E+00	1.70E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.08E-01	4.93E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F11	Mean	5.71E-01	1.09E-01	6.35E-02	3.86E-03	**0.00E+00**	1.20E-02	**0.00E+00**	**0.00E+00**
	Std.	7.09E-02	5.96E-02	1.12E-01	7.29E-03	0.00E+00	8.90E-03	0.00E+00	0.00E+00
F12	Mean	−3.82E+02	−3.47E+02	**−3.92E + 02**	**−3.92E+02**	**−3.92E+02**	**−3.92E+02**	**−3.92E+02**	**−3.92E+02**
	Std.	1.01E+01	2.28E+01	6.67E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.03E-04
F13	Mean	3.62E+04	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.28E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F14	Mean	1.14E-03	2.46E-03	5.66E-04	5.66E-04	3.77E-04	5.85E-04	2.52E-04	**7.64E-05**
	Std.	1.72E-04	2.71E-04	1.22E-04	0.00E+00	2.67E-04	6.00E-05	3.26E-04	1.95E-04
F15	Mean	5.74E-01	8.14E-02	4.21E-01	**0.00E+00**	**0.00E+00**	5.92E-07	**0.00E+00**	**0.00E+00**
	Std.	1.18E-01	3.62E-01	1.01E+00	0.00E+00	0.00E+00	9.60E-07	0.00E+00	0.00E+00
F16	Mean	−7.46E+00	−7.02E+00	−6.36E+00	−9.65E+00	−9.61E+00	**−9.66E+00**	−9.23E+00	−9.57E+00
	Std.	2.60E-01	8.53E-01	1.05E+00	2.92E-02	5.93E-02	9.19E-04	3.02E-01	7.60E-02

The bold entries are applied to highlight the best results

E.2 30 Dimensions

Table 33 Comparative results against the state-of-the-art algorithms on functions $F1$-$F16$ with D=30 (Classical set)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.09E+04	2.06E+05	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.31E+02	0.00E+00	0.00E+00	0.00E+00
F2	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.92E+00	2.89E-01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.19E+04	1.72E+03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.11E+03	0.00E+00	0.00E+00	0.00E+00
F4	Mean	**1.12E-02**	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.26E+01	3.64E+01	**0.00E+00**	**0.00E+00**
	Std.	1.21E-02	0.00E+00	0.00E+00	0.00E+00	2.06E+01	0.00E+00	0.00E+00	0.00E+00
F5	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.68E+00	1.23E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E+00	0.00E+00	0.00E+00	0.00E+00
F6	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.22E-07	4.64E-07	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.88E-07	0.00E+00	0.00E+00	0.00E+00
F7	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.84E+02	2.12E+02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.68E+01	0.00E+00	0.00E+00	0.00E+00
F8	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	8.80E+03	6.99E+03	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.93E+03	0.00E+00	0.00E+00	0.00E+00
F9	Mean	**0.00E+00**	8.69E+00	**0.00E+00**	2.94E+01	1.57E+02	1.61E+02	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	3.75E+00	0.00E+00	7.15E+00	2.92E+01	0.00E+00	0.00E+00	0.00E+00
F10	Mean	**0.00E+00**	0.00E+00	**0.00E+00**	**0.00E+00**	4.00E+00	9.45E+00	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.30E-01	0.00E+00	0.00E+00	0.00E+00
F11	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.03E-02	2.05E+00	1.95E+01	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	1.07E-02	2.06E-01	0.00E+00	0.00E+00	0.00E+00
F12	Mean	**−1.17E+03**	−1.17E+03	**−1.17E+03**	−1.16E+03	−1.02E+03	−1.01E+03	−1.15E+03	−1.16E+03
	Std.	0.00E+00	5.27E+00	4.17E-04	1.79E+01	4.12E+01	0.00E+00	3.86E+01	5.78E+01
F13	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.35E+05	3.00E+09	**0.00E+00**	0.00E+00
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.57E+04	0.00E+00	0.00E+00	0.00E+00
F14	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F15	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	9.54E+00	5.05E+00	**0.00E+00**	**0.00E+00**
	Std.	1.69E-07	0.00E+00	0.00E+00	0.00E+00	2.09E+00	0.00E+00	0.00E+00	0.00E+00
F16	Mean	-2.96E+01	−2.83E+01	**−2.96E+01**	−2.77E+01	−1.39E+01	−1.73E+01	−2.57E+01	−2.88E+01
	Std.	2.01E-02	3.93E-01	2.64E-03	3.54E-01	1.11E+00	0.00E+00	1.28E+00	4.48E-01

The bold entries are applied to highlight the best results

Table 34 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F16$ with D=30 (Classical set)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.33E+05	5.15E+04	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.16E+04	1.80E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F2	Mean	1.52E+00	4.17E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.36E-01	4.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	5.02E+04	1.72E+05	**0.00E+00**	1.97E-05	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	7.80E+03	2.22E+05	0.00E+00	6.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	1.33E+03	8.69E+02	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.54E+02	2.47E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F5	Mean	4.84E+01	8.79E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	3.71E+00	1.00E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F6	Mean	1.16E-05	1.72E-07	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	4.85E-06	4.34E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F7	Mean	1.70E+02	1.75E+02	9.86E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.84E+01	6.64E+01	3.38E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F8	Mean	5.44E+03	1.67E+04	1.84E-02	2.58E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	5.17E+02	5.68E+03	3.35E-02	3.68E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F9	Mean	1.67E+02	1.24E+02	**0.00E+00**	1.03E+00	**0.00E+00**	4.58E+00	**0.00E+00**	**0.00E+00**
	Std.	7.63E+00	3.64E+01	0.00E+00	9.08E-01	0.00E+00	2.16E+00	0.00E+00	0.00E+00
F10	Mean	8.61E+00	1.87E+01	**0.00E+00**	1.07E-01	**0.00E+00**	1.25E+01	**0.00E+00**	**0.00E+00**
	Std.	3.07E-01	3.80E+00	0.00E+00	3.26E-01	0.00E+00	6.45E+00	0.00E+00	0.00E+00
F11	Mean	1.34E+00	1.39E+00	3.52E-03	1.97E-03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.69E-02	1.01E+00	8.19E-03	6.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F12	Mean	-1.11E+03	−1.01E+03	**−1.17E+03**	−1.14E+03	−1.17E+03	**−1.17E+03**	−1.15E+03	−1.16E+03
	Std.	1.02E+01	4.11E+01	1.68E-04	1.91E+01	7.24E+00	0.00E+00	3.86E+01	5.78E+01
F13	Mean	8.79E+07	5.08E+06	**0.00E+00**	1.90E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.65E+07	1.05E+07	0.00E+00	5.03E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F14	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F15	Mean	9.82E+00	6.59E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	8.35E-01	2.97E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-07	0.00E+00	0.00E+00
F16	Mean	−1.37E+01	−1.71E+01	−1.49E+01	−2.61E+01	−2.88E+01	−2.86E+01	−2.57E+01	**−2.88E+01**
	Std.	4.24E-01	1.70E+00	1.61E+00	5.59E-01	2.55E-01	2.48E-01	1.28E+00	4.48E-01

The bold entries are applied to highlight the best results

E.3 100 Dimensions

Table 35 Comparative results against the state-of-the-art algorithms on functions $F1$-$F15$ with D=100 (Classical set)

Func.	Metric	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.14E+02	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.45E+07	1.61E+06	**0.00E+00**	**0.00E+00**
	Std.	6.53E+01	0.00E+00	0.00E+00	0.00E+00	3.70E+05	0.00E+00	0.00E+00	0.00E+00
F2	Mean	5.33E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	5.93E+09	1.83E+02	**0.00E+00**	**0.00E+00**
	Std.	2.53E-01	0.00E+00	0.00E+00	0.00E+00	8.19E+09	0.00E+00	0.00E+00	0.00E+00
F3	Mean	1.86E+01	**0.00E+00**	**0.00E+00**	0.00E+00	2.49E+07	1.50E+06	**0.00E+00**	**0.00E+00**
	Std.	1.21E+01	0.00E+00	0.00E+00	0.00E+00	1.97E+06	0.00E+00	0.00E+00	0.00E+00
F4	Mean	2.22E+00	2.86E-05	5.61E-06	1.20E+00	9.30E+01	7.05E+01	**0.00E+00**	**0.00E+00**
	Std.	2.23E-01	1.51E-05	2.70E-05	1.74E-01	1.06E+00	0.00E+00	0.00E+00	0.00E+00
F5	Mean	1.76E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.91E+04	1.67E+03	**0.00E+00**	**0.00E+00**
	Std.	8.79E-02	0.00E+00	0.00E+00	0.00E+00	6.76E+02	0.00E+00	0.00E+00	0.00E+00
F6	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	5.82E-01	5.10E-07	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.03E-01	0.00E+00	0.00E+00	0.00E+00
F7	Mean	1.84E-01	**0.00E+00**	**0.00E+00**	1.35E-03	1.62E+13	1.28E+03	**0.00E+00**	**0.00E+00**
	Std.	6.95E-02	0.00E+00	0.00E+00	5.66E-03	1.21E+13	0.00E+00	0.00E+00	0.00E+00
F8	Mean	1.35E+01	5.10E-06	6.14E-03	1.39E-01	2.53E+05	5.76E+04	**0.00E+00**	**0.00E+00**
	Std.	3.64E+00	3.10E-06	8.50E-03	7.27E-01	2.51E+04	0.00E+00	0.00E+00	0.00E+00
F9	Mean	2.71E+01	1.23E+00	3.32E-02	1.17E+02	1.52E+03	6.56E+02	**0.00E+00**	**0.00E+00**
	Std.	5.57E+00	1.33E+00	1.79E-01	1.22E+01	3.18E+01	0.00E+00	0.00E+00	0.00E+00
F10	Mean	1.48E+00	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.08E+01	1.33E+01	**0.00E+00**	**0.00E+00**
	Std.	2.15E-01	0.00E+00	0.00E+00	0.00E+00	3.76E-02	0.00E+00	0.00E+00	0.00E+00
F11	Mean	4.21E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.08E+03	1.65E+02	**0.00E+00**	**0.00E+00**
	Std.	1.29E-01	0.00E+00	0.00E+00	0.00E+00	1.11E+02	0.00E+00	0.00E+00	0.00E+00
F12	Mean	−3.88E+03	−3.88E+03	**−3.92E+03**	−3.73E+03	−1.43E+03	−2.95E+03	−3.74E+03	−3.80E+03
	Std.	2.79E+01	1.53E+01	5.58E-03	4.49E+01	5.28E+01	0.00E+00	9.78E+01	7.69E+01
F13	Mean	2.55E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	1.41E+13	4.81E+10	**0.00E+00**	**0.00E+00**
	Std.	1.98E-01	0.00E+00	0.00E+00	0.00E+00	6.90E+11	0.00E+00	0.00E+00	0.00E+00
F14	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F15	Mean	4.33E-01	**0.00E+00**	**0.00E+00**	3.11E-07	2.27E+02	6.24E+01	**0.00E+00**	**0.00E+00**
	Std.	2.58E-01	0.00E+00	0.00E+00	6.04E-07	7.26E+00	0.00E+00	0.00E+00	0.00E+00

The bold entries are applied to highlight the best results

Table 36 Comparative results against popular meta-heuristic algorithms on functions $F1$-$F15$ with D=100 (Classical set)

Func.	Metric	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.97E+06	5.31E+06	**0.00E+00**	1.36E+04	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	8.34E+04	1.58E+06	0.00E+00	6.40E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F2	Mean	2.02E+01	9.78E+02	**0.00E+00**	1.32E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	7.17E-01	7.84E+02	0.00E+00	6.06E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	1.10E+06	3.58E+06	**0.00E+00**	2.35E+03	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	6.78E+04	2.12E+06	0.00E+00	1.69E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	1.99E+04	4.98E+04	**0.00E+00**	1.18E+02	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	8.51E+02	1.33E+04	0.00E+00	6.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F5	Mean	2.41E+03	6.11E+03	**0.00E+00**	1.82E+01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	9.90E+01	1.65E+03	0.00E+00	9.88E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F6	Mean	7.48E-05	7.86E-07	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.03E-05	8.94E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F7	Mean	1.09E+03	2.57E+03	1.62E+03	2.06E+00	**0.00E+00**	1.12E+00	**0.00E+00**	**0.00E+00**
	Std.	4.92E+01	5.87E+02	1.26E+02	2.22E+00	0.00E+00	1.11E+00	0.00E+00	0.00E+00
F8	Mean	1.38E+05	1.97E+05	3.51E+03	2.67E+03	**0.00E+00**	2.86E+02	**0.00E+00**	**0.00E+00**
	Std.	5.36E+03	5.02E+04	5.49E+03	1.07E+03	0.00E+00	2.99E+02	0.00E+00	0.00E+00
F9	Mean	8.94E+02	7.36E+02	**0.00E+00**	1.26E+02	**0.00E+00**	8.54E+01	**0.00E+00**	**0.00E+00**
	Std.	1.72E+01	8.63E+01	0.00E+00	9.72E+01	0.00E+00	1.45E+01	0.00E+00	0.00E+00
F10	Mean	1.36E+01	2.00E+01	**0.00E+00**	3.96E+00	**0.00E+00**	1.98E+01	**0.00E+00**	**0.00E+00**
	Std.	1.38E-01	6.13E-03	0.00E+00	7.23E-01	0.00E+00	4.99E-02	0.00E+00	0.00E+00
F11	Mean	6.03E+00	1.40E+01	1.35E-03	8.20E-01	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	1.88E-01	3.48E+00	4.08E-03	2.15E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F12	Mean	−2.95E+03	−2.69E+03	**−3.92E+03**	−3.55E+03	−3.82E+03	−3.81E+03	−3.74E+03	−3.80E+03
	Std.	2.99E+01	1.13E+02	6.16E-04	7.06E+01	2.86E+01	3.93E+01	9.78E+01	7.69E+01
F13	Mean	3.56E+10	1.00E+11	**0.00E+00**	7.98E+07	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	4.20E+09	5.23E+10	0.00E+00	6.51E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F14	Mean	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F15	Mean	7.81E+01	7.86E+01	**0.00E+00**	7.70E-02	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**
	Std.	2.08E+00	1.38E+01	0.00E+00	6.55E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00

The bold entries are applied to highlight the best results

Appendix F: The computational cost of compared algorithms

Table 37 Time and solution comparisons against the state-of-the-art on functions $F1$-$F30$ with D=10 (CEC2014)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	31.62 (3)	10.46 (1)	5.27 (1)	22.59 (6)	181.24 (7)	121.26 (8)	18.57 (4)	32.23 (5)
F2	32.50 (1)	9.12 (1)	4.81 (1)	23.46 (6)	159.97 (8)	65.11 (7)	9.26 (1)	16.22 (1)
F3	31.15 (1)	7.77 (1)	3.73 (1)	24.47 (6)	131.46 (7)	155.36 (8)	9.95 (1)	15.35 (1)
F4	31.90 (1)	12.00 (6)	11.58 (2)	20.85 (7)	159.25 (8)	81.88 (3)	15.86 (5)	30.83 (4)
F5	38.70 (2)	28.13 (3)	16.59 (1)	23.38 (6)	83.88 (8)	8.48 (7)	15.45 (5)	31.20 (4)
F6	42.21 (4)	13.06 (1)	8.62 (1)	26.84 (3)	200.65 (7)	40.08 (8)	18.30 (5)	32.35 (6)
F7	39.13 (2)	12.66 (1)	10.02 (3)	19.75 (6)	188.96 (8)	44.10 (7)	15.90 (5)	30.26 (4)
F8	29.42 (1)	22.32 (4)	7.48 (1)	19.57 (6)	133.50 (8)	64.69 (7)	16.90 (3)	30.20 (5)
F9	39.08 (4)	21.05 (1)	12.03 (2)	20.47 (6)	124.36 (8)	35.17 (7)	16.66 (3)	29.98 (5)
F10	37.95 (1)	30.81 (4)	15.19 (2)	23.19 (6)	187.25 (7)	55.62 (8)	17.53 (3)	30.95 (5)
F11	42.49 (3)	29.26 (1)	15.64 (2)	23.19 (4)	178.32 (7)	65.54 (8)	17.36 (5)	30.79 (6)
F12	40.43 (3)	31.19 (4)	20.99 (2)	25.15 (1)	150.72 (8)	130.45 (7)	16.20 (6)	32.22 (5)
F13	42.28 (2)	29.55 (1)	18.08 (4)	21.08 (5)	111.65 (7)	43.54 (8)	11.30 (6)	26.87 (3)
F14	43.76 (3)	30.11 (4)	19.69 (2)	20.96 (6)	76.07 (8)	21.87 (7)	3.79 (5)	23.93 (1)
F15	45.69 (3)	25.72 (2)	20.04 (1)	22.21 (5)	101.17 (8)	23.58 (7)	15.86 (6)	29.93 (4)
F16	43.16 (3)	30.79 (1)	19.63 (2)	22.98 (5)	137.72 (8)	71.85 (6)	15.87 (7)	29.79 (4)
F17	38.77 (5)	23.65 (3)	15.06 (1)	26.88 (6)	190.28 (7)	158.19 (8)	18.54 (2)	32.03 (4)
F18	44.44 (5)	34.51 (2)	22.33 (1)	26.45 (7)	177.61 (8)	10.80 (6)	17.36 (3)	32.88 (4)
F19	43.84 (3)	26.82 (2)	20.23 (1)	24.23 (6)	148.10 (8)	110.02 (7)	14.45 (5)	32.76 (4)
F20	44.01 (5)	32.60 (2)	23.04 (1)	25.48 (7)	177.73 (8)	126.13 (6)	16.14 (3)	32.21 (4)
F21	48.47 (5)	36.31 (2)	22.45 (1)	26.38 (6)	179.17 (8)	102.54 (7)	18.10 (3)	33.22 (4)
F22	45.70 (2)	36.55 (3)	22.91 (1)	24.08 (6)	131.53 (8)	132.52 (7)	17.51 (4)	33.25 (5)
F23	37.89 (1)	9.77 (4)	6.16 (4)	26.06 (4)	173.25 (8)	136.18 (7)	6.00 (2)	8.68 (2)
F24	47.21 (6)	23.56 (1)	14.89 (2)	24.28 (5)	150.23 (8)	45.51 (7)	17.55 (3)	38.50 (4)
F25	48.95 (1)	21.05 (3)	15.60 (2)	24.15 (4)	197.76 (5)	88.81 (6)	7.97 (7)	20.19 (8)
F26	54.43 (3)	33.36 (1)	31.19 (4)	35.58 (5)	114.51 (8)	42.26 (7)	14.07 (6)	39.81 (2)
F27	52.64 (3)	34.69 (5)	31.51 (4)	37.17 (7)	191.32 (6)	50.78 (8)	18.77 (1)	43.17 (2)
F28	44.63 (5)	17.81 (7)	25.19 (3)	31.16 (4)	194.77 (6)	50.61 (8)	8.68 (1)	15.76 (1)
F29	56.87 (3)	34.85 (2)	29.46 (1)	34.78 (6)	178.24 (7)	80.88 (8)	20.21 (4)	42.71 (5)
F30	49.33 (2)	30.69 (3)	29.93 (1)	36.22 (6)	181.73 (7)	128.82 (8)	20.07 (4)	43.67 (5)

Table 38 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=10 (CEC2014)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	1.68 (5)	0.50 (6)	3.17 (7)	8.12 (3)	3.43 (4)	15.12 (1)	18.57 (2)
F2	1.23 (6)	0.32 (7)	3.17 (5)	3.59 (1)	3.00 (4)	6.79 (1)	9.26 (1)
F3	1.32 (6)	0.61 (5)	3.15 (7)	3.47 (1)	3.06 (1)	6.13 (1)	9.95 (1)
F4	1.24 (6)	0.13 (7)	3.18 (5)	3.12 (4)	3.44 (1)	5.88 (3)	15.86 (2)
F5	1.68 (1)	0.58 (4)	3.18 (7)	6.01 (3)	3.41 (2)	15.08 (6)	15.45 (5)
F6	3.67 (5)	1.48 (6)	5.72 (7)	7.21 (2)	4.40 (1)	18.12 (4)	18.30 (3)
F7	1.34 (5)	0.11 (7)	3.26 (6)	7.95 (2)	3.41 (1)	15.21 (3)	15.90 (4)
F8	1.39 (5)	0.10 (6)	3.19 (7)	1.90 (2)	0.65 (3)	14.75 (1)	16.90 (4)
F9	1.37 (5)	0.14 (6)	3.06 (7)	7.72 (4)	3.39 (2)	14.92 (1)	16.66 (3)
F10	1.74 (5)	0.21 (7)	3.26 (6)	6.82 (2)	1.67 (1)	15.16 (4)	17.53 (3)
F11	1.77 (5)	0.36 (6)	3.32 (7)	7.60 (4)	3.53 (2)	15.24 (1)	17.36 (3)
F12	1.33 (7)	1.24 (3)	3.91 (6)	7.17 (5)	4.21 (2)	15.90 (1)	16.20 (4)
F13	1.31 (5)	0.21 (6)	2.90 (7)	5.17 (3)	1.03 (2)	14.82 (1)	11.30 (4)
F14	1.27 (5)	0.24 (7)	3.08 (6)	6.55 (3)	1.72 (4)	14.90 (1)	3.79 (2)

- Data format: Average time (Ranking of solution quality)
- Average time unit: CPU second(s)

Table 39 Time and solution comparisons against the state-of-the-art on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	421.57 (3)	97.34 (1)	68.36 (2)	60.82 (4)	278.59 (7)	210.37 (8)	81.06 (6)	44.94 (5)
F2	431.28 (5)	61.25 (1)	11.92 (1)	63.57 (6)	289.01 (7)	125.05 (8)	27.63 (1)	13.84 (1)
F3	368.33 (5)	55.31 (1)	9.64 (1)	65.71 (6)	262.16 (8)	613.27 (7)	36.40 (1)	15.99 (1)
F4	378.26 (2)	102.02 (1)	34.34 (3)	52.69 (6)	237.26 (7)	152.06 (8)	80.44 (5)	45.43 (4)
F5	262.60 (3)	225.81 (2)	63.01 (4)	55.37 (1)	64.18 (7)	37.64 (8)	79.21 (6)	47.46 (5)
F6	319.15 (6)	91.05 (1)	73.69 (3)	95.84 (2)	386.14 (7)	137.42 (8)	66.12 (4)	69.12 (5)
F7	333.05 (1)	42.60 (1)	7.15 (4)	48.86 (5)	364.59 (7)	127.30 (8)	39.29 (6)	19.99 (1)
F8	316.11 (1)	149.91 (5)	19.77 (1)	57.98 (6)	239.24 (8)	119.43 (7)	69.38 (4)	43.48 (3)
F9	312.54 (6)	179.36 (1)	28.79 (5)	59.04 (4)	357.52 (8)	121.08 (7)	64.55 (2)	44.14 (3)
F10	289.44 (2)	202.10 (5)	45.43 (1)	58.03 (6)	186.09 (7)	118.25 (8)	75.70 (4)	45.49 (3)
F11	277.40 (1)	213.18 (6)	50.90 (5)	56.37 (2)	183.03 (7)	163.80 (8)	77.76 (3)	39.49 (4)
F12	260.45 (3)	237.52 (4)	73.92 (2)	68.97 (1)	169.44 (8)	177.76 (7)	85.82 (6)	41.28 (5)
F13	334.39 (3)	176.80 (2)	56.48 (4)	57.43 (5)	215.37 (8)	86.32 (7)	40.31 (6)	43.25 (1)
F14	384.00 (2)	175.39 (4)	53.55 (5)	58.51 (6)	365.56 (7)	124.98 (8)	10.95 (3)	33.94 (1)
F15	409.48 (3)	204.32 (1)	66.11 (2)	64.37 (4)	323.18 (8)	665.71 (7)	76.23 (5)	48.69 (6)
F16	273.09 (4)	212.95 (1)	66.54 (2)	62.69 (5)	316.51 (7)	15.01 (8)	71.98 (6)	48.13 (3)
F17	335.40 (3)	189.79 (1)	72.31 (2)	65.32 (4)	461.96 (8)	189.18 (7)	84.93 (6)	49.68 (5)
F18	328.01 (5)	196.59 (1)	70.20 (4)	62.12 (6)	369.42 (8)	145.10 (7)	84.90 (2)	49.45 (3)
F19	430.62 (3)	187.43 (2)	77.90 (1)	75.48 (6)	239.09 (8)	192.12 (7)	89.37 (5)	53.87 (4)
F20	469.13 (5)	193.86 (1)	69.32 (4)	74.52 (6)	237.56 (8)	397.01 (7)	86.97 (2)	49.21 (3)
F21	354.87 (4)	214.93 (1)	78.78 (2)	74.24 (6)	275.47 (7)	232.62 (8)	83.49 (5)	39.25 (3)
F22	316.23 (5)	216.94 (3)	75.75 (4)	71.57 (6)	223.91 (8)	450.58 (7)	83.45 (2)	39.24 (1)
F23	494.16 (6)	99.32 (3)	19.70 (3)	101.01 (5)	194.17 (8)	90.66 (7)	13.37 (1)	7.13 (1)
F24	406.89 (6)	257.48 (4)	134.19 (5)	233.24 (3)	221.50 (8)	61.10 (7)	14.69 (1)	3.88 (1)
F25	425.57 (4)	161.52 (3)	47.37 (5)	57.39 (6)	146.76 (8)	225.77 (7)	6.27 (1)	3.35 (1)
F26	449.35 (2)	305.85 (1)	167.00 (3)	394.44 (8)	347.71 (6)	378.26 (4)	112.00 (5)	137.21 (7)
F27	488.77 (6)	154.14 (3)	174.93 (5)	106.01 (4)	409.67 (7)	143.20 (8)	16.64 (1)	9.50 (1)
F28	373.72 (6)	156.94 (4)	18.51 (5)	58.48 (3)	377.20 (7)	112.76 (8)	10.82 (1)	8.07 (1)
F29	505.49 (4)	245.60 (3)	52.73 (6)	270.66 (5)	389.95 (8)	286.68 (7)	57.79 (1)	53.14 (2)
F30	415.78 (4)	268.64 (1)	72.72 (3)	231.21 (6)	414.52 (8)	427.37 (7)	90.53 (5)	55.51 (2)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 40 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	8.77 (6)	1.33 (7)	19.51 (5)	35.31 (3)	22.54 (4)	67.18 (1)	81.06 (2)
F2	8.08 (6)	0.92 (7)	18.75 (5)	18.70 (4)	4.52 (3)	19.80 (1)	27.63 (1)
F3	7.31 (7)	1.76 (6)	18.04 (5)	25.12 (3)	6.35 (4)	21.80 (1)	36.40 (1)
F4	9.05 (6)	0.78 (7)	19.63 (5)	17.04 (4)	20.73 (3)	66.92 (1)	80.44 (2)
F5	8.46 (7)	5.86 (3)	19.55 (4)	22.22 (6)	20.49 (1)	67.08 (2)	79.21 (5)
F6	33.50 (5)	6.89 (6)	59.86 (7)	59.14 (1)	59.79 (3)	105.09 (4)	66.12 (2)
F7	8.62 (6)	0.96 (7)	18.15 (5)	17.99 (3)	5.52 (2)	19.42 (1)	39.29 (4)
F8	6.64 (5)	0.62 (6)	17.13 (7)	23.89 (1)	17.15 (3)	64.31 (2)	69.38 (4)
F9	9.63 (5)	0.78 (6)	17.45 (7)	27.85 (4)	19.84 (3)	63.36 (2)	64.55 (1)
F10	10.26 (7)	0.79 (5)	19.37 (6)	35.75 (4)	18.55 (1)	68.12 (3)	75.70 (2)

Table 40 continued

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F11	9.61 (7)	3.25 (4)	19.89 (6)	27.25 (5)	21.25 (3)	69.38 (2)	77.76 (1)
F12	14.24 (7)	14.86 (2)	30.23 (6)	33.84 (5)	31.59 (3)	79.18 (1)	85.82 (4)
F13	7.52 (5)	0.81 (7)	17.18 (6)	25.43 (3)	8.02 (2)	67.66 (1)	40.31 (4)
F14	6.14 (6)	0.59 (7)	17.55 (4)	24.64 (3)	6.58 (2)	67.71 (5)	10.95 (1)
F15	6.46 (5)	1.39 (7)	17.75 (6)	25.63 (4)	20.80 (3)	67.27 (1)	76.23 (2)
F16	8.39 (7)	4.07 (6)	20.04 (5)	25.38 (3)	20.70 (2)	68.10 (1)	71.98 (4)
F17	8.65 (5)	2.04 (7)	22.59 (6)	37.76 (4)	23.96 (3)	71.31 (1)	84.93 (2)
F18	9.54 (6)	1.27 (7)	21.62 (5)	37.70 (4)	23.70 (3)	70.38 (2)	84.90 (1)
F19	13.04 (5)	1.74 (7)	30.15 (6)	46.20 (4)	32.46 (3)	80.70 (1)	89.37 (2)
F20	8.85 (5)	7.04 (7)	21.45 (6)	37.34 (3)	24.13 (4)	71.78 (2)	86.97 (1)
F21	9.78 (5)	1.84 (6)	26.44 (7)	37.89 (3)	24.13 (4)	70.73 (1)	83.49 (2)
F22	11.65 (3)	2.09 (6)	23.42 (7)	37.31 (5)	24.80 (4)	71.72 (2)	83.45 (1)
F23	38.10 (5)	1.46 (7)	73.49 (6)	30.31 (4)	0.44 (1)	37.68 (3)	13.37 (1)
F24	13.29 (6)	1.83 (7)	34.42 (4)	63.35 (5)	0.25 (1)	108.88 (3)	14.69 (1)
F25	17.40 (5)	2.35 (7)	27.62 (6)	53.71 (4)	0.36 (1)	99.59 (3)	6.27 (1)
F26	77.11 (3)	12.90 (7)	130.20 (4)	119.90 (5)	54.04 (2)	196.33 (1)	112.00 (6)
F27	59.17 (5)	12.76 (7)	98.79 (6)	101.61 (3)	1.34 (1)	137.75 (4)	16.64 (1)
F28	21.29 (5)	4.08 (6)	49.77 (7)	103.03 (4)	0.70 (1)	93.13 (3)	10.82 (1)
F29	25.58 (4)	3.94 (7)	23.10 (6)	79.62 (3)	7.21 (1)	115.07 (5)	57.79 (2)
F30	28.37 (5)	2.15 (7)	62.87 (6)	48.69 (3)	10.86 (1)	118.83 (4)	90.53 (2)

Table 41 Time and solution comparisons against the state-of-the-art on functions $F1$-$F30$ with D=100 (CEC2014)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	2838.22 (4)	1515.15 (1)	8234.87 (2)	165.30 (3)	0.87 (8)	292.90 (7)	201.74 (5)	107.66 (6)
F2	3215.71 (5)	1323.59 (1)	9061.23 (2)	158.72 (3)	1.02 (8)	209.51 (7)	209.18 (6)	108.47 (4)
F3	3012.30 (3)	1475.64 (1)	8868.74 (2)	181.07 (5)	0.66 (8)	1569.37 (7)	194.77 (4)	107.86 (6)
F4	2893.27 (6)	1571.25 (1)	8227.57 (2)	146.11 (5)	0.54 (8)	145.28 (7)	204.86 (3)	103.76 (4)
F5	920.67 (4)	2667.91 (2)	9430.10 (3)	163.67 (1)	0.36 (8)	18.15 (7)	188.78 (6)	97.65 (5)
F6	2157.55 (6)	1866.85 (1)	11557.66 (5)	418.98 (2)	1.04 (8)	253.98 (7)	216.08 (3)	246.28 (4)
F7	3092.60 (6)	1000.14 (1)	1768.87 (4)	133.60 (3)	0.98 (8)	233.55 (7)	71.88 (5)	53.78 (1)
F8	2560.22 (2)	1406.43 (4)	3894.32 (1)	142.84 (6)	0.88 (8)	232.18 (7)	148.05 (5)	99.66 (3)
F9	1965.64 (5)	1377.84 (1)	2714.30 (6)	166.26 (4)	0.51 (8)	295.73 (7)	168.50 (3)	100.49 (2)
F10	2138.21 (2)	2031.51 (6)	8286.92 (1)	144.11 (5)	0.68 (8)	247.36 (7)	170.49 (3)	105.31 (4)
F11	1618.20 (6)	2135.03 (5)	9148.23 (4)	174.90 (1)	0.34 (8)	254.64 (7)	192.74 (2)	111.60 (3)
F12	1397.58 (3)	2895.52 (4)	10101.24 (2)	243.43 (1)	1.19 (8)	170.37 (7)	261.94 (6)	126.06 (5)
F13	2946.95 (3)	1418.01 (2)	6780.79 (4)	170.19 (5)	0.29 (8)	165.04 (7)	109.56 (6)	91.83 (1)
F14	2920.06 (3)	1360.00 (6)	6061.01 (5)	170.04 (4)	0.67 (8)	149.27 (7)	49.80 (2)	48.79 (1)
F15	2724.79 (6)	1337.47 (1)	6391.99 (4)	176.79 (3)	0.78 (8)	1111.66 (7)	188.95 (2)	107.92 (5)
F16	1279.80 (4)	2299.97 (3)	8550.98 (1)	147.45 (5)	1.03 (8)	38.40 (7)	175.56 (6)	97.01 (2)
F17	2313.08 (4)	1551.70 (1)	9121.99 (2)	157.98 (3)	0.97 (8)	479.87 (7)	214.36 (5)	119.37 (6)
F18	2656.01 (4)	1542.83 (1)	8934.43 (6)	145.77 (2)	0.65 (8)	293.52 (7)	211.36 (3)	123.78 (5)
F19	2497.60 (6)	1652.76 (2)	9169.84 (3)	202.72 (1)	0.80 (8)	554.98 (7)	281.83 (5)	153.18 (4)
F20	2454.94 (3)	1715.04 (1)	7046.30 (2)	155.73 (6)	0.69 (8)	1432.60 (7)	212.95 (4)	113.30 (5)
F21	2555.63 (2)	1595.46 (1)	6477.99 (3)	159.49 (4)	1.21 (8)	259.71 (7)	215.92 (5)	125.39 (6)
F22	2115.60 (4)	1632.76 (3)	8212.98 (6)	161.98 (5)	0.82 (8)	1224.96 (7)	203.38 (1)	134.33 (2)

Table 41 continued

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F23	4060.65 (6)	1939.24 (4)	3868.09 (3)	444.71 (5)	3.05 (8)	119.91 (7)	229.58 (1)	25.54 (1)
F24	3348.56 (6)	1763.12 (5)	9135.69 (3)	392.38 (4)	0.83 (8)	142.56 (7)	280.07 (2)	12.23 (1)
F25	1682.28 (5)	1846.64 (3)	2836.24 (6)	348.66 (4)	0.61 (8)	130.46 (7)	213.90 (1)	7.80 (1)
F26	3439.79 (1)	3006.89 (5)	15752.64 (2)	913.35 (6)	2.25 (8)	326.78 (7)	390.67 (4)	76.38 (3)
F27	3565.90 (6)	2582.87 (3)	17516.94 (5)	743.20 (4)	3.09 (8)	309.23 (7)	126.93 (1)	30.86 (2)
F28	2836.35 (5)	3277.69 (3)	13256.48 (4)	655.32 (6)	2.29 (8)	286.19 (7)	46.15 (1)	56.31 (2)
F29	3014.91 (5)	2566.45 (3)	6466.49 (6)	652.58 (4)	0.91 (8)	395.63 (7)	92.55 (1)	22.40 (1)
F30	1400.07 (5)	2932.73 (3)	12440.05 (4)	350.34 (6)	1.24 (8)	623.83 (7)	63.70 (1)	47.41 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 42 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F30$ with D=100 (CEC2014)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	30.28 (6)	5.23 (7)	64.82 (5)	103.46 (4)	80.30 (2)	170.58 (1)	201.74 (3)
F2	30.75 (6)	5.81 (7)	62.39 (3)	48.02 (5)	75.14 (1)	170.44 (2)	209.18 (4)
F3	33.95 (7)	5.63 (6)	61.01 (5)	106.85 (4)	77.00 (2)	162.22 (1)	194.77 (3)
F4	32.83 (6)	6.10 (7)	60.20 (4)	53.70 (5)	76.49 (2)	169.24 (1)	204.86 (3)
F5	29.83 (7)	36.18 (2)	62.13 (4)	54.35 (6)	73.10 (1)	163.50 (3)	188.78 (5)
F6	200.05 (5)	42.84 (6)	333.10 (7)	273.97 (3)	345.99 (2)	433.22 (4)	216.08 (1)
F7	28.60 (6)	4.05 (7)	58.91 (4)	33.01 (5)	70.67 (2)	59.59 (1)	71.88 (3)
F8	20.71 (6)	1.37 (7)	48.22 (5)	82.37 (4)	62.75 (3)	146.70 (2)	148.05 (1)
F9	27.49 (6)	4.45 (7)	58.86 (5)	72.53 (4)	73.57 (3)	155.75 (2)	168.50 (1)
F10	27.48 (7)	3.55 (6)	51.25 (5)	90.17 (4)	66.50 (1)	156.57 (3)	170.49 (2)
F11	26.58 (6)	16.81 (4)	68.01 (5)	77.29 (7)	79.05 (3)	174.29 (2)	192.74 (1)
F12	66.13 (7)	104.55 (3)	140.58 (5)	114.96 (6)	152.77 (4)	243.76 (1)	261.94 (2)
F13	29.97 (6)	1.55 (7)	54.23 (4)	60.56 (3)	23.94 (2)	164.14 (1)	109.56 (5)
F14	25.92 (6)	3.23 (7)	56.20 (4)	50.51 (3)	21.68 (2)	164.13 (5)	49.80 (1)
F15	30.30 (6)	4.61 (7)	61.13 (5)	85.30 (4)	75.81 (3)	166.92 (2)	188.95 (1)
F16	29.83 (7)	28.99 (4)	60.93 (6)	61.25 (5)	75.82 (2)	165.94 (1)	175.56 (3)
F17	39.24 (6)	10.62 (7)	73.80 (5)	105.40 (4)	94.74 (3)	185.19 (1)	214.36 (2)
F18	33.36 (6)	11.37 (7)	73.23 (5)	51.94 (3)	90.95 (2)	178.26 (4)	211.36 (1)
F19	72.10 (5)	11.32 (7)	127.68 (6)	113.04 (4)	142.30 (3)	232.58 (1)	281.83 (2)
F20	35.77 (6)	7.31 (7)	70.84 (5)	117.86 (3)	96.14 (4)	181.03 (1)	212.95 (2)
F21	37.06 (6)	13.13 (7)	73.24 (5)	101.01 (4)	100.67 (3)	187.07 (1)	215.92 (2)
F22	38.62 (5)	10.21 (7)	81.38 (6)	117.30 (4)	98.92 (3)	191.67 (2)	203.38 (1)
F23	134.11 (6)	25.41 (7)	113.43 (3)	139.07 (5)	1.77 (1)	307.78 (4)	229.58 (1)
F24	72.52 (6)	11.98 (7)	139.43 (3)	79.87 (5)	2.60 (1)	455.43 (4)	280.07 (1)
F25	83.99 (6)	17.86 (7)	62.65 (1)	63.40 (5)	0.97 (1)	755.72 (4)	213.90 (1)
F26	567.64 (1)	71.49 (7)	321.83 (2)	1167.74 (5)	4.65 (2)	985.55 (6)	390.67 (2)
F27	434.55 (5)	76.86 (6)	775.08 (7)	508.58 (3)	6.30 (1)	1955.07 (4)	126.93 (1)
F28	137.55 (5)	37.92 (6)	320.99 (7)	493.75 (4)	5.00 (1)	681.34 (3)	46.15 (1)
F29	195.82 (4)	95.04 (7)	269.80 (6)	523.82 (3)	1.93 (1)	542.81 (5)	92.55 (1)
F30	73.64 (5)	30.31 (7)	164.53 (6)	134.82 (4)	3.71 (1)	1090.68 (3)	63.70 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 43 Time and solution comparisons against the state-of-the-art on functions $F1$-$F10$ with D=10 (CEC2021)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
B-F1	43.32 (1)	8.63 (1)	3.80 (1)	48.55 (6)	157.67 (8)	48.89 (7)	1.42 (1)	2.47 (1)
B-F2	45.49 (1)	41.27 (5)	16.44 (4)	45.54 (6)	174.79 (7)	48.85 (8)	1.27 (1)	2.10 (1)
B-F3	45.79 (1)	43.03 (5)	29.87 (4)	48.69 (6)	128.49 (7)	3.70 (8)	1.00 (1)	1.75 (1)
B-F4	66.21 (3)	47.70 (5)	34.76 (4)	48.78 (6)	85.18 (8)	124.38 (7)	0.40 (1)	0.52 (1)
B-F5	43.17 (1)	28.98 (5)	7.41 (1)	48.44 (6)	146.88 (8)	25.97 (7)	1.52 (1)	2.52 (1)
B-F6	65.39 (3)	57.67 (5)	40.67 (4)	46.58 (6)	130.11 (7)	114.29 (8)	3.27 (1)	6.01 (1)
B-F7	102.52 (3)	55.18 (5)	39.51 (4)	46.79 (6)	134.58 (7)	33.78 (8)	3.77 (1)	5.69 (1)
B-F8	60.50 (1)	11.99 (1)	5.74 (1)	45.95 (6)	134.18 (8)	90.81 (7)	1.00 (1)	1.72 (1)
B-F9	47.06 (1)	10.04 (1)	4.44 (1)	47.69 (1)	107.64 (8)	69.23 (7)	1.56 (1)	3.11 (1)
B-F10	70.51 (3)	43.90 (5)	21.29 (4)	47.07 (6)	115.85 (8)	89.14 (7)	3.15 (1)	5.25 (1)
S-F1	43.35 (1)	8.85 (1)	3.82 (1)	45.57 (6)	116.51 (8)	80.28 (7)	6.02 (1)	10.51 (1)
S-F2	46.85 (1)	47.68 (3)	17.62 (2)	45.73 (6)	120.58 (7)	25.34 (8)	33.17 (4)	59.24 (5)
S-F3	62.16 (1)	42.95 (4)	31.69 (1)	48.02 (6)	109.18 (7)	12.34 (8)	32.67 (3)	59.44 (5)
S-F4	66.50 (1)	49.38 (4)	34.40 (2)	43.57 (6)	93.83 (8)	10.10 (7)	31.88 (5)	58.96 (3)
S-F5	44.47 (1)	34.54 (5)	8.55 (2)	48.26 (6)	162.12 (8)	32.88 (7)	23.30 (4)	48.83 (3)
S-F6	70.37 (1)	64.67 (5)	40.59 (2)	42.48 (6)	144.95 (8)	62.44 (7)	27.92 (4)	59.41 (3)
S-F7	72.16 (1)	61.72 (5)	39.10 (3)	46.35 (6)	144.00 (8)	79.51 (7)	24.11 (4)	60.57 (2)
S-F8	51.12 (1)	18.50 (5)	13.17 (4)	44.85 (6)	151.49 (8)	58.22 (7)	27.91 (2)	61.58 (3)
S-F9	53.34 (1)	27.92 (3)	18.22 (2)	41.54 (6)	141.98 (7)	48.23 (8)	26.10 (4)	59.90 (5)
S-F10	62.57 (1)	21.45 (1)	12.46 (1)	44.41 (6)	145.20 (8)	51.37 (7)	12.99 (5)	34.12 (1)
BS-F1	57.77 (1)	8.83 (1)	3.77 (1)	45.03 (6)	132.35 (8)	77.10 (7)	6.07 (1)	10.46 (1)
BS-F2	51.07 (1)	49.01 (4)	16.86 (2)	45.54 (6)	125.12 (7)	24.57 (8)	34.45 (3)	59.88 (5)
BS-F3	69.82 (1)	38.51 (5)	15.65 (1)	45.02 (6)	82.36 (7)	12.01 (8)	32.42 (3)	59.46 (4)
BS-F4	62.25 (1)	38.17 (4)	28.67 (2)	38.25 (6)	70.68 (8)	10.71 (7)	32.59 (5)	58.34 (3)
BS-F5	44.41 (1)	28.13 (5)	8.14 (2)	46.00 (6)	165.00 (8)	33.33 (7)	24.77 (4)	47.82 (3)
BS-F6	68.23 (1)	65.38 (5)	39.86 (2)	42.65 (6)	111.48 (8)	59.88 (7)	28.75 (4)	59.25 (3)
BS-F7	71.12 (1)	63.37 (5)	39.68 (2)	45.99 (6)	157.54 (7)	83.21 (8)	22.86 (4)	61.08 (3)
BS-F8	53.92 (1)	17.12 (5)	11.18 (3)	41.28 (6)	151.29 (8)	18.32 (7)	26.74 (2)	62.77 (4)
BS-F9	55.13 (1)	26.39 (5)	14.23 (2)	38.66 (4)	156.44 (8)	50.31 (7)	22.98 (3)	58.19 (6)
BS-F10	54.32 (1)	15.54 (1)	8.01 (1)	44.59 (6)	144.58 (8)	53.11 (7)	13.13 (1)	20.04 (1)
SR-F1	47.85 (1)	10.56 (1)	5.12 (1)	46.83 (6)	131.63 (8)	70.71 (7)	13.61 (1)	23.23 (1)
SR-F2	55.34 (3)	40.61 (1)	23.73 (4)	47.24 (6)	143.37 (7)	41.37 (8)	34.24 (2)	59.34 (5)
SR-F3	61.89 (5)	43.97 (1)	31.75 (3)	48.55 (6)	102.53 (7)	70.15 (8)	33.08 (2)	58.66 (4)
SR-F4	72.86 (1)	51.55 (2)	30.73 (3)	44.03 (6)	99.83 (8)	32.11 (7)	31.26 (5)	59.40 (4)
SR-F5	53.07 (5)	39.00 (4)	25.83 (1)	50.14 (6)	119.93 (8)	146.21 (7)	35.26 (2)	60.74 (3)
SR-F6	67.75 (2)	63.09 (3)	40.88 (1)	43.74 (7)	100.64 (8)	80.19 (6)	27.64 (5)	58.83 (4)
SR-F7	69.96 (5)	64.06 (3)	41.01 (1)	49.12 (6)	160.78 (8)	102.70 (7)	33.44 (4)	61.76 (2)
SR-F8	58.50 (1)	18.83 (3)	13.85 (4)	45.39 (6)	170.96 (8)	38.89 (7)	26.69 (5)	60.83 (2)
SR-F9	49.38 (1)	31.14 (3)	16.84 (2)	41.24 (6)	156.54 (7)	73.35 (8)	32.15 (4)	59.70 (5)
SR-F10	48.50 (1)	23.69 (5)	11.09 (4)	41.83 (6)	150.55 (8)	151.26 (7)	19.44 (2)	59.59 (3)
BSR-F1	47.31 (1)	10.61 (1)	5.14 (1)	45.78 (6)	140.02 (8)	73.87 (7)	13.26 (1)	23.04 (1)
BSR-F2	56.63 (2)	43.93 (1)	22.17 (4)	45.70 (6)	159.00 (7)	41.72 (8)	33.92 (3)	59.17 (5)

Table 43 continued

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
BSR-F3	53.44 (5)	35.66 (2)	17.09 (4)	43.97 (6)	108.84 (7)	70.55 (8)	32.85 (1)	58.18 (3)
BSR-F4	69.76 (1)	41.13 (3)	25.84 (2)	40.79 (6)	110.19 (8)	74.93 (7)	32.52 (5)	58.82 (4)
BSR-F5	49.93 (5)	31.65 (4)	17.53 (1)	49.70 (6)	141.56 (8)	135.31 (7)	35.19 (2)	61.60 (3)
BSR-F6	68.32 (3)	59.71 (2)	41.11 (1)	45.10 (7)	100.08 (8)	87.56 (6)	29.36 (5)	58.50 (4)
BSR-F7	69.82 (4)	67.54 (3)	41.00 (1)	49.16 (6)	106.86 (8)	114.38 (7)	32.51 (5)	61.71 (2)
BSR-F8	48.24 (1)	17.24 (5)	12.02 (3)	41.85 (6)	111.65 (7)	31.24 (8)	26.67 (2)	60.80 (4)
BSR-F9	52.69 (1)	24.73 (3)	13.96 (2)	37.65 (6)	160.55 (8)	53.84 (7)	31.17 (4)	59.51 (5)
BSR-F10	49.17 (1)	17.54 (5)	8.35 (4)	39.12 (6)	145.49 (8)	154.11 (7)	19.60 (2)	56.15 (3)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 44 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F10$ with D=10 (CEC2021)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
B-F1	2.92 (7)	0.82 (6)	1.56 (1)	0.94 (1)	0.06 (1)	4.37 (1)	1.42 (1)
B-F2	6.21 (6)	0.59 (7)	1.85 (5)	7.16 (3)	0.05 (1)	30.22 (4)	1.27 (1)
B-F3	3.33 (7)	0.87 (6)	1.18 (1)	11.66 (4)	0.04 (1)	30.11 (5)	1.00 (1)
B-F4	3.23 (7)	1.17 (6)	0.52 (3)	14.51 (5)	0.03 (1)	29.85 (4)	0.40 (1)
B-F5	2.94 (7)	0.42 (6)	1.55 (1)	2.03 (5)	0.05 (1)	11.97 (1)	1.52 (1)
B-F6	2.84 (6)	0.71 (7)	6.03 (4)	16.89 (5)	0.11 (1)	29.85 (3)	3.27 (1)
B-F7	2.99 (7)	0.37 (6)	6.16 (3)	17.17 (5)	0.11 (1)	29.72 (4)	3.77 (1)
B-F8	2.34 (6)	0.58 (7)	1.06 (1)	1.70 (1)	0.05 (1)	6.55 (1)	1.00 (1)
B-F9	3.57 (7)	0.27 (6)	2.37 (5)	1.15 (1)	0.07 (1)	5.53 (1)	1.56 (1)
B-F10	2.69 (6)	0.85 (7)	6.41 (3)	7.90 (5)	0.12 (1)	30.46 (4)	3.15 (1)
S-F1	2.86 (6)	0.22 (7)	6.40 (5)	0.93 (1)	1.08 (1)	4.51 (1)	6.02 (1)
S-F2	3.66 (5)	0.32 (6)	6.67 (7)	8.26 (4)	2.55 (1)	30.39 (2)	33.17 (3)
S-F3	3.17 (6)	0.33 (5)	6.51 (7)	11.15 (2)	4.78 (3)	30.12 (1)	32.67 (4)
S-F4	2.51 (5)	0.71 (7)	6.45 (6)	14.21 (3)	7.11 (1)	30.35 (2)	31.88 (4)
S-F5	2.66 (6)	0.44 (5)	6.62 (7)	2.81 (4)	0.98 (3)	11.86 (1)	23.30 (2)
S-F6	2.94 (5)	0.76 (6)	6.60 (7)	16.66 (4)	6.83 (3)	30.20 (1)	27.92 (2)
S-F7	3.92 (6)	0.45 (5)	6.59 (7)	16.80 (4)	6.56 (2)	30.08 (1)	24.11 (3)
S-F8	2.93 (6)	0.32 (7)	7.18 (5)	8.75 (4)	3.93 (1)	27.77 (2)	27.91 (3)
S-F9	2.95 (5)	0.39 (7)	7.12 (6)	5.37 (2)	5.97 (1)	11.92 (4)	26.10 (3)
S-F10	2.37 (5)	0.36 (7)	7.05 (6)	5.57 (4)	2.89 (1)	16.62 (1)	12.99 (1)
BS-F1	2.54 (6)	0.18 (7)	6.37 (5)	0.94 (1)	1.24 (1)	4.36 (1)	6.07 (1)
BS-F2	3.29 (5)	0.38 (6)	6.66 (7)	8.11 (4)	4.81 (1)	29.60 (2)	34.45 (3)
BS-F3	2.62 (6)	0.16 (5)	6.43 (7)	4.12 (1)	1.74 (3)	29.34 (2)	32.42 (4)
BS-F4	2.80 (5)	0.58 (7)	6.39 (6)	13.28 (3)	6.91 (1)	29.15 (2)	32.59 (4)
BS-F5	3.02 (6)	0.38 (5)	6.62 (7)	4.64 (4)	1.02 (3)	12.73 (1)	24.77 (2)
BS-F6	2.92 (5)	0.79 (6)	6.69 (7)	31.40 (4)	5.98 (2)	37.19 (1)	28.75 (3)
BS-F7	2.63 (6)	0.39 (5)	7.24 (7)	16.83 (4)	5.29 (2)	35.06 (3)	22.86 (1)
BS-F8	3.19 (6)	0.23 (7)	7.17 (5)	9.15 (4)	3.09 (3)	27.24 (1)	26.74 (2)
BS-F9	3.22 (5)	0.16 (6)	7.13 (7)	3.82 (2)	5.31 (1)	11.31 (4)	22.98 (3)
BS-F10	2.58 (6)	0.34 (7)	7.12 (4)	3.30 (5)	3.94 (1)	7.77 (1)	13.13 (1)
SR-F1	2.79 (6)	0.31 (7)	6.42 (5)	4.63 (1)	4.55 (4)	9.52 (1)	13.61 (1)
SR-F2	3.31 (5)	0.72 (6)	6.64 (7)	15.53 (3)	6.93 (1)	29.34 (4)	34.24 (2)

Table 44 continued

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
SR-F3	3.29 (6)	0.49 (5)	6.55 (7)	15.60 (2)	6.96 (3)	29.22 (4)	33.08 (1)
SR-F4	3.59 (5)	0.71 (7)	6.45 (6)	13.39 (4)	6.98 (2)	29.10 (1)	31.26 (3)
SR-F5	3.54 (5)	1.15 (6)	6.62 (7)	16.58 (3)	7.15 (4)	29.41 (2)	35.26 (1)
SR-F6	2.89 (5)	0.53 (6)	6.66 (7)	15.69 (4)	6.83 (1)	29.41 (3)	27.64 (2)
SR-F7	3.23 (6)	1.18 (5)	6.68 (7)	16.77 (4)	6.83 (3)	29.36 (1)	33.44 (2)
SR-F8	3.54 (5)	0.53 (7)	7.23 (6)	16.79 (3)	7.44 (2)	30.39 (4)	26.69 (1)
SR-F9	3.61 (5)	0.38 (6)	7.20 (7)	15.13 (2)	7.48 (1)	29.86 (4)	32.15 (3)
SR-F10	3.34 (5)	0.34 (7)	7.17 (6)	10.19 (4)	7.37 (3)	24.22 (2)	19.44 (1)
BSR-F1	3.00 (6)	0.34 (7)	6.44 (5)	4.72 (1)	4.10 (4)	9.73 (1)	13.26 (1)
BSR-F2	3.64 (5)	0.45 (6)	6.71 (7)	15.32 (3)	6.67 (1)	29.95 (4)	33.92 (2)
BSR-F3	3.00 (6)	0.10 (5)	6.53 (7)	15.45 (4)	6.67 (2)	29.62 (3)	32.85 (1)
BSR-F4	2.84 (5)	0.44 (7)	6.53 (6)	13.22 (4)	6.93 (3)	29.54 (1)	32.52 (2)
BSR-F5	3.46 (5)	0.76 (6)	6.66 (7)	16.68 (4)	12.74 (3)	29.83 (2)	35.19 (1)
BSR-F6	2.81 (5)	0.51 (6)	6.62 (7)	15.87 (3)	9.79 (1)	29.74 (4)	29.36 (2)
BSR-F7	2.22 (6)	1.23 (5)	6.72 (7)	16.59 (4)	6.64 (2)	29.76 (1)	32.51 (3)
BSR-F8	3.90 (5)	0.20 (7)	7.21 (6)	16.78 (2)	7.23 (3)	29.91 (4)	26.67 (1)
BSR-F9	3.52 (5)	0.28 (7)	7.20 (6)	14.45 (2)	7.26 (1)	29.87 (4)	31.17 (3)
BSR-F10	2.46 (5)	0.18 (7)	7.11 (6)	12.39 (4)	6.95 (2)	24.38 (3)	19.60 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 45 Time and solution comparisons against the state-of-the-art on functions $F1$-$F10$ with D=20 (CEC2021)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
B-F1	260.16 (1)	30.53 (1)	3.29 (1)	116.83 (6)	69.71 (7)	19.55 (8)	1.29 (1)	1.32 (1)
B-F2	249.90 (1)	183.66 (5)	35.62 (4)	109.56 (6)	71.84 (7)	25.18 (8)	1.20 (1)	1.12 (1)
B-F3	230.34 (1)	250.28 (6)	78.14 (5)	116.02 (4)	56.98 (7)	23.50 (8)	0.93 (1)	0.85 (1)
B-F4	357.88 (3)	313.36 (5)	84.65 (4)	116.20 (6)	57.48 (7)	71.69 (8)	0.34 (1)	0.33 (1)
B-F5	250.85 (1)	207.24 (5)	15.06 (4)	114.13 (6)	72.80 (8)	75.96 (7)	1.30 (1)	1.36 (1)
B-F6	364.27 (3)	308.82 (5)	112.84 (4)	112.74 (6)	62.11 (7)	22.43 (8)	4.07 (2)	3.25 (1)
B-F7	381.56 (3)	262.93 (5)	111.47 (4)	110.12 (6)	71.03 (8)	75.61 (7)	4.38 (2)	3.30 (1)
B-F8	223.22 (1)	33.12 (1)	6.65 (1)	116.62 (6)	63.88 (7)	20.71 (8)	1.04 (1)	0.95 (1)
B-F9	271.76 (1)	34.29 (1)	4.18 (1)	117.05 (1)	68.93 (7)	18.99 (8)	1.70 (1)	1.70 (1)
B-F10	380.20 (3)	233.37 (4)	39.43 (6)	117.53 (5)	61.29 (7)	45.57 (8)	3.24 (1)	2.99 (1)
S-F1	259.83 (1)	31.14 (1)	3.28 (1)	102.84 (6)	63.93 (7)	28.63 (8)	23.79 (1)	22.61 (1)
S-F2	256.90 (1)	247.04 (5)	41.07 (2)	108.75 (6)	62.73 (7)	22.56 (8)	109.19 (4)	166.08 (3)
S-F3	345.75 (1)	250.10 (5)	87.96 (1)	123.08 (6)	67.61 (7)	19.73 (8)	147.51 (4)	170.47 (3)
S-F4	373.70 (1)	326.89 (4)	102.04 (2)	106.20 (6)	76.39 (7)	93.30 (8)	160.40 (5)	169.20 (3)
S-F5	263.11 (1)	219.06 (5)	21.03 (2)	113.92 (6)	70.99 (8)	78.48 (7)	89.91 (4)	102.00 (3)
S-F6	386.85 (1)	291.79 (3)	106.25 (2)	107.22 (6)	67.10 (7)	21.07 (8)	127.80 (5)	173.74 (4)
S-F7	404.26 (1)	281.98 (5)	101.62 (2)	109.22 (6)	72.36 (8)	45.78 (7)	132.59 (3)	167.66 (4)
S-F8	296.24 (1)	62.82 (2)	13.56 (2)	114.82 (6)	63.91 (7)	38.45 (8)	64.81 (5)	55.67 (2)
S-F9	349.68 (1)	181.96 (4)	58.45 (2)	107.93 (3)	71.22 (8)	34.48 (7)	76.51 (6)	149.19 (5)
S-F10	321.34 (1)	119.90 (4)	24.79 (2)	96.24 (6)	66.20 (8)	61.32 (7)	88.66 (5)	77.30 (3)
BS-F1	259.73 (1)	31.18 (1)	3.33 (1)	103.72 (6)	73.13 (7)	33.49 (8)	24.07 (1)	23.05 (1)
BS-F2	256.25 (1)	260.90 (5)	31.88 (2)	109.27 (6)	76.01 (7)	28.44 (8)	105.56 (4)	168.83 (3)

Table 45 continued

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
BS-F3	281.07 (1)	206.78 (5)	16.30 (1)	108.58 (6)	53.01 (7)	23.21 (8)	147.49 (4)	164.79 (3)
BS-F4	353.99 (1)	283.01 (4)	79.51 (2)	94.43 (6)	35.33 (7)	82.62 (8)	163.96 (5)	171.38 (3)
BS-F5	260.95 (1)	198.75 (5)	25.64 (2)	120.02 (6)	67.66 (8)	65.69 (7)	89.49 (4)	101.04 (3)
BS-F6	383.68 (1)	287.48 (3)	113.07 (2)	107.66 (6)	57.25 (7)	38.63 (8)	144.66 (5)	175.88 (4)
BS-F7	392.99 (1)	247.48 (5)	107.47 (2)	109.90 (6)	69.79 (8)	88.14 (7)	134.66 (3)	177.40 (4)
BS-F8	284.04 (1)	119.20 (2)	28.36 (5)	112.77 (6)	73.30 (7)	38.17 (8)	73.81 (4)	36.11 (2)
BS-F9	326.84 (1)	77.48 (4)	61.54 (2)	100.99 (3)	60.08 (8)	19.66 (7)	74.29 (6)	118.21 (5)
BS-F10	341.93 (1)	59.54 (3)	30.02 (2)	86.34 (6)	70.74 (8)	39.60 (7)	95.67 (5)	82.23 (4)
SR-F1	290.42 (1)	36.87 (1)	4.73 (1)	111.29 (6)	75.67 (7)	21.97 (8)	47.40 (1)	43.27 (1)
SR-F2	299.55 (1)	253.37 (5)	53.23 (4)	109.79 (6)	71.98 (7)	29.14 (8)	130.16 (3)	170.86 (2)
SR-F3	356.98 (1)	261.99 (5)	93.76 (4)	115.87 (6)	56.31 (7)	35.77 (8)	152.81 (3)	171.05 (2)
SR-F4	399.02 (1)	314.29 (4)	93.24 (2)	105.98 (6)	44.05 (7)	274.25 (8)	171.36 (5)	172.31 (3)
SR-F5	306.70 (5)	198.22 (2)	48.70 (1)	115.11 (6)	65.07 (8)	75.24 (7)	183.10 (4)	175.77 (3)
SR-F6	386.30 (1)	298.97 (3)	113.62 (2)	105.10 (6)	62.14 (7)	16.18 (8)	140.44 (5)	164.08 (4)
SR-F7	385.43 (5)	307.75 (3)	112.96 (4)	123.17 (6)	70.03 (7)	61.11 (8)	188.40 (1)	179.07 (2)
SR-F8	292.94 (1)	63.78 (2)	15.59 (2)	117.26 (6)	75.88 (7)	48.86 (8)	69.69 (5)	75.49 (2)
SR-F9	292.49 (1)	161.84 (2)	48.63 (6)	104.00 (3)	68.91 (8)	23.98 (7)	108.09 (5)	168.09 (4)
SR-F10	305.45 (2)	92.04 (5)	28.78 (1)	96.37 (6)	67.33 (7)	58.11 (8)	95.34 (4)	93.55 (3)
BSR-F1	293.30 (1)	36.94 (1)	5.22 (1)	110.99 (6)	106.15 (8)	22.87 (7)	46.96 (1)	43.98 (1)
BSR-F2	297.46 (1)	262.65 (5)	46.82 (4)	109.38 (6)	81.86 (8)	18.75 (7)	126.95 (3)	172.96 (2)
BSR-F3	305.92 (2)	199.81 (5)	26.51 (4)	109.15 (6)	68.70 (7)	22.79 (8)	153.61 (3)	170.24 (1)
BSR-F4	379.39 (1)	296.21 (4)	72.26 (2)	97.69 (6)	52.87 (7)	152.53 (8)	165.76 (5)	172.95 (3)
BSR-F5	293.70 (5)	175.81 (2)	35.68 (3)	115.85 (6)	68.31 (8)	93.12 (7)	182.50 (4)	176.40 (1)
BSR-F6	380.61 (1)	290.05 (3)	103.90 (2)	105.50 (6)	65.15 (7)	19.75 (8)	121.87 (5)	170.08 (4)
BSR-F7	387.73 (5)	295.48 (2)	109.90 (3)	113.24 (6)	60.18 (8)	75.77 (7)	184.39 (4)	170.22 (1)
BSR-F8	256.21 (1)	128.35 (2)	17.78 (5)	112.25 (6)	57.47 (7)	27.52 (8)	65.31 (4)	45.23 (2)
BSR-F9	290.68 (1)	81.78 (2)	14.31 (6)	101.20 (3)	56.42 (8)	28.87 (7)	112.35 (5)	159.53 (4)
BSR-F10	286.25 (1)	53.76 (5)	31.25 (2)	89.11 (6)	79.24 (8)	57.27 (7)	101.97 (4)	85.52 (3)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 46 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F10$ with D=20 (CEC2021)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
B-F1	12.79 (7)	0.55 (6)	4.09 (1)	1.53 (1)	0.07 (1)	16.86 (1)	1.29 (1)
B-F2	16.19 (7)	0.72 (6)	4.69 (1)	29.53 (4)	0.05 (1)	154.61 (5)	1.20 (1)
B-F3	15.85 (6)	0.53 (7)	2.07 (1)	64.36 (4)	0.05 (1)	149.68 (5)	0.93 (1)
B-F4	14.49 (7)	1.23 (6)	5.05 (3)	72.79 (5)	0.02 (1)	152.40 (4)	0.34 (1)
B-F5	16.30 (6)	0.56 (7)	4.08 (1)	11.17 (5)	0.06 (1)	69.62 (4)	1.30 (1)
B-F6	16.56 (6)	0.50 (7)	34.41 (3)	87.08 (5)	0.12 (1)	151.66 (4)	4.07 (1)
B-F7	17.97 (7)	0.70 (6)	34.09 (3)	87.50 (5)	0.13 (1)	151.91 (4)	4.38 (1)
B-F8	12.65 (6)	2.00 (7)	1.92 (1)	29.34 (5)	0.06 (1)	42.67 (4)	1.04 (1)
B-F9	16.58 (7)	2.50 (6)	7.08 (1)	1.90 (1)	0.09 (1)	19.99 (1)	1.70 (1)
B-F10	18.47 (6)	2.50 (7)	41.08 (3)	32.55 (5)	0.15 (1)	159.79 (4)	3.24 (1)
S-F1	14.73 (6)	0.43 (7)	35.35 (5)	1.56 (1)	1.28 (1)	17.16 (1)	23.79 (1)
S-F2	17.64 (5)	1.62 (6)	37.90 (7)	38.48 (3)	21.07 (2)	157.02 (4)	109.19 (1)

Table 46 continued

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
S-F3	15.80 (5)	0.63 (6)	35.85 (7)	63.75 (2)	26.69 (4)	152.94 (1)	147.51 (3)
S-F4	17.40 (5)	0.77 (7)	36.26 (6)	75.78 (4)	37.86 (2)	154.04 (1)	160.40 (3)
S-F5	18.71 (5)	0.80 (7)	37.53 (6)	16.68 (4)	5.46 (2)	77.84 (3)	89.91 (1)
S-F6	17.48 (5)	0.91 (6)	37.18 (7)	86.42 (3)	37.38 (1)	157.14 (4)	127.80 (2)
S-F7	14.68 (5)	0.85 (7)	37.13 (6)	85.86 (4)	36.04 (2)	157.72 (3)	132.59 (1)
S-F8	18.29 (5)	2.38 (7)	43.35 (6)	16.16 (3)	14.04 (1)	99.69 (4)	64.81 (2)
S-F9	16.88 (5)	1.74 (6)	43.59 (7)	37.22 (2)	18.56 (3)	98.05 (4)	76.51 (1)
S-F10	20.39 (6)	2.15 (7)	43.22 (5)	26.52 (2)	23.79 (1)	57.23 (4)	88.66 (3)
BS-F1	14.18 (6)	0.40 (7)	33.77 (5)	1.55 (1)	1.30 (1)	16.68 (1)	24.07 (1)
BS-F2	17.39 (5)	1.11 (6)	36.09 (7)	40.11 (3)	21.42 (2)	152.57 (4)	105.56 (1)
BS-F3	17.54 (5)	0.66 (6)	32.95 (7)	21.44 (2)	12.89 (4)	139.62 (1)	147.49 (3)
BS-F4	14.08 (5)	0.52 (7)	34.76 (6)	75.53 (4)	37.34 (2)	150.18 (1)	163.96 (3)
BS-F5	15.64 (5)	0.51 (7)	35.89 (6)	19.27 (4)	8.42 (2)	71.08 (3)	89.49 (1)
BS-F6	16.96 (5)	1.02 (6)	35.45 (7)	85.59 (4)	34.26 (1)	151.29 (3)	144.66 (2)
BS-F7	19.27 (6)	0.70 (7)	35.54 (5)	83.73 (4)	30.62 (2)	151.94 (3)	134.66 (1)
BS-F8	17.90 (5)	1.62 (7)	41.21 (6)	8.15 (3)	3.15 (1)	65.30 (4)	73.81 (2)
BS-F9	20.08 (5)	0.53 (6)	41.85 (7)	15.60 (1)	5.57 (3)	41.07 (4)	74.29 (2)
BS-F10	20.88 (6)	1.03 (7)	41.55 (5)	12.52 (2)	22.92 (1)	42.42 (3)	95.67 (4)
SR-F1	16.64 (6)	0.63 (7)	33.90 (5)	7.74 (1)	5.53 (1)	33.07 (1)	47.40 (1)
SR-F2	17.42 (5)	1.90 (6)	36.47 (7)	86.14 (4)	23.52 (1)	156.09 (3)	130.16 (2)
SR-F3	17.38 (5)	0.81 (6)	33.29 (7)	85.49 (1)	30.96 (2)	152.57 (4)	152.81 (3)
SR-F4	16.10 (5)	1.22 (7)	34.90 (6)	73.55 (4)	37.55 (3)	153.70 (1)	171.36 (2)
SR-F5	13.51 (5)	1.76 (7)	36.19 (6)	86.87 (3)	38.72 (4)	156.11 (1)	183.10 (2)
SR-F6	16.00 (5)	0.81 (6)	35.71 (7)	86.23 (4)	37.04 (1)	154.74 (3)	140.44 (2)
SR-F7	16.74 (5)	1.19 (7)	35.27 (6)	86.24 (3)	38.32 (4)	155.14 (1)	188.40 (2)
SR-F8	19.33 (4)	6.24 (7)	41.84 (6)	20.85 (3)	18.42 (2)	120.92 (5)	69.69 (1)
SR-F9	18.99 (5)	3.79 (6)	42.31 (7)	85.56 (4)	35.30 (2)	152.56 (3)	108.09 (1)
SR-F10	20.22 (5)	2.45 (7)	42.21 (6)	50.99 (4)	30.27 (3)	72.49 (2)	95.34 (1)
BSR-F1	14.73 (6)	0.52 (7)	34.44 (5)	7.84 (1)	6.06 (1)	32.44 (1)	46.96 (1)
BSR-F2	17.41 (5)	2.01 (7)	36.68 (6)	87.01 (4)	26.70 (1)	155.87 (3)	126.95 (2)
BSR-F3	14.65 (5)	0.59 (6)	34.20 (7)	86.32 (1)	24.92 (2)	149.60 (4)	153.61 (3)
BSR-F4	16.53 (5)	0.66 (7)	34.71 (6)	71.57 (4)	37.55 (3)	151.38 (1)	165.76 (2)
BSR-F5	14.85 (5)	1.61 (7)	36.30 (6)	86.66 (3)	38.98 (4)	153.94 (1)	182.50 (2)
BSR-F6	17.15 (5)	0.60 (6)	36.14 (7)	86.73 (4)	34.49 (2)	153.25 (3)	121.87 (1)
BSR-F7	16.00 (5)	1.72 (6)	35.91 (7)	88.48 (3)	38.47 (4)	153.22 (1)	184.39 (2)
BSR-F8	18.86 (4)	3.65 (7)	42.26 (6)	21.33 (3)	9.06 (2)	116.97 (5)	65.31 (1)
BSR-F9	17.56 (5)	1.29 (6)	42.33 (7)	84.33 (4)	34.44 (2)	139.37 (3)	112.35 (1)
BSR-F10	20.89 (4)	1.26 (7)	41.87 (6)	41.05 (5)	30.39 (3)	49.31 (2)	101.97 (1)

- Data format: Average time (Ranking of solution quality)
- Average time unit: CPU second(s)

Table 47 Time and solution comparisons against the state-of-the-art on functions $F1$-$F16$ with D=10 (Classical set)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	31.67 (1)	6.24 (1)	2.92 (1)	13.91 (1)	157.97 (8)	62.92 (7)	1.03 (1)	1.48 (1)
F2	27.33 (1)	4.52 (1)	2.02 (1)	15.41 (1)	190.58 (8)	159.25 (7)	0.58 (1)	0.80 (1)
F3	29.47 (1)	6.04 (1)	2.67 (1)	21.01 (1)	206.32 (8)	95.40 (7)	1.08 (1)	1.67 (1)
F4	28.78 (1)	9.20 (1)	5.67 (1)	21.26 (1)	182.25 (7)	75.06 (8)	1.31 (1)	2.14 (1)
F5	27.36 (1)	4.53 (1)	2.03 (1)	16.23 (1)	171.49 (8)	52.59 (7)	0.50 (1)	1.01 (1)
F6	14.88 (1)	1.65 (1)	0.61 (1)	10.34 (1)	178.59 (8)	37.69 (1)	0.17 (1)	0.31 (1)
F7	29.24 (1)	6.34 (1)	2.95 (1)	15.90 (1)	169.24 (8)	180.66 (7)	0.71 (1)	1.11 (1)
F8	32.42 (1)	7.61 (1)	4.74 (1)	19.91 (1)	188.63 (8)	112.34 (7)	1.04 (1)	1.73 (1)
F9	28.79 (1)	21.30 (5)	7.36 (1)	24.76 (6)	157.65 (7)	34.96 (8)	0.83 (1)	1.47 (1)
F10	31.39 (1)	8.24 (1)	4.23 (1)	24.09 (1)	128.72 (8)	63.67 (7)	1.56 (1)	2.63 (1)
F11	35.43 (1)	13.38 (5)	9.57 (4)	24.82 (6)	178.40 (8)	65.49 (7)	0.88 (1)	1.56 (1)
F12	20.19 (1)	4.25 (1)	1.99 (1)	14.23 (6)	204.38 (7)	41.59 (8)	4.02 (1)	6.16 (1)
F13	23.48 (1)	3.49 (1)	1.69 (1)	9.58 (1)	186.31 (8)	82.35 (7)	0.20 (1)	0.36 (1)
F14	41.28 (3)	26.86 (3)	19.82 (3)	25.64 (6)	190.88 (7)	32.78 (8)	11.14 (2)	10.45 (1)
F15	36.25 (1)	17.41 (1)	13.52 (1)	21.81 (1)	173.49 (8)	57.75 (7)	1.38 (1)	2.01 (1)
F16	31.39 (1)	24.86 (3)	7.56 (2)	25.15 (6)	195.94 (7)	65.23 (8)	16.67 (5)	30.03 (4)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 48 Time and solution comparisons against popular meta-heuristic algorithms on functions F1-F16 with D=10 (Classical set)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	1.41 (7)	0.05 (1)	0.62 (1)	0.70 (1)	0.04 (1)	2.84 (1)	1.03 (1)
F2	1.93 (6)	0.12 (7)	0.28 (1)	0.51 (1)	0.04 (1)	2.36 (1)	0.58 (1)
F3	1.74 (7)	0.74 (6)	0.82 (1)	0.72 (1)	0.05 (1)	2.78 (1)	1.08 (1)
F4	1.55 (6)	0.23 (5)	2.89 (7)	1.82 (1)	0.06 (1)	4.89 (1)	1.31 (1)
F5	1.61 (7)	0.05 (1)	0.34 (1)	0.50 (1)	0.04 (1)	2.31 (1)	0.50 (1)
F6	1.46 (7)	0.03 (1)	0.10 (1)	0.17 (1)	0.01 (1)	1.13 (1)	0.17 (1)
F7	1.47 (7)	0.86 (6)	3.46 (5)	2.09 (1)	0.04 (1)	5.64 (1)	0.71 (1)
F8	3.90 (7)	4.50 (6)	7.41 (5)	3.82 (1)	0.10 (1)	8.37 (1)	1.04 (1)
F9	1.87 (7)	0.33 (6)	0.79 (1)	1.83 (1)	0.04 (1)	14.37 (1)	0.83 (1)
F10	1.84 (7)	0.19 (6)	1.25 (1)	1.09 (1)	0.08 (1)	4.01 (1)	1.56 (1)
F11	1.66 (7)	0.41 (6)	1.87 (5)	3.44 (3)	0.05 (1)	15.00 (4)	0.88 (1)
F12	1.19 (6)	0.22 (7)	1.13 (1)	0.51 (1)	0.35 (1)	1.90 (1)	4.02 (1)
F13	2.07 (7)	0.05 (1)	0.24 (1)	0.39 (1)	0.02 (1)	2.11 (1)	0.20 (1)
F14	2.18 (6)	1.16 (7)	3.47 (3)	7.59 (4)	2.31 (2)	14.78 (5)	11.14 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 49 Time and solution comparisons against the state-of-the-art on functions $F1$-$F16$ with D=30 (Classical set)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	287.98 (1)	43.21 (1)	3.84 (1)	37.37 (1)	347.41 (7)	131.09 (8)	0.72 (1)	0.81 (1)
F2	258.67 (1)	33.02 (1)	2.92 (1)	43.47 (1)	401.68 (8)	778.50 (7)	0.55 (1)	0.62 (1)
F3	317.61 (1)	41.14 (1)	5.61 (1)	52.49 (1)	315.85 (8)	231.35 (7)	0.89 (1)	1.09 (1)
F4	245.32 (6)	66.35 (1)	9.23 (1)	49.70 (1)	403.23 (7)	101.15 (8)	1.07 (1)	1.37 (1)
F5	279.14 (1)	33.43 (1)	2.89 (1)	40.72 (1)	419.07 (7)	88.09 (8)	0.52 (1)	0.61 (1)
F6	178.65 (1)	9.30 (1)	0.67 (1)	23.68 (1)	262.05 (7)	217.31 (8)	0.15 (1)	0.21 (1)
F7	277.74 (1)	62.37 (1)	9.05 (1)	38.57 (1)	269.17 (7)	474.17 (8)	0.76 (1)	1.00 (1)
F8	344.56 (1)	79.62 (1)	30.01 (1)	77.92 (1)	457.64 (8)	103.39 (7)	1.48 (1)	1.59 (1)
F9	289.53 (1)	146.07 (5)	17.80 (1)	63.39 (6)	302.56 (7)	67.34 (8)	0.63 (1)	0.84 (1)
F10	315.81 (1)	50.68 (1)	5.14 (1)	60.65 (1)	440.64 (7)	122.41 (8)	1.08 (1)	1.57 (1)
F11	294.22 (1)	40.07 (1)	3.80 (1)	50.23 (6)	467.85 (7)	134.36 (8)	0.62 (1)	0.78 (1)
F12	270.79 (1)	45.36 (3)	5.83 (1)	45.61 (4)	446.35 (7)	114.61 (8)	23.39 (6)	31.58 (5)
F13	260.40 (1)	25.74 (1)	2.18 (1)	25.94 (1)	392.13 (7)	207.43 (8)	0.26 (1)	0.22 (1)
F14	26.81 (1)	21.55 (1)	0.50 (1)	21.18 (1)	52.76 (1)	63.08 (1)	0.14 (1)	0.12 (1)
F15	277.85 (1)	113.59 (1)	29.82 (1)	52.14 (1)	308.87 (8)	114.61 (7)	1.06 (1)	1.37 (1)
F16	290.58 (2)	186.25 (4)	48.70 (1)	63.00 (5)	130.77 (8)	134.62 (7)	77.36 (6)	85.37 (3)

- Data format: Average time (Ranking of solution quality)
- Average time unit: CPU second(s)

Table 50 Time and solution comparisons against popular meta-heuristic algorithms on functions F1-F16 with D=30 (Classical set)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	7.79 (7)	0.65 (6)	1.35 (1)	1.28 (1)	0.06 (1)	12.54 (1)	0.72 (1)
F2	9.99 (6)	0.97 (7)	0.44 (1)	1.10 (1)	0.05 (1)	11.46 (1)	0.55 (1)
F3	7.07 (6)	0.90 (7)	2.23 (1)	7.53 (5)	0.06 (1)	12.38 (1)	0.89 (1)
F4	7.14 (5)	0.69 (6)	13.76 (7)	31.15 (4)	0.07 (1)	57.13 (3)	1.07 (1)
F5	8.72 (6)	0.60 (7)	0.66 (1)	0.95 (1)	0.04 (1)	11.30 (1)	0.52 (1)
F6	7.10 (7)	0.42 (6)	0.16 (1)	0.20 (1)	0.02 (1)	7.08 (1)	0.15 (1)
F7	10.21 (7)	1.35 (6)	23.27 (5)	10.87 (1)	0.05 (1)	32.83 (1)	0.76 (1)
F8	45.48 (6)	17.16 (7)	91.61 (4)	86.19 (5)	0.23 (1)	95.40 (1)	1.48 (1)
F9	7.80 (7)	0.65 (6)	1.16 (1)	23.70 (4)	0.05 (1)	61.10 (5)	0.63 (1)
F10	11.31 (6)	1.74 (7)	3.97 (1)	2.66 (5)	0.09 (1)	15.85 (1)	1.08 (1)

- Data format: Average time (Ranking of solution quality)
- Average time unit: CPU second(s)

Table 51 Time and solution comparisons against the state-of-the-art on functions $F1$-$F16$ with D=50 (Classical set)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	893.47 (6)	99.83 (1)	5.23 (1)	47.69 (1)	184.67 (7)	136.96 (8)	0.80 (1)	0.99 (1)
F2	865.96 (6)	86.92 (1)	4.05 (1)	53.06 (1)	181.63 (8)	518.33 (7)	0.59 (1)	0.59 (1)
F3	891.69 (6)	100.69 (1)	9.51 (1)	61.86 (1)	182.38 (7)	165.59 (8)	1.21 (1)	1.04 (1)
F4	414.44 (6)	151.99 (1)	12.79 (1)	64.33 (5)	140.34 (8)	150.16 (7)	1.29 (1)	1.22 (1)
F5	894.67 (6)	78.79 (1)	4.45 (1)	52.38 (1)	187.03 (7)	110.98 (8)	0.69 (1)	0.61 (1)
F6	546.56 (1)	29.80 (1)	0.85 (1)	30.49 (1)	176.42 (7)	142.78 (8)	0.20 (1)	0.18 (1)
F7	739.65 (6)	161.61 (1)	15.18 (1)	48.83 (1)	162.69 (7)	358.10 (8)	1.07 (1)	1.00 (1)
F8	980.22 (6)	227.14 (1)	122.97 (1)	128.19 (1)	148.07 (8)	139.31 (7)	2.50 (1)	2.20 (1)
F9	664.07 (4)	203.67 (5)	30.21 (1)	70.06 (6)	160.80 (8)	88.43 (7)	0.96 (1)	0.83 (1)
F10	813.99 (6)	108.01 (1)	7.02 (1)	64.97 (1)	193.52 (7)	133.59 (8)	1.38 (1)	1.36 (1)
F11	904.49 (6)	82.96 (1)	5.24 (1)	45.43 (5)	180.47 (7)	121.75 (8)	0.78 (1)	0.84 (1)
F12	661.96 (1)	109.66 (3)	11.62 (1)	66.59 (6)	173.41 (8)	125.94 (7)	37.18 (5)	52.58 (4)
F13	906.98 (6)	71.42 (1)	3.14 (1)	33.20 (1)	185.00 (7)	126.35 (8)	0.30 (1)	0.21 (1)
F14	9.28 (1)	11.86 (1)	0.09 (1)	4.30 (1)	8.76 (1)	7.78 (1)	0.03 (1)	0.03 (1)
F15	683.36 (6)	188.65 (5)	24.83 (1)	60.95 (1)	173.21 (7)	155.62 (8)	1.32 (1)	1.37 (1)
F16	650.01 (2)	263.90 (5)	70.01 (1)	74.70 (3)	162.52 (8)	132.53 (7)	99.22 (6)	91.83 (4)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 52 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F16$ with D=50 (Classical set)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	8.94 (6)	0.62 (7)	1.95 (1)	19.03 (5)	0.07 (1)	20.21 (1)	0.80 (1)
F2	12.67 (6)	1.62 (7)	0.59 (1)	23.07 (5)	0.06 (1)	19.58 (1)	0.59 (1)
F3	11.44 (6)	1.02 (7)	2.27 (1)	21.08 (5)	0.09 (1)	20.14 (1)	1.21 (1)
F4	7.45 (5)	0.82 (6)	14.72 (7)	40.09 (4)	0.08 (1)	71.01 (3)	1.29 (1)
F5	8.13 (6)	0.64 (7)	0.74 (1)	18.54 (5)	0.06 (1)	18.77 (1)	0.69 (1)
F6	8.07 (7)	0.59 (6)	0.16 (1)	0.34 (1)	0.02 (1)	13.75 (1)	0.20 (1)
F7	12.09 (5)	2.46 (6)	24.64 (7)	41.91 (3)	0.08 (1)	81.71 (4)	1.07 (1)
F8	75.68 (6)	31.57 (7)	147.61 (5)	165.71 (4)	0.43 (1)	214.94 (3)	2.50 (1)
F9	11.45 (7)	0.70 (6)	1.28 (1)	42.42 (5)	0.06 (1)	77.22 (4)	0.96 (1)
F10	12.92 (6)	1.45 (7)	4.15 (1)	19.07 (5)	0.10 (1)	24.77 (1)	1.38 (1)
F11	10.48 (6)	0.88 (7)	2.86 (4)	17.59 (5)	0.05 (1)	22.58 (1)	0.78 (1)
F12	11.80 (6)	0.80 (7)	7.07 (1)	19.96 (5)	6.08 (3)	32.50 (2)	37.18 (4)
F13	9.90 (6)	1.59 (7)	0.45 (1)	23.50 (5)	0.04 (1)	19.86 (1)	0.30 (1)
F14	0.01 (1)	0.01 (1)	0.01 (1)	0.02 (1)	0.01 (1)	0.01 (1)	0.03 (1)
F15	10.48 (7)	1.02 (6)	2.83 (1)	4.74 (1)	0.08 (1)	32.75 (1)	1.32 (1)
F16	12.15 (7)	2.82 (5)	25.33 (6)	46.19 (4)	29.30 (1)	84.59 (2)	99.22 (3)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 53 Time and solution comparisons against the state-of-the-art on functions $F1$-$F15$ with D=100 (Classical set)

Func.	NL-SHADE-RSP	NL-SHADE-LBC	EA4EIG	DISGSA	HEBO	LSSP	AdaGuiDE	AdaGuiDE-PS
F1	3259.87 (6)	772.51 (1)	279.04 (1)	206.61 (1)	0.66 (8)	207.06 (7)	0.76 (1)	0.39 (1)
F2	2798.81 (6)	804.61 (1)	199.65 (1)	236.02 (1)	0.65 (8)	2204.90 (7)	0.50 (1)	0.27 (1)
F3	3238.17 (6)	860.86 (1)	708.39 (1)	285.60 (1)	0.59 (8)	156.62 (7)	0.92 (1)	0.49 (1)
F4	675.66 (6)	1288.25 (4)	1345.21 (3)	282.32 (5)	0.48 (8)	125.09 (7)	0.99 (1)	0.52 (1)
F5	2704.76 (6)	710.07 (1)	289.77 (1)	234.90 (1)	0.40 (8)	120.37 (7)	0.50 (1)	0.34 (1)
F6	1957.84 (1)	419.96 (1)	41.11 (1)	135.93 (1)	0.06 (8)	502.56 (7)	0.14 (1)	0.08 (1)
F7	2975.53 (6)	1371.54 (1)	3969.47 (1)	273.28 (5)	0.53 (8)	1107.51 (7)	0.99 (1)	0.50 (1)
F8	3061.70 (6)	2491.64 (3)	13496.68 (4)	1299.18 (5)	1.13 (8)	400.29 (7)	3.39 (1)	1.45 (1)
F9	2656.30 (5)	1127.09 (4)	3442.83 (3)	302.32 (6)	0.60 (8)	117.09 (7)	0.72 (1)	0.43 (1)
F10	2094.66 (6)	814.49 (1)	373.86 (1)	299.90 (1)	0.70 (8)	94.41 (7)	1.14 (1)	0.55 (1)
F11	3304.84 (6)	731.07 (1)	328.72 (1)	189.06 (1)	0.78 (8)	219.46 (7)	0.65 (1)	0.35 (1)
F12	2587.51 (3)	1231.66 (2)	1030.26 (1)	294.03 (6)	0.69 (8)	236.84 (7)	62.95 (5)	46.41 (4)
F13	3335.67 (6)	621.73 (1)	171.63 (1)	196.80 (1)	1.34 (8)	235.19 (7)	0.23 (1)	0.13 (1)
F14	14.77 (1)	155.37 (1)	0.58 (1)	0.03 (1)	0.01 (1)	1.54 (1)	0.01 (1)	0.01 (1)
F15	1615.07 (6)	1004.31 (1)	1037.67 (1)	291.60 (5)	0.51 (8)	245.79 (7)	1.14 (1)	0.52 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Table 54 Time and solution comparisons against popular meta-heuristic algorithms on functions $F1$-$F15$ with D=100 (Classical set)

Func.	GA	PSO	WOA	DE	AMPO	CSDE	AdaGuiDE
F1	14.82 (6)	0.60 (7)	2.24 (1)	21.89 (5)	0.07 (1)	37.04 (1)	0.76 (1)
F2	28.47 (6)	3.01 (7)	0.72 (1)	29.21 (5)	0.07 (1)	39.64 (1)	0.50 (1)
F3	17.10 (6)	1.18 (7)	3.30 (1)	25.69 (5)	0.08 (1)	38.37 (1)	0.92 (1)
F4	15.76 (7)	1.24 (6)	28.59 (5)	67.52 (3)	0.08 (1)	120.67 (4)	0.99 (1)
F5	15.30 (6)	0.75 (7)	0.98 (1)	25.40 (5)	0.05 (1)	35.49 (1)	0.50 (1)
F6	18.73 (7)	1.80 (6)	0.16 (1)	0.39 (1)	0.02 (1)	31.60 (1)	0.14 (1)
F7	19.24 (5)	2.66 (7)	43.06 (6)	81.20 (4)	0.08 (1)	135.93 (3)	0.99 (1)
F8	238.93 (6)	86.82 (7)	517.97 (5)	518.56 (4)	0.70 (1)	616.97 (3)	3.39 (1)
F9	17.87 (7)	1.01 (6)	1.35 (1)	71.07 (5)	0.05 (1)	128.37 (4)	0.72 (1)
F10	21.30 (6)	1.33 (7)	5.61 (1)	24.35 (5)	0.10 (1)	44.44 (1)	1.14 (1)
F11	17.87 (6)	1.09 (7)	1.76 (1)	20.96 (5)	0.07 (1)	38.83 (1)	0.65 (1)
F12	19.50 (6)	1.11 (7)	12.91 (1)	28.54 (5)	41.73 (2)	63.72 (3)	62.95 (4)
F13	20.17 (6)	1.60 (7)	0.43 (1)	23.80 (5)	0.04 (1)	40.26 (1)	0.23 (1)
F14	0.01 (1)	0.01 (1)	0.01 (1)	0.01 (1)	0.01 (1)	0.01 (1)	0.01 (1)
F15	15.09 (6)	1.07 (7)	3.96 (1)	27.53 (5)	0.08 (1)	49.41 (1)	1.14 (1)

• Data format: Average time (Ranking of solution quality)
• Average time unit: CPU second(s)

Appendix G: The comparative results on the ablation study

Table 55 Comparative results of ablation study on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	Metric	AdaGuiDE	AdaGuiDE	AdaGuiDE	AdaGuiDE	AdaGuiDE-PS	AdaGuiDE
F1	Mean	1.34E+05	4.28E+05	1.51E+05	1.15E+05	1.23E+05	5.87E+05
	Std.	8.80E+04	5.33E+05	9.20E+04	6.50E+04	6.39E+04	8.11E+05
F2	Mean	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02
	Std.	0.00E+00	0.00E+00	0.00E+00	2.84E-01	0.00E+00	0.00E+00
F3	Mean	3.00E+02	3.00E+02	3.00E+02	3.02E+02	3.00E+02	3.00E+02
	Std.	0.00E+00	0.00E+00	0.00E+00	1.86E+00	0.00E+00	0.00E+00
F4	Mean	4.01E+02	4.12E+02	4.05E+02	5.23E+02	4.23E+02	4.07E+02
	Std.	4.97E-02	3.05E+01	1.57E+01	2.23E+01	3.09E+01	2.36E+01
F5	Mean	5.20E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02
	Std.	6.93E-02	3.57E-02	3.46E-02	1.30E-01	4.66E-02	4.08E-02
F6	Mean	6.03E+02	6.03E+02	6.04E+02	6.29E+02	6.17E+02	6.02E+02
	Std.	2.25E+00	4.31E+00	2.22E+00	3.35E+00	1.39E+00	1.73E+00
F7	Mean	7.00E+02	7.00E+02	7.00E+02	7.19E+02	7.00E+02	7.00E+02
	Std.	0.00E+00	0.00E+00	0.00E+00	4.04E+00	1.25E-06	0.00E+00
F8	Mean	8.04E+02	8.06E+02	8.06E+02	8.69E+02	8.11E+02	8.07E+02
	Std.	2.43E+00	2.37E+00	2.19E+00	1.13E+01	2.48E+00	3.23E+00
F9	Mean	9.35E+02	9.24E+02	9.39E+02	9.86E+02	9.48E+02	9.31E+02
	Std.	8.87E+00	5.75E+00	1.05E+01	1.65E+01	7.78E+00	8.61E+00
F10	Mean	1.06E+03	1.05E+03	1.10E+03	1.06E+03	1.06E+03	1.05E+03
	Std.	8.65E+01	5.45E+01	8.98E+01	4.80E+01	5.68E+01	6.75E+01
F11	Mean	3.37E+03	2.66E+03	3.61E+03	3.41E+03	3.51E+03	3.11E+03
	Std.	4.55E+02	5.52E+02	6.36E+02	6.05E+02	3.78E+02	4.97E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	1.01E-01	1.13E-01	1.22E-01	1.77E-01	6.00E-02	1.33E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03
	Std.	4.56E-02	2.34E-02	5.06E-02	6.26E-01	3.02E-02	1.44E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.41E+03	1.40E+03	1.40E+03
	Std.	2.09E-02	3.51E-02	2.28E-02	4.31E+00	2.02E-02	2.72E-02
F15	Mean	1.50E+03	1.50E+03	1.50E+03	1.52E+03	1.51E+03	1.50E+03
	Std.	1.07E+00	6.44E-01	7.18E-01	5.33E+00	1.14E+00	7.01E-01
F16	Mean	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03
	Std.	6.46E-01	8.36E-01	5.05E-01	2.68E-01	2.94E-01	8.10E-01
F17	Mean	3.53E+03	1.32E+04	3.34E+03	3.24E+03	3.32E+03	6.15E+04
	Std.	2.35E+03	2.19E+04	8.59E+02	7.40E+02	7.92E+02	1.51E+05
F18	Mean	1.82E+03	1.84E+03	1.82E+03	1.84E+03	1.84E+03	1.82E+03
	Std.	7.87E+00	5.80E+01	8.28E+00	1.38E+01	1.07E+01	8.24E+00
F19	Mean	1.90E+03	1.90E+03	1.90E+03	1.91E+03	1.91E+03	1.90E+03
	Std.	6.28E-01	9.26E-01	8.31E-01	3.40E+00	7.91E-01	7.52E-01
F20	Mean	2.01E+03	2.01E+03	2.01E+03	2.03E+03	2.02E+03	2.01E+03
	Std.	3.36E+00	3.28E+00	2.78E+00	1.32E+01	4.55E+00	4.21E+00
F21	Mean	2.38E+03	2.53E+03	2.34E+03	2.39E+03	2.56E+03	4.85E+03
	Std.	1.56E+02	5.62E+02	1.17E+02	1.92E+02	2.35E+02	1.23E+04
F22	Mean	2.23E+03	2.23E+03	2.23E+03	2.25E+03	2.27E+03	2.24E+03
	Std.	2.25E+01	1.01E+01	2.51E+01	2.76E+01	3.80E+01	3.01E+01
F23	Mean	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 55 (Continued)

Func.	Metric	AdaGuiDE	AdaGuiDE	AdaGuiDE	AdaGuiDE	AdaGuiDE-PS	AdaGuiDE
F24	Mean	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F25	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F26	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	5.28E-02	1.66E-02	1.79E+01	8.12E-01	4.84E-02	1.69E-02
F27	Mean	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F28	Mean	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F29	Mean	3.22E+03	3.51E+03	3.32E+03	3.30E+03	3.28E+03	3.57E+03
	Std.	2.79E+02	6.42E+02	3.09E+02	3.78E+02	3.21E+02	8.14E+02
F30	Mean	4.04E+03	4.42E+03	4.08E+03	3.98E+03	3.93E+03	3.90E+03
	Std.	9.22E+02	1.22E+03	9.33E+02	9.18E+02	7.98E+02	1.06E+03

Table 56 (Cont'd) Comparative results of ablation study on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	Metric	AdaGuiDE DYN-GUIDED	AdaGuiDE-PS DYN-GUIDED	AdaGuiDE GUIDED-BR	AdaGuiDE-PS GUIDED-BR	AdaGuiDE	AdaGuiDE-PS
F1	Mean	1.50E+05	1.20E+05	3.77E+05	6.62E+05	6.43E+05	5.76E+05
	Std.	8.68E+04	7.56E+04	4.27E+05	1.17E+06	8.78E+05	9.38E+05
F2	Mean	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02
	Std.	1.71E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	3.01E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02
	Std.	7.64E-01	0.00E+00	1.10E-07	0.00E+00	0.00E+00	0.00E+00
F4	Mean	5.18E+02	4.25E+02	4.38E+02	4.43E+02	4.50E+02	4.25E+02
	Std.	2.05E+01	3.45E+01	3.85E+01	4.30E+01	4.21E+01	3.69E+01
F5	Mean	5.20E+02	5.20E+02	5.21E+02	5.20E+02	5.21E+02	5.20E+02
	Std.	1.32E-01	5.88E-02	9.62E-02	1.09E-01	1.17E-01	1.62E-01
F6	Mean	6.31E+02	6.18E+02	6.03E+02	6.03E+02	6.02E+02	6.05E+02
	Std.	2.78E+00	1.98E+00	1.57E+00	3.69E+00	1.65E+00	2.97E+00
F7	Mean	7.16E+02	7.00E+02	7.01E+02	7.00E+02	7.00E+02	7.00E+02
	Std.	3.92E+00	1.83E-07	4.21E-01	0.00E+00	4.24E-01	0.00E+00
F8	Mean	8.58E+02	8.14E+02	8.05E+02	8.02E+02	8.08E+02	8.04E+02
	Std.	1.10E+01	4.04E+00	1.96E+00	2.06E+00	2.56E+00	3.04E+00
F9	Mean	9.93E+02	9.48E+02	9.16E+02	9.15E+02	9.19E+02	9.21E+02
	Std.	1.68E+01	1.08E+01	3.98E+00	4.30E+00	4.67E+00	5.22E+00
F10	Mean	1.09E+03	1.07E+03	1.03E+03	1.04E+03	1.07E+03	1.03E+03
	Std.	7.54E+01	6.36E+01	4.63E+01	4.51E+01	7.19E+01	3.07E+01
F11	Mean	3.48E+03	3.46E+03	2.59E+03	2.45E+03	2.78E+03	2.89E+03
	Std.	4.57E+02	5.03E+02	5.66E+02	4.46E+02	5.01E+02	4.90E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	1.65E-01	1.00E-01	1.93E-01	1.27E-01	1.49E-01	1.38E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03
	Std.	1.08E+00	4.44E-02	4.27E-02	1.78E-02	5.88E-02	1.52E-02
F14	Mean	1.41E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03
	Std.	4.48E+00	2.35E-02	4.41E-02	3.02E-02	2.65E-02	3.26E-02

Table 56 continued

Func.	Metric	AdaGuiDE DYN-GUIDED	AdaGuiDE-PS DYN-GUIDED	AdaGuiDE GUIDED-BR	AdaGuiDE-PS GUIDED-BR	AdaGuiDE	AdaGuiDE-PS
F15	Mean	1.52E+03	1.51E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
	Std.	3.69E+00	1.58E+00	7.92E-01	7.49E-01	8.72E-01	1.12E+00
F16	Mean	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03
	Std.	2.59E-01	3.72E-01	2.61E-01	7.57E-01	3.85E-01	6.65E-01
F17	Mean	3.66E+03	3.08E+03	2.04E+04	1.55E+04	3.92E+04	2.58E+04
	Std.	1.05E+03	7.47E+02	4.13E+04	2.54E+04	8.89E+04	5.69E+04
F18	Mean	1.83E+03	1.83E+03	1.81E+03	1.82E+03	1.82E+03	1.82E+03
	Std.	1.00E+01	9.65E+00	4.77E+00	7.73E+00	8.93E+00	1.14E+01
F19	Mean	1.91E+03	1.91E+03	1.91E+03	1.90E+03	1.91E+03	1.90E+03
	Std.	2.97E+00	9.93E-01	9.26E-01	7.56E-01	8.47E-01	5.15E-01
F20	Mean	2.03E+03	2.02E+03	2.01E+03	2.01E+03	2.01E+03	2.01E+03
	Std.	1.17E+01	7.34E+00	2.53E+00	2.49E+00	1.94E+00	3.41E+00
F21	Mean	2.39E+03	2.48E+03	2.44E+03	2.42E+03	3.88E+03	2.38E+03
	Std.	1.58E+02	1.95E+02	1.76E+02	1.86E+02	6.23E+03	1.85E+02
F22	Mean	2.25E+03	2.28E+03	2.23E+03	2.23E+03	2.24E+03	2.23E+03
	Std.	2.42E+01	4.12E+01	1.54E+01	1.25E+01	3.13E+01	1.04E+01
F23	Mean	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F25	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F26	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.71E+03
	Std.	1.10E+00	1.79E+01	5.48E-02	1.74E-02	1.79E+01	2.49E+01
F27	Mean	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F28	Mean	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F29	Mean	3.38E+03	3.35E+03	3.26E+03	3.30E+03	3.31E+03	3.31E+03
	Std.	3.99E+02	3.30E+02	3.29E+02	3.47E+02	3.60E+02	3.28E+02
F30	Mean	4.27E+03	3.87E+03	4.38E+03	3.95E+03	4.36E+03	3.97E+03
	Std.	1.17E+03	9.13E+02	1.09E+03	1.02E+03	1.21E+03	1.08E+03

Appendix H: The comparative results on the hyper-parameter analysis

Table 57 Comparative results of hyper-parameter analysis on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	Metric	HYPER-1	HYPER-2	HYPER-3	HYPER-4	HYPER-5	HYPER-6	HYPER-7	HYPER-8
F1	Mean	4.83E+05	7.38E+05	7.00E+05	7.61E+05	3.32E+05	2.91E+05	1.56E+06	6.72E+05
	Std.	8.29E+05	1.33E+06	9.47E+05	1.17E+06	5.14E+05	3.63E+05	4.69E+06	8.55E+05
F2	Mean	3.42E+02	3.78E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02
	Std.	4.62E+02	9.59E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	4.16E+02	4.27E+02	4.22E+02	4.21E+02	4.21E+02	4.33E+02	4.17E+02	4.41E+02
	Std.	2.76E+01	4.11E+01	3.68E+01	3.86E+01	3.15E+01	3.72E+01	3.48E+01	4.84E+01
F5	Mean	5.20E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02
	Std.	1.05E-01	4.06E-02	2.01E-02	1.11E-03	7.61E-02	3.99E-02	7.70E-02	1.07E-01
F6	Mean	6.02E+02	6.02E+02	6.04E+02	6.04E+02	6.11E+02	6.12E+02	6.03E+02	6.02E+02
	Std.	2.61E+00	2.04E+00	3.99E+00	2.45E+00	4.97E+00	4.07E+00	3.64E+00	1.59E+00
F7	Mean	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02
	Std.	4.53E-02	0.00E+00	0.00E+00	1.33E-03	4.79E-03	1.58E-04	0.00E+00	1.24E-02
F8	Mean	8.06E+02	8.04E+02	8.04E+02	8.05E+02	8.11E+02	8.11E+02	8.04E+02	8.05E+02
	Std.	2.23E+00	1.97E+00	2.05E+00	2.49E+00	4.06E+00	3.89E+00	3.10E+00	2.62E+00
F9	Mean	9.14E+02	9.15E+02	9.16E+02	9.17E+02	9.30E+02	9.28E+02	9.18E+02	9.16E+02
	Std.	5.01E+00	2.72E+00	4.98E+00	4.76E+00	6.86E+00	6.15E+00	5.96E+00	5.33E+00
F10	Mean	1.06E+03	1.08E+03	1.04E+03	1.04E+03	1.04E+03	1.06E+03	1.04E+03	1.06E+03
	Std.	7.67E+01	8.52E+01	4.10E+01	4.08E+01	3.79E+01	6.98E+01	5.68E+01	6.65E+01
F11	Mean	1.84E+03	2.26E+03	2.47E+03	2.76E+03	3.09E+03	3.00E+03	2.85E+03	2.65E+03
	Std.	4.14E+02	3.48E+02	5.52E+02	5.63E+02	5.15E+02	3.93E+02	5.16E+02	5.73E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	2.02E-01	1.43E-01	1.07E-01	7.10E-02	9.95E-02	7.48E-02	1.48E-01	1.37E-01
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03
	Std.	2.94E-02	1.63E-02	2.17E-02	1.91E-02	1.87E-02	2.05E-02	1.51E-02	1.70E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03
	Std.	3.16E-02	3.92E-02	3.50E-02	3.97E-02	2.64E-02	2.82E-02	2.32E-02	2.94E-02
F15	Mean	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.51E+03	1.50E+03	1.50E+03	1.50E+03
	Std.	8.12E-01	6.75E-01	4.79E-01	4.10E-01	8.27E-01	7.17E-01	7.53E-01	6.67E-01
F16	Mean	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03
	Std.	1.43E+00	6.92E-01	9.16E-01	7.40E-01	6.10E-01	5.84E-01	7.17E-01	8.65E-01
F17	Mean	9.31E+03	4.17E+04	2.52E+04	5.69E+04	7.67E+03	2.07E+04	1.82E+04	2.17E+04
	Std.	2.00E+04	7.25E+04	4.52E+04	1.59E+05	1.69E+04	3.43E+04	3.06E+04	6.19E+04
F18	Mean	1.83E+03	1.82E+03	1.89E+03	1.82E+03	1.82E+03	1.82E+03	1.83E+03	1.83E+03
	Std.	1.74E+01	1.08E+01	3.85E+02	8.51E+00	1.05E+01	8.75E+00	6.09E+01	1.01E+01
F19	Mean	1.90E+03	1.90E+03	1.90E+03	1.90E+03	1.91E+03	1.91E+03	1.90E+03	1.90E+03
	Std.	9.88E-01	8.43E-01	8.96E-01	8.52E-01	9.20E-01	7.14E-01	8.74E-01	1.00E+00
F20	Mean	2.01E+03	2.01E+03	2.01E+03	2.01E+03	2.01E+03	2.01E+03	2.01E+03	2.01E+03
	Std.	6.03E+00	2.83E+00	2.49E+00	4.80E+00	4.32E+00	2.27E+00	2.33E+00	7.75E+00
F21	Mean	3.92E+03	2.66E+03	2.78E+03	3.14E+03	2.43E+03	2.96E+03	3.91E+03	2.68E+03
	Std.	4.02E+03	8.48E+02	1.51E+03	1.84E+03	2.44E+02	1.98E+03	6.94E+03	6.53E+02

Table 57 (Continued)

Func.	Metric	HYPER-1	HYPER-2	HYPER-3	HYPER-4	HYPER-5	HYPER-6	HYPER-7	HYPER-8
F22	Mean	2.25E+03	2.24E+03	2.24E+03	2.25E+03	2.23E+03	2.23E+03	2.24E+03	2.24E+03
	Std.	5.87E+01	1.79E+01	4.87E+01	4.86E+01	6.00E+00	6.92E+00	2.68E+01	4.06E+01
F23	Mean	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F25	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F26	Mean	2.72E+03	2.71E+03	2.72E+03	2.71E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	3.72E+01	2.49E+01	3.72E+01	3.40E+01	1.79E+01	2.73E-02	1.59E-02	1.79E+01
F27	Mean	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F28	Mean	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F29	Mean	3.41E+03	3.30E+03	3.43E+03	3.41E+03	3.44E+03	3.38E+03	3.34E+03	3.27E+03
	Std.	3.63E+02	3.07E+02	3.46E+02	4.11E+02	4.66E+02	4.23E+02	4.43E+02	3.25E+02
F30	Mean	4.90E+03	4.32E+03	4.26E+03	4.29E+03	3.57E+03	4.02E+03	4.33E+03	4.49E+03
	Std.	1.41E+03	1.14E+03	1.26E+03	1.15E+03	7.05E+02	1.08E+03	1.21E+03	1.27E+03

Table 58 (Cont'd) Comparative results of hyper-parameter analysis on functions $F1$-$F30$ with D=30 (CEC2014)

Func.	Metric	HYPER-9	HYPER-10	HYPER-11	HYPER-12	HYPER-13	HYPER-14	HYPER-15	HYPER-16
F1	Mean	4.07E+05	5.53E+05	3.91E+05	4.61E+05	7.42E+05	6.88E+05	6.34E+05	5.82E+05
	Std.	2.15E+05	4.64E+05	2.48E+05	3.08E+05	3.08E+05	2.67E+05	3.90E+05	2.74E+05
F2	Mean	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F3	Mean	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F4	Mean	4.16E+02	4.04E+02	4.44E+02	4.39E+02	4.01E+02	4.01E+02	4.70E+02	4.51E+02
	Std.	2.95E+01	1.52E+01	3.57E+01	4.08E+01	1.43E-01	1.87E-01	2.07E+01	3.64E+01
F5	Mean	5.20E+02	5.20E+02	5.20E+02	5.21E+02	5.20E+02	5.20E+02	5.20E+02	5.20E+02
	Std.	8.11E-02	8.71E-02	1.29E-01	1.39E-01	7.48E-02	1.48E-01	1.20E-01	1.14E-01
F6	Mean	6.08E+02	6.02E+02	6.22E+02	6.22E+02	6.09E+02	6.19E+02	6.16E+02	6.22E+02
	Std.	5.43E+00	1.41E+00	1.27E+00	4.64E+00	7.34E+00	6.74E+00	4.58E+00	1.25E+00
F7	Mean	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02	7.00E+02
	Std.	3.76E-06	0.00E+00	3.18E-05	0.00E+00	2.79E-07	0.00E+00	4.01E-04	6.46E-04
F8	Mean	8.05E+02	8.04E+02	8.28E+02	8.26E+02	8.07E+02	8.08E+02	8.13E+02	8.26E+02
	Std.	4.95E+00	2.88E+00	1.04E+01	1.38E+01	5.74E+00	6.81E+00	7.98E+00	7.36E+00
F9	Mean	9.25E+02	9.26E+02	9.72E+02	9.55E+02	9.36E+02	9.43E+02	9.34E+02	9.75E+02
	Std.	7.46E+00	7.04E+00	2.12E+01	2.53E+01	1.49E+01	2.27E+01	1.04E+01	1.79E+01
F10	Mean	1.09E+03	1.05E+03	1.19E+03	1.17E+03	1.26E+03	1.44E+03	1.39E+03	1.57E+03
	Std.	1.04E+02	5.36E+01	1.70E+02	3.20E+02	2.54E+02	5.26E+02	3.68E+02	4.48E+02
F11	Mean	3.49E+03	3.26E+03	3.80E+03	4.10E+03	4.33E+03	4.96E+03	4.06E+03	4.48E+03
	Std.	6.69E+02	4.51E+02	6.55E+02	8.59E+02	6.18E+02	6.26E+02	1.07E+03	8.77E+02
F12	Mean	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03
	Std.	8.86E-02	1.02E-01	1.90E-01	2.02E-01	1.55E-01	2.68E-01	1.38E-01	1.64E-01

Table 58 continued

Func.	Metric	HYPER-9	HYPER-10	HYPER-11	HYPER-12	HYPER-13	HYPER-14	HYPER-15	HYPER-16
F13	Mean	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03	1.30E+03
	Std.	1.77E-02	1.33E-02	2.33E-02	2.41E-02	1.97E-02	2.28E-02	2.20E-02	2.36E-02
F14	Mean	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03
	Std.	2.13E-02	2.89E-02	2.32E-02	2.07E-02	2.03E-02	2.25E-02	2.52E-02	2.35E-02
F15	Mean	1.50E+03	1.50E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03	1.51E+03
	Std.	1.10E+00	6.63E-01	1.33E+00	1.91E+00	1.47E+00	2.13E+00	1.74E+00	2.56E+00
F16	Mean	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03	1.61E+03
	Std.	4.74E-01	8.11E-01	3.51E-01	6.69E-01	5.06E-01	7.37E-01	5.09E-01	3.26E-01
F17	Mean	1.20E+04	1.23E+04	3.39E+03	3.51E+03	4.30E+03	5.32E+03	8.80E+03	4.48E+03
	Std.	3.56E+04	2.37E+04	4.15E+02	7.66E+02	1.18E+03	1.94E+03	2.31E+04	1.32E+03
F18	Mean	1.82E+03	1.84E+03	1.85E+03	1.84E+03	1.85E+03	1.88E+03	1.84E+03	1.86E+03
	Std.	8.65E+00	4.02E+01	1.47E+01	1.97E+01	5.21E+01	3.05E+01	8.15E+01	1.74E+01
F19	Mean	1.90E+03	1.90E+03	1.91E+03	1.91E+03	1.90E+03	1.91E+03	1.91E+03	1.91E+03
	Std.	8.94E-01	7.43E-01	5.82E-01	1.24E+00	9.06E-01	1.37E+00	1.11E+00	6.66E-01
F20	Mean	2.01E+03	2.01E+03	2.02E+03	2.01E+03	2.02E+03	2.03E+03	2.01E+03	2.03E+03
	Std.	2.37E+00	2.60E+00	5.12E+00	5.94E+00	8.63E+00	1.11E+01	5.65E+00	5.91E+00
F21	Mean	2.59E+03	2.72E+03	2.55E+03	2.50E+03	2.69E+03	2.84E+03	2.69E+03	2.70E+03
	Std.	1.43E+02	9.89E+02	2.09E+02	1.97E+02	4.48E+02	6.80E+02	4.86E+02	2.61E+02
F22	Mean	2.23E+03	2.23E+03	2.25E+03	2.27E+03	2.24E+03	2.27E+03	2.25E+03	2.27E+03
	Std.	1.26E+01	8.77E+00	1.69E+01	4.84E+01	1.80E+01	4.52E+01	2.69E+01	2.71E+01
F23	Mean	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F24	Mean	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03	2.60E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F25	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F26	Mean	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03	2.70E+03
	Std.	1.79E+01	1.57E-02	2.32E-02	2.03E-02	2.02E-02	3.34E-02	1.78E-02	4.03E-02
F27	Mean	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03	2.90E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F28	Mean	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03	3.00E+03
	Std.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F29	Mean	3.43E+03	3.25E+03	3.41E+03	3.36E+03	3.21E+03	3.38E+03	3.30E+03	3.33E+03
	Std.	4.88E+02	3.81E+02	4.08E+02	4.12E+02	2.96E+02	4.32E+02	5.78E+02	4.17E+02
F30	Mean	3.90E+03	3.96E+03	4.06E+03	3.82E+03	3.69E+03	3.95E+03	3.72E+03	3.73E+03
	Std.	9.19E+02	1.14E+03	1.13E+03	8.46E+02	9.18E+02	1.02E+03	9.22E+02	1.01E+03

Acknowledgements We are most grateful to the anonymous reviewers for their careful work and thoughtful suggestions, which have helped us improve this paper substantially.

Author Contributions **Zhenglong Li**: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing-original draft. **Vincent Tam**: Conceptualization, Methodology, Supervision, Writing-review and editing.

Funding Not applicable.

Availability of Data and Materials All data generated or analysed during this study are included in this published article and its supplementary information files. The used datasets can be downloaded from https://github.com/P-N-Suganthan/CEC2014 and https://github.com/P-N-Suganthan/2021-SO-BCO.

Code Availability The source code of the AdaGuiDE will be released at https://github.com/SteamerLee/AdaGuiDE after publication.

Declarations

Conflict of interest/Competing interests (check journal-specific guidelines for which heading to use) Not applicable.

Ethics Approval Not applicable.

Consent to Participate Not applicable.

References

1. Dabre R, Chu C, Kunchukuttan A (2020) A survey of multilingual neural machine translation. ACM Computing Surveys (CSUR) 53(5):1–38
2. Mocanu E, Mocanu DC, Nguyen PH, Liotta A, Webber ME, Gibescu M, Slootweg JG (2018) On-line building energy optimization using deep reinforcement learning. IEEE transactions on smart grid 10(4):3698–3708
3. Chen X, Kundu K, Zhang Z, Ma H, Fidler S, Urtasun R (2016) Monocular 3d object detection for autonomous driving. In: Proceedings of the IEEE conference on computer vision and pattern recognition, pp 2147–2156
4. Tunyasuvunakool K, Adler J, Wu Z, Green T, Zielinski M, Žídek A, Bridgland A, Cowie A, Meyer C, Laydon A et al (2021) Highly accurate protein structure prediction for the human proteome. Nature 596(7873):590–596
5. Imajo K, Minami K, Ito K, Nakagawa K et al (2021) Deep portfolio optimization via distributional prediction of residual factors. Proceedings of the AAAI Conference on Artificial Intelligence 35:213–222
6. Støren S, Hertzberg T (1995) The sequential linear quadratic programming algorithm for solving dynamic optimization problems-a review. Computers & Chemical Engineering 19:495–500
7. Geoffrion AM, Marsten RE (1972) Integer programming algorithms: a framework and state-of-the-art survey. Manage Sci 18(9):465–491
8. Alizadeh F, Goldfarb D (2003) Second-order cone programming. Mathematical programming 95(1):3–51
9. Voulodimos A, Doulamis N, Doulamis A, Protopapadakis E (2018) Deep learning for computer vision: a brief review. Computational intelligence and neuroscience 2018
10. Zhang S, Yao L, Sun A, Tay Y (2019) Deep learning based recommender system: a survey and new perspectives. ACM Computing Surveys (CSUR) 52(1):1–38
11. Zhang L, Wang S, Liu B (2018) Deep learning for sentiment analysis: a survey. Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery 8(4):1253
12. Ghosh A, Jana ND, Mallik S, Zhao Z (2022) Designing optimal convolutional neural network architecture using differential evolution algorithm. Patterns 3(9):100567
13. Ali IM, Essam D, Kasmarik K (2019) A novel differential evolution mapping technique for generic combinatorial optimization problems. Appl Soft Comput 80:297–309
14. Van Laarhoven PJ, Aarts EH (1987) Simulated annealing. Simulated Annealing: Theory and Applications. Springer, Dordrecht, pp 7–15
15. Glover F, Laguna M (1998) Tabu Search. Springer, Boston
16. Dorigo M, Birattari M, Stutzle T (2006) Ant colony optimization. IEEE Comput Intell Mag 1(4):28–39
17. Kennedy J, Eberhart R (1995) Particle swarm optimization. In:Proceedings of ICNN'95-international Conference on Neural Networks, vol 4, pp 1942–1948. IEEE
18. Karaboga D, Basturk B (2008) On the performance of artificial bee colony (abc) algorithm. Appl Soft Comput 8(1):687–697
19. Dorigo M, Gambardella LM (1997) Ant colonies for the travelling salesman problem. Biosystems 43(2): 73–81
20. Storn R, Price K (1997) Differential evolution-a simple and efficient heuristic for global optimization over continuous spaces. J Global Optim 11(4):341–359
21. Zhang J, Sanderson AC (2009) Jade: adaptive differential evolution with optional external archive. IEEE Trans Evol Comput 13(5):945–958
22. Sun G, Yang B, Yang Z, Xu G (2020) An adaptive differential evolution with combined strategy for global numerical optimization. Soft Comput 24(9):6277–6296
23. Gämperle R, M üller SD, Koumoutsakos P (2002) A parameter study for differential evolution. Advances in intelligent systems, fuzzy systems, evolutionary computation 10(10):293–298
24. Ronkkonen J, Kukkonen S, Price KV (2005) Real-parameter optimization with differential evolution. In: 2005 IEEE congress on evolutionary computation, vol 1, pp 506–513. IEEE
25. Zielinski K, Weitkemper P, Laur R, Kammeyer KD (2006) Parameter study for differential evolution using a power allocation problem including interference cancellation. In: 2006 IEEE international conference on evolutionary computation, pp 1857–1864. IEEE
26. Neri F, Tirronen V (2010) Recent advances in differential evolution: a survey and experimental analysis. Artif Intell Rev 33(1):61–106
27. Liu J (2002) On setting the control parameter of the differential evolution method. In: Proceedings of the 8th international conference on soft computing (MENDEL 2002), pp 11–18
28. Qin AK, Suganthan PN (2005) Self-adaptive differential evolution algorithm for numerical optimization. In: 2005 IEEE congress on evolutionary computation, vol 2, pp 1785–1791. IEEE

29. Qin AK, Huang VL, Suganthan PN (2008) Differential evolution algorithm with strategy adaptation for global numerical optimization. IEEE Trans Evol Comput 13(2):398–417
30. Tanabe R, Fukunaga A (2013) Success-history based parameter adaptation for differential evolution. In: 2013 IEEE Congress on evolutionary computation, pp 71–78. IEEE
31. Sun B, Sun Y, Li W (2022) Multiple topology shade with tolerance-based composite framework for cec2022 single objective bound constrained numerical optimization. In: 2022 IEEE Congress on Evolutionary Computation (CEC), pp 1–8. Ieee
32. Sallam KM, Abdel-Basset M, El-Abd M, Wagdy A (2022) Imodeii: an improved imode algorithm based on the reinforcement learning. In: 2022 IEEE Congress on Evolutionary Computation (CEC), pp 1–8. IEEE
33. Van Cuong L, Bao NN, Phuong N.K, Binh HTT (2022) Dynamic perturbation for population diversity management in differential evolution. In: Proceedings of the genetic and evolutionary computation conference companion, pp 391–394
34. Yang J, Wang K, Wang Y, Wang J, Lei Z, Gao S (2024) Dynamic population structures-based differential evolution algorithm. IEEE Transactions on Emerging Topics in Computational Intelligence
35. Sui Q, Yu Y, Wang K, Zhong L, Lei Z, Gao S (2024) Best-worst individuals driven multiple-layered differential evolution. Inf Sci 655:119889
36. Tanabe R, Fukunaga AS (2014) Improving the search performance of shade using linear population size reduction. In: 2014 IEEE Congress on Evolutionary Computation (CEC), pp 1658–1665. IEEE
37. Stanovov V, Akhmedova S, Semenkin E (2018) Lshade algorithm with rank-based selective pressure strategy for solving cec 2017 benchmark problems. In: 2018 IEEE Congress on Evolutionary Computation (CEC), pp 1–8. IEEE
38. Stanovov V, Akhmedova S, Semenkin E (2021) Nl-shade-rsp algorithm with adaptive archive and selective pressure for cec 2021 numerical optimization. In: 2021 IEEE Congress on Evolutionary Computation (CEC), pp 809–816. IEEE
39. Stanovov V, Akhmedova S, Semenkin E (2022) Nl-shade-lbc algorithm with linear parameter adaptation bias change for cec 2022 numerical optimization. In: 2022 IEEE Congress on Evolutionary Computation (CEC), pp 01–08. IEEE
40. Bujok P, Kolenovsky P (2022) Eigen crossover in cooperative model of evolutionary algorithms applied to cec 2022 single objective numerical optimisation. In: 2022 IEEE Congress on Evolutionary Computation (CEC), pp 1–8. IEEE
41. Karmakar B, Kumar A, Mallipeddi R, Lee DG (2023) Cma-es with exponential based multiplicative covariance matrix adaptation for global optimization. Swarm Evol Comput 79:101296
42. Fontaine M, Nikolaidis S (2023) Covariance matrix adaptation map-annealing. In: Proceedings of the genetic and evolutionary computation conference, pp 456–465
43. Guo A, Wang Y, Guo L, Zhang R, Yu Y, Gao S (2023) An adaptive position-guided gravitational search algorithm for function optimization and image threshold segmentation. Eng Appl Artif Intell 121:106040
44. Abdel-Basset M, Mohamed R, Azeem SAA, Jameel M, Abouhawwash M (2023) Kepler optimization algorithm: a new metaheuristic algorithm inspired by kepler's laws of planetary motion. Knowl-Based Syst 268:110454
45. Shaheen MA, Ullah Z, Hasanien HM, Tostado-V é liz M, Ji H, Qais MH, Alghuwainem S, Jurado F (2023) Enhanced transient search optimization algorithm-based optimal reactive power dispatch including electric vehicles. Energy 277:127711
46. Mirjalili S, Lewis A (2016) The whale optimization algorithm. Adv Eng Softw 95:51–67
47. Wang Y, Han Z (2021) Ant colony optimization for traveling salesman problem based on parameters optimization. Appl Soft Comput 107:107439
48. Sun B, Li W, Huang Y (2022) Performance of composite ppso on single objective bound constrained numerical optimization problems of cec 2022. In: 2022 IEEE Congress on Evolutionary Computation (CEC), pp 1–8. IEEE
49. Zheng H (2011) An improved niche genetic algorithm based on simulated annealing: Sanga. In: 2011 International Conference on Computational Problem-Solving (ICCP), pp 1–5. IEEE
50. Mo ZJ, Zhu XJ, Wei LY, Cao GY (2006) Parameter optimization for a pemfc model with a hybrid genetic algorithm. Int J Energy Res 30(8):585–597
51. Voudouris C, Tsang EP, Alsheddy A (2010) Guided local search. Handbook of Metaheuristics. Springer, Boston, pp 321–361
52. Voudouris C, Tsang E (1999) Guided local search and its application to the traveling salesman problem. Eur J Oper Res 113(2):469–499
53. Shi J, Zhang Q, Tsang E (2018) Eb-gls: an improved guided local search based on the big valley structure. Memetic Computing 10(3):333–350
54. Tsang E, Voudouris C (1997) Fast local search and guided local search and their application to british telecom's workforce scheduling problem. Oper Res Lett 20(3):119–127
55. Voudouris C (1998) Guided local search-an illustrative example in function optimisation. BT Technol J 16(3):46–50
56. Li Z, Tam V, Yeung LK (2021) An adaptive multi-population optimization algorithm for global continuous optimization. IEEE Access 9:19960–19989
57. Wolpert DH, Macready WG (1997) No free lunch theorems for optimization. IEEE Trans Evol Comput 1(1):67–82
58. Liang JJ, Qu BY, Suganthan PN (2013) Problem definitions and evaluation criteria for the cec 2014 special session and competition on single objective real-parameter numerical optimization. Computational Intelligence Laboratory, Zhengzhou University, Zhengzhou China and Technical Report, Nanyang Technological University, Singapore 635:490
59. Wagdy A, Hadi AA, Mohamed AK, Agrawal P, Kumar A, Suganthan PN (2021) Problem definitions and evaluation criteria for the cec 2021 special session and competition on single objective bound constrained numerical optimization. Technical Report, Nanyang Technological University, Singapore
60. Kumar M, Husain M, Upreti N, Gupta D (2010) Genetic algorithm: Review and application. Available at SSRN 3529843
61. Cowen-Rivers AI, Lyu W, Wang Z, Tutunov R, Jianye H, Wang J, Ammar HB (2020) Hebo: heteroscedastic evolutionary bayesian optimisation 7. arXiv:2012.03826
62. Sazanovich M, Nikolskaya A, Belousov Y, Shpilman A (2021) Solving black-box optimization challenge via learning search space partition for local bayesian optimization. In: NeurIPS 2020 Competition and Demonstration Track, pp 77–85. PMLR
63. Derrac J, García S, Molina D, Herrera F, (2011) A practical tutorial on the use of nonparametric statistical tests as a methodology for comparing evolutionary and swarm intelligence algorithms. Swarm Evol Comput 1(1):3–18

Zhenglong Li received the B.Eng. degree in Electronic Information Science and Technology and B.Econ. degree in Financial Engineering both from Jinan University, China, and then the M.S. degree in Electrical and Electronics Engineering from the University of Hong Kong. He is currently pursuing the Ph.D degree with the Department of Electrical and Electronic Engineering at the University of Hong Kong. His research interest lies in intelligent techniques and computational finance including meta-heuristic optimization, deep reinforcement learning, portfolio optimization, and risk management.

Vincent Tam completed his Ph.D. in Computer Science in the University of Melbourne in 1998. He is currently a Principal Lecturer in the Department of Electrical and Electronic Engineering, the University of Hong Kong. Dr. Tam has over 190 internationally refereed publications including 10 book chapters. His main research interests include artificial intelligence, computational finance, machine learning and information visualization. In addition, he served as the Chairman of the IEEE (HK) Computational Intelligence Chapter during 2014 - 2017.