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Research on Collaboration Model Design and Computational Methods of Interdisciplinary Collaboration Platform for Higher Education under Simulated Annealing Algorithm

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SUMMARY: *The operation quality of interdisciplinary cooperation platform in higher education is an important factor in determining interdisciplinary development. For this reason, the article establishes the collaboration model of interdisciplinary cooperation platform in higher education with the support of ecosystem theory. In order to realize the efficient use of interdisciplinary scientific research resources, this paper transforms the scheduling of scientific research resources on the interdisciplinary cooperation platform into a multi-objective optimization mathematical model and introduces the simulated annealing algorithm improved by the PSO algorithm to design ISA-PSO algorithm for solving the model. Then the data from China Knowledge Network (CNN) from 2010 to 2024 are selected to analyze the current evolutionary characteristics of interdisciplinary cooperation efficiency in higher education and explore the application effect of ISA-PSO algorithm. The results show that the overall publication volume of the five higher education institutions shows an upward trend, and the average annual growth rate of their total publication volume is 3.07% from 2010 to 2024.The ISA-PSO algorithm obtains the optimal mean value of 15.215 after 32 iterations, which is more efficient than the comparison algorithm. Its application to the scheduling of research resources in interdisciplinary cooperation platform can significantly improve the scheduling efficiency and ensure the effective development of interdisciplinary cooperation mode.*

KEYWORDS: *simulated annealing algorithm; PSO algorithm; ISA-PSO algorithm; interdisciplinary cooperation*

1 Introduction

For higher education research, many issues cannot be decided by one discipline on its own, but require multidisciplinary cooperation and joint discussion among many experts from different disciplinary perspectives. Higher education needs both unidisciplinary research, multidisciplinary research and interdisciplinary research [1]. Single-disciplinary research is committed to the depth of exploration, multidisciplinary research is committed to the expansion of the breadth, and to integrate this depth and breadth to obtain a comprehensive vision requires interdisciplinary research [2, 3]. Interdisciplinary research can make up for the gulf caused by disciplinary segmentation, make three-dimensional communication between disciplines possible, so as to provide a completely new approach to real problem solving and promote the

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sustainable development of higher education [4, 5]. And the interdisciplinary cooperation platform injects new kinetic energy into higher education teaching innovation.

Luo et al. developed the online interactive learning tool "Seafarer" and customized "OneZoom" maps, which required collaboration from multiple disciplines such as botany, network programming, and database. The team carried out cross-year international collaborative design through platforms like GitHub, and solved complex design reasoning and project management challenges [6]. Tai and Ting created an app for interdisciplinary collaboration between engineering and English majors, in which students viewed programming as a cross-disciplinary communication medium by designing an English learning app, incorporating instructor feedback, and effectively promoting knowledge integration and collaborative skills to inform interdisciplinary teaching practices in higher education [7]. Rogers et al. Based on a collaborative project serving families educating children, the team solved the platform accessibility problem by co-designing online resources and collaborating with experts in machine vision research and other fields, significantly improving user experience and engagement, and validating the effectiveness of cross-disciplinary collaboration [8]. Zubair and Ahmed developed a structured interdisciplinary collaboration framework for scientific research and creative design, which can effectively optimize the collaboration process and enhance the creativity and innovation efficiency of complex design projects in higher education by integrating empirical analyses, data analyses, and human-centered design methods [9]. However, in interdisciplinary collaboration platforms, their collaboration models and computational methods often have difficulties in interdisciplinary knowledge integration, collaborative team building, resource allocation, etc., which become the main factors restricting the effectiveness of interdisciplinary collaboration and innovation in higher education [10-13].

The simulated annealing (SA) algorithm is a general-purpose probabilistic algorithm that aims to find a globally optimal solution to a given function in a large search space in fixed time [14]. It is commonly used in discrete search spaces, especially for deterministic problems, and the SA algorithm is generally superior to the exhaustive method due to the fact that only an acceptable optimal solution is generally required, rather than an exact optimal solution.Chown et al. used the SA algorithm to solve the student program assignment problem, which can take into account the constraints of student preferences, instructor workload, and program capacity, and quickly generates high-quality matching programs [15]. Celik and Dal proposed a distributed cluster task scheduling meta-heuristic based on the SA algorithm, whose experimental results outperform existing benchmark methods in terms of processing time and scheduling latency [16]. Brahimi et al. constructed an optimization model incorporating socio-cultural constraints and applied the SA algorithm with a neighborhood search heuristic to effectively achieve a balanced distribution of teacher workload and maximize satisfaction [17]. Nageh et al. created two improved algorithms to solve the team formation problem, in which a hybrid heap optimizer based on the SA algorithm incorporates the SA algorithm to enhance the global optimization search capability, and experiments have shown that it outperforms a variety of classical algorithms in team optimization dealing with complex constraints [18]. SA algorithms are capable of realizing tasks such as resource allocation, resource scheduling, and team formation, and thus the potential for application in interdisciplinary collaboration has begun to emerge.

In order to solve the current interdisciplinary cooperation with insufficient coordination and low resource allocation efficiency, this paper designs an interdisciplinary collaboration model based on ecosystem theory. Then a multi-objective optimization model is designed with the objective function of research resource scheduling efficiency in the interdisciplinary collaboration platform, and the ISA-PSO algorithm is designed to solve the model by introducing PSO and SA algorithms, aiming to enhance the effect of scientific research resource integration under the interdisciplinary collaboration platform. The current scale and evolutionary trend of interdisciplinary cooperation in higher education institutions are also analyzed with the support of China Knowledge Network data.

2 Models of collaboration for interdisciplinary cooperation platforms in higher education

Interdisciplinary collaboration is an important form and trend of higher education research in the new era, and has a driving role in both scientific innovation and social progress. Interdisciplinary collaboration is widely recognized as a necessary means of solving complex scientific problems and social issues by carrying out academic research through various forms of cooperation, realizing the integration of multidisciplinary knowledge elements and producing innovative research results.

2.1 Collaborative interdisciplinary research

Interdisciplinary research is a mode of research conducted by teams or individuals that integrates information, data, methods, tools, perspectives, concepts, and theories from two or more disciplines or groups of expertise in order to fundamentally deepen the understanding of, or address, problems that are beyond the scope of a single discipline or area of research practice. In this definition, we can make it clear that the following three elements need to be considered in interdisciplinary collaborative research:

(1) Interdisciplinary research requires the integration of knowledge.

(2) Knowledge integration in interdisciplinary research can be accomplished by teams or individuals; teamwork may better facilitate interdisciplinary research, but it is not a defining characteristic of interdisciplinarity.

(3) Knowledge integration in interdisciplinary research can take many forms, either the integration of ideas (perspectives, concepts, and theories) or the integration of information (data).

Based on this definition, this study expands the computational dimensions of interdisciplinary research by measuring the degree of integration of interdisciplinary knowledge, the degree of convergence of interdisciplinary knowledge, and the degree of crossover of interdisciplinary cooperation in terms of the dimensions of References, Target Literature, and Mode of Collaboration, respectively.

2.2 Ecosystem theory

Ecosystem theory is based on the ecosystem model, which places individual development in the context of a multilevel environmental system, including the microsystem, the mesosystem, the exosystem and the macrosystem. Among them, the micro system is the environment that individuals directly contact in their activities, the intermediate system is the field environment in which the micro systems are interconnected, the outer system is the policy and guarantee environment that indirectly influences the activities of individuals, and the macro system is the social environment in which the individuals live in terms of culture, customs and values. Bucher's theory concretizes and structures the social-ecological system, emphasizes the complex interaction between individual development and its surrounding environment, and helps to understand the complexity of the context in which individuals live. However, it places too much emphasis on environmental factors and neglects the key role of human beings as dynamic subjects.

On this basis, some researchers have broken the dichotomy between the individual and the environment by dividing the social-ecological system into three hierarchical systems: micro, meso and macro. Among them, the micro system is the individual, which can be divided into three sub-systems: biological, social and psychological. Mesosystems are small-scale groups that are in direct contact with individuals. Macrosystems are larger social systems, including institutions, cultures, systems, customs, etc., and there are multiple interactions between systems at each level. Ecosystem theory is now widely used as a more mature theory in education, medicine, management and other fields.

2.3 Interdisciplinary Collaboration Framework

In the practice of academic communication, the interdisciplinary collaboration model is a system that covers the subjects, influencing factors, and stakeholders, and is an ecosystem that interacts and dynamically develops with the multilayered environment. From the perspective of researchers, interdisciplinary collaboration is not only driven by self-research needs, but also influenced by the current research environment and social development needs, and the collaborative team and the organization also play a role in the development of collaborative behavior, which is consistent with the connotation of ecosystem theory. Based on this, this paper establishes a collaboration model based on ecosystem theory under the support of interdisciplinary cooperation platform in higher education, as shown in Figure 1, which not only integrates and presents the system hierarchies composed of cooperative subjects, influencing elements, and stakeholders in interdisciplinary collaboration, but also reveals the interaction relationship.

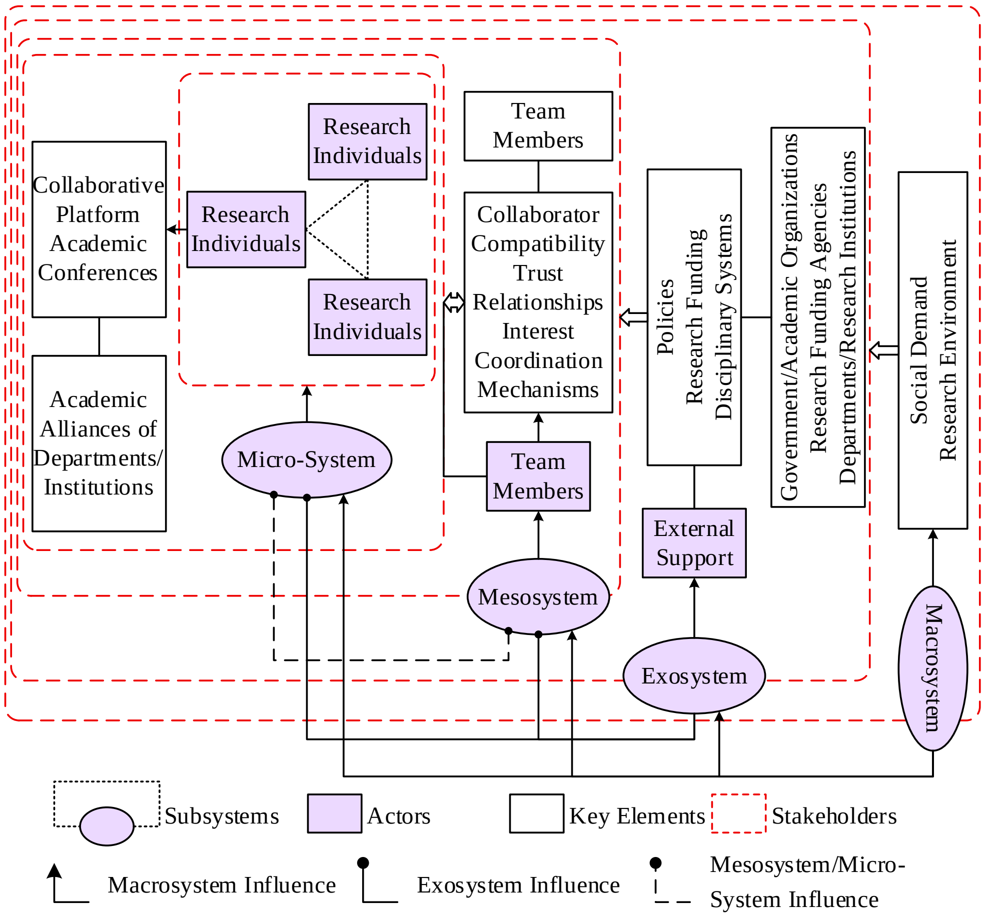


Figure 1: Interdisciplinary collaboration framework

(1) Influence of the macrosystem on the outer, intermediate, and microsystems. Interdisciplinary collaboration is problem-oriented and demand-driven, while the macrosystem reflects the role of elements such as culture, subculture and social environment on the development of human behavior. Thus, the macrosystem, characterized by the needs of social development and changes in the research environment, drives the interdisciplinary collaboration practices of external supporters, collaborative networks, and individual researchers at the level of the external environment.

(2) Influence of the outer system on the intermediate system and micro system. Interdisciplinary collaboration is a kind of scientific research behavior, which needs to be analyzed in a specific scientific community, and the outer system characterized by relevant policies, scientific research funding, and disciplinary institutions has a driving effect on the formation and development of interdisciplinary collaboration networks and the collaborative behaviors of scientific research individuals.

(3) Interaction between intermediate systems and microsystems. Microsystems cover elements that directly interact with individual activities, while individuals are embedded in the collaboration network, and different individuals are located in microsystems that interact with each other. Interdisciplinary collaborative behavior occurs in the interaction process of individuals from different disciplines, and the more active the individual elements involved are, the more they can positively influence the elements of the collaborative network, thus sustaining the development of interdisciplinary teams, and the benign development of the team also strengthens the individual's willingness to collaborate and behavioral attitudes.

3 Research resource scheduling algorithms for interdisciplinary collaboration platforms

Accompanied by the gradual progress of the current higher education teaching reform, the full implementation of various new educational concepts, educational ideas, educational methods and the rapid development of information technology, so that the higher education interdisciplinary collaboration platform has been fully integrated into the scientific research. When promoting interdisciplinary collaboration, how to effectively achieve the maximization of the platform's scientific research resources and scheduling has become a key research object to enhance the efficiency and quality of interdisciplinary collaboration.

3.1 Problem description and multi-objective optimization model

3.1.1 Description of the research resource scheduling problem

It is assumed that there are multiple research resource scheduling requests on a higher education interdisciplinary collaboration platform, and each research resource scheduling task request is divided into several research resource scheduling subtasks after task decomposition. Each research resource scheduling subtask contains one or more scheduling procedures (these scheduling procedures are predetermined). Each scheduling procedure has multiple candidate research resources on which services can be randomly scheduled. The completion time of the procedures varies with the importance of the scientific research resources. Since the scientific research resources may be at different high efficiencies, some scheduling cost is incurred at different program nodes. The research resource scheduling task often suffers from unexpected perturbations during execution such as network failures, advancement or delay of research time. The goal of scheduling is to select the most suitable research resources for each program, determine the optimal order and time on each research resource in the research resource scheduling task, and optimize the service period and various performance indicators of the research resource scheduling service. In order to make the research more operable, this paper sets the following assumptions:

(1) The collaborative scheduling of scientific research resources among universities on the interdisciplinary cooperation platform is mainly studied, and the internal scientific research resource scheduling process of universities is not considered.

(2) The same research resource scheduling service task can only be accomplished by one research resource.

(3) A research service resource can accomplish at least one research resource service task.

(4) The scheduling cost and scheduling time between different research resources are proportional.

(5) The execution time of each resource scheduling subtask is based on the relationship between tasks and the execution order.

3.1.2 Resource scheduling multi-objective optimization model

According to the characteristics of scientific research resources on the interdisciplinary cooperation platform, it is impossible to establish a multi-objective optimization mathematical model that takes into account the scheduling efficiency and load balance, and satisfy the optimality of all the objectives, but only according to the user's different weight requirements for each optimization objective to get a relatively better result.

The task of research resource scheduling under the interdisciplinary cooperation platform requires N sub-tasks to be completed, with a total of M higher education institutions providing services. Remember the research resource set $S=(s_j^i)_{M\times N}$, $1\le i\le M$, $1\le j\le N$, where s_j^i is the state of node i executing sub-tasks j, and this state consists of scheduling efficiency and load degree of nodes executing tasks. The set of scheduling efficiency of each node of this resource set $E=(e_j^i)_{M\times N}$, $1\le i\le M$, $1\le j\le N$, where e_j^i is the scheduling efficiency of the node i in executing the sub-task j, and the set of load degree of each node $L=(l_j^i)_{M\times N}$, $1\le i\le M$, $1\le j\le N$, where l_j^i is the load degree of node i when executing subtask j.

The state of each research resource can be represented as:

$$s_j^i=\{e_j^i,l_j^i\},1\le i\le M,1\le j\le N \tag{1}$$

Denote the set of virtual research resources mapped by N sub-tasks as $X=\{x_1,x_2,\cdots,x_N\}$, with x being a virtual research resource mapped by one of the sub-tasks, and the scheduling efficiency weight of the user's request as W_E, and loadiness weight as W_L, and the conditions are satisfied:

$$W_E+W_L=1 \tag{2}$$

The objective function of the obtained multi-objective optimization model is denoted as:

$$\begin{aligned}\max Y&=f\left(S,X,W\right)\\&=f\left(E,L,x_1,x_2,\cdots,x_N,W_E,W_L\right)\end{aligned} \tag{3}$$

$$s.t.\ x_j \in X \ \ And \ \ x \le M, e_j^i \ge e_{\min}, 0 < l_j^i \le l_{\max} \tag{4}$$

where $e_{\min}$ is the minimum scheduling efficiency value that meets the research requirements, $l_{\max}$ is the maximum load degree value that a research resource node can bear, and the set of research resources $X = \{x_1, x_2, \cdots, x_N\}$ is calculated its optimal allocation by the ISA-PSO algorithm. The values of W_E and W_L are set by the user according to his/her needs.

The objective function value Y consists of two main parts, i.e., the sum of the scheduling efficiency objective value and the load balance objective value under the condition of considering the user's objective weight, which is given by the formula

$$Y = W_E E + W_L L \tag{5}$$

(1) Calculation of research resource scheduling task efficiency and resource load balance degree

The scheduling efficiency of each virtual scientific research resource is the scheduling efficiency of N sub-tasks executed at the resource node, then according to the current state of the virtual scientific research resource can be found out the scheduling efficiency E is:

$$E(X) = E_{x_N}^i = 1 - \frac{\sum_{j=1}^{N} c_{ij} \cdot OT_{x_j}^i}{\sum_{j=1}^{N} c_{ij} \cdot SOT_{x_j}^i} \times 100\%, 1 \le i \le M \tag{6}$$

The load balancing degree of research resources during the experiment is the standard deviation of the load degree of each resource node, then the load balancing degree L can be derived as:

$$L(X) = \sqrt{\frac{1}{N} \sum_{j=1}^{N} \left(l_{x_j}^i - \frac{1}{N} \sum_{j=1}^{N} c_{ij} \cdot l_{x_j}^i \right)^2} \tag{7}$$

(2) Calculation of relative advantage

Substituting the set of research resources $X = \{x_1, x_2, \cdots, x_N\}$ into Eq. (6), the scheduling efficiency value $E(X)$ can be obtained. Similarly, substituting into Eq. (7) yields the load degree $L(X)$.

Calculate the values of all particles $E(X)$ and $L(X)$ in the population and count the maximum and minimum values of each target. Scheduling efficiency reflects the speed of manufacturing, theoretically the larger the better, so the larger the value of the target $E(X)$ the better, the relative dominance degree of scheduling efficiency is:

$$Y_E(X) = \left(E(X) - E_{\min}\right) / \left(E_{\max} - E_{\min}\right) \tag{8}$$

The load balancing degree reflects the balanced state of the load, theoretically the smaller the better, so the smaller the value of the target $L(X)$ the better, the relative advantage degree of the load degree is:

$$Y_L(X) = \left(L_{\max} - L(X)\right) / \left(L_{\max} - L_{\min}\right) \tag{9}$$

(3) Calculation of the fitness function

From the objective weights and relative advantage degree, the optimization model of virtual research resource scheduling can be synthesized as:

$$g(X,W) = W_E Y_E(X) + W_L Y_L(X) \tag{10}$$

The value of the fitness function of all particles is calculated in the iterative process, and the larger the final result is, the better the scheduling and allocation strategy of research resources corresponding to that particle.

3.2 Particle swarm algorithm improved by simulated annealing

3.2.1 Simulated Annealing Algorithm

The Simulated Annealing (SA) algorithm is an algorithm designed by simulating the process of metal annealing in life, based on which it searches for commonality with combinatorial optimization problems. The process of this algorithm is the same as the process of metal annealing, which involves the process of heating and warming, isothermal temperature and cooling. The simulated annealing algorithm sets the initial temperature value to represent the metal heating process, and the Metropolis criterion is utilized in this algorithm to bring the system state to equilibrium, which is equivalent to the process of metal isothermal. The cooling process of the algorithm is equivalent to cooling, the energy of the system decreases steadily, and finally the cooling process ends and the algorithm finds the optimal solution.

The Metropolis criterion focuses on realizing new states with a certain probability, rather than using fully deterministic rules. First a current state i is chosen, then the energy of the current state is E_i. And then the position of the perturbed particle will be changed, even if it is a small change, a new state j will appear, and the energy of the new state will be E_j. If $E_j < E_i$, the new state is judged to be significant and accepted. Conversely, if $E_j > E_i$, the probability of jumping from the current state to the new state needs to be judged. Based on the above theory, the Metropolis criterion formula can then be obtained expressed as:

$$P = \begin{cases} 1 & E_j \le E_i \\ \exp\left(-\dfrac{E_j - E_i}{T}\right) & E_j > E_i \end{cases} \tag{11}$$

The system will determine whether to accept the new state based on the P value. From equation (11), when the temperature T of the substance is high, the new state with a large difference compared to the current energy can be accepted. When the temperature T is small, only new states with a small difference compared to the current energy will be accepted. When the temperature gradually approaches 0 degrees, basically no state E_i will accept new states E_j that are larger than its current energy.

The SA algorithm operates as follows:

Step1 Setting of basic parameters, initialization temperature t_0, chain length L, cooling rate r, termination temperature t_1, select any state to get x_0 to calculate function value $f(x_0)$.

Step2 Generate a new solution x_1 by random perturbation and calculate the function value $f(x_1)$.

Step3 Decide whether $f(x_1) \le f(x_0)$, if yes, accept the new solution x_1. Otherwise, decide whether the new solution is accepted according to Metropolis criterion, if it is accepted, then $f(x_1)$ is a new solution; if not, then $f(x_0)$ is a new solution.

Step4 Determine whether the termination condition is satisfied, if it is satisfied, then proceed to the next step, if it is not satisfied, then re-run Step2.

Step5 Run the cooling operation.

Step6 Determine whether the annealing process is finished, if it is finished, continue Step7, otherwise re-run Step2.

Step7 The algorithm ends and the optimal solution is obtained.

The SA algorithm is widely used in optimization model solving due to its strong local search ability, simplicity and easy implementation. However, the algorithm also has certain defects, the optimization process has a strong dependence on the setting of the cooling speed, the cooling speed is too slow, resulting in a longer optimization time, while the cooling speed is too fast and easy to skip the optimal solution, so it is necessary to adjust the cooling speed to ensure that the algorithm to find the optimal.

3.2.2 Particle Swarm Optimization Algorithm

Particle Swarm Algorithm (PSO) is an optimization algorithm based on group intelligence by simulating the migratory behavior of birds during foraging. In PSO, the search space of the problem is analogous to the flight space of birds, and the process of solving the optimal solution of the problem is regarded as the process of birds' foraging.PSO abstracts each bird as a massless and volume-less particle, and each particle has two eigenvectors of position and velocity. The spatial location of the particle represents the feasible solution of the problem. In the optimization process of the algorithm, the spatial position and flight speed of each particle are first randomly initialized, and then the position and speed are updated through iterations. At each iteration, the position and velocity need to be updated by two poles. The first extreme value is the best solution of the objective function currently found by each particle, which is the value of the fitness function corresponding to the best position found by each particle. The second extreme value is the best solution of the objective function found for the entire population, and it is the fitness function value corresponding to the best position found for the entire population. In general, the fitness function is the objective function of the required solution, and the optimal solution to the problem is usually found by iterating.

Let the search space dimension of the target be D and the population number of particles be N. The velocity and position update formula for each particle can be expressed as:

$$V_i(t+1) = \omega \cdot V_i(t) + c_1 r_1 \left(pbest_i(t) - X_i(t) \right) + c_2 r_2 \left(gbest(t) - X_i(t) \right) \tag{12}$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{13}$$

where $X_i = (x_{i1}, x_{i2}, \cdots, x_{iD})$ denotes the position of the i th particle, $V_i = (v_{i1}, v_{i2}, \cdots, v_{iD})$ denotes the i th particle's velocity, and $pbest_i = (p_{i1}, p_{i2}, \cdots, p_{iD})$ denotes the best position found by the i th particle. $gbest = (g_{i1}, g_{i2}, \cdots, g_{iD})$ denotes the best position found by the whole population, $i = 1, 2, \cdots, N$, and t denotes the number of current iterations. c_1, c_2 are the learning factors, which are the weight coefficients of the particles when they update their movement based on their own experience and social experience. r_1, r_2 are random numbers uniformly distributed on $[0,1]$, ω is the inertia weights, and a large value of ω has stronger global convergence and weaker local convergence. Smaller values of ω result in stronger local convergence and weaker global convergence. A dynamic linearly decreasing strategy is usually used in use with:

$$\omega = \omega_{\max} - \frac{\left(\omega_{\max} - \omega_{\min}\right) \cdot t}{t_{\max}} \tag{14}$$

where $t_{\max}$ denotes the maximum number of iterations, and $\omega_{\max}, \omega_{\min}$ denote the maximum inertia weight and the minimum inertia weight, respectively, and in general, $\omega_{\max} = 0.95$, $\omega_{\min} = 0.35$.

Let the maximum velocity of the particle be $V_{\max}$. In order to prevent the particle from leaving the search space with too large or too small a velocity, boundary conditions need to be set, i.e.:

$$V_i(t+1) = \begin{cases} V_{\max} & V_i(t+1) > V_{\max} \\ -V_{\max} & V_i(t+1) < V_{\max} \\ V_i(t+1) & \text{otherwise} \end{cases} \tag{15}$$

3.2.3 ISA-PSO algorithm flow

The SA algorithm is easier to find the global optimal solution, but the convergence speed is slow, and the PSO algorithm converges quickly, but it is easy to fall into the local optimal solution. In order to make the two methods complement each other, a simulated annealing-improved particle swarm algorithm (ISA-PSO) is designed to solve the multi-objective optimization model of scientific research resource scheduling under the interdisciplinary cooperation platform, i.e., the standard particle swarm algorithm is in the outer layer, and the simulated annealing algorithm is in the inner layer. The basic idea is to simulate annealing with the initial value of the population optimal solution $g_{best} = (g_1, g_2, \cdots, g_d)$ obtained by the current iteration of the standard particle swarm algorithm, and after annealing, $\tilde{g}_{best}$ is obtained, and if $\tilde{g}_{best}$ is better than g_{best}, $\tilde{g}_{best}$ replaces $g_{best}\left(g_{best} \leftarrow \tilde{g}_{best}\right)$, otherwise, the original population optimal solution remains unchanged, and then enters into the next iteration of the standard particle swarm algorithm.

The improvement of SA algorithm to PSO algorithm is mainly to make the algorithm quickly jump out of the local optimal solution, and search for the global optimal solution in the vicinity of better particles. At the same time, in order to reduce the time complexity of the algorithm, the optimal solution of the population in the first j ($j < ger$, ger is the iteration number of the standard particle swarm algorithm) generations of the PSO algorithm is subjected to simulated annealing, and the global search for the optimal solution after the first j generation is completed by the PSO algorithm.

The steps of ISA-PSO algorithm are as follows:

(1) Parameter initialization. Input the number of populations in the outer standard particle swarm algorithm N, the number of iterations ger, the number of generations of inner simulated annealing for the optimal solution of the population j; input the initial temperature

of the inner simulated annealing algorithm T_0, the cooling coefficient α, the number of cooling times γ, and the number of iterations L for each value of the temperature; and input the penalty factor σ.

(2) Randomly initialize the initial position of each particle in the population $s_i = (s_{i1}, s_{i2}, \cdots, s_{id})$, $i = 1, 2, \cdots, N$, and the initial velocity $v_i = (v_{i1}, v_{i2}, \cdots, v_{id})$, $i = 1, 2, \cdots, N$.

(3) Calculate the value of fitness function f_i for each particle s_i, $i = 1, 2, \cdots, N$.

(4) Compare the value of each f_i to find the historical individual optimal solution for each particle $p_{besti} = (p_{i1}, p_{i2}, \cdots, p_{id})$, $i = 1, 2, \cdots, N$, and find the population optimal solution $g_{best} = (g_1, g_2, \cdots, g_d)$.

(5) Calculate the fitness function value $f(g_{best})$ of the population optimal solution, and perform simulated annealing with the population optimal solution g_{best} as the initial value.

(6) Generate a random perturbation on g_{best} to obtain a new solution $\tilde{g}_{best}$, and compute the value of the fitness function of the new solution $f(\tilde{g}_{best})$.

(7) Compute the increment of the fitness value $\Delta f = f(\tilde{g}_{best}) - f(g_{best})$.

(8) If $\Delta f \geq 0$, accept the new solution $\tilde{g}_{best}$ as the current solution g_{best}, otherwise accept the new solution as the current solution with probability $p_{met}(\Delta f)$ (Metropolis criterion).

(9) Repeat (5) to (8) until the number of repetitions reaches L to obtain a new solution g_{best}, and go to (10).

(10) Cool down the temperature T_0, $T_0 \leftarrow \alpha T_0$.

(11) Repeat (5) to (10) until the number of cooling reaches γ, obtaining a new solution g_{best}, and go to (12).

(12) Update the position and velocity of the particle to get the new position s_i, velocity v_i, respectively.

(13) Repeat (3) ~ (12) until the number of repetitions reaches j to get the new g_{best}, go to (14).

(14) Repeat (3), (4), (12) until the number of iterations of the outer standard particle swarm algorithm reaches ger and the algorithm ends.

Based on the above algorithm steps, the ISA-PSO algorithm flow is obtained as shown in Fig. 2.

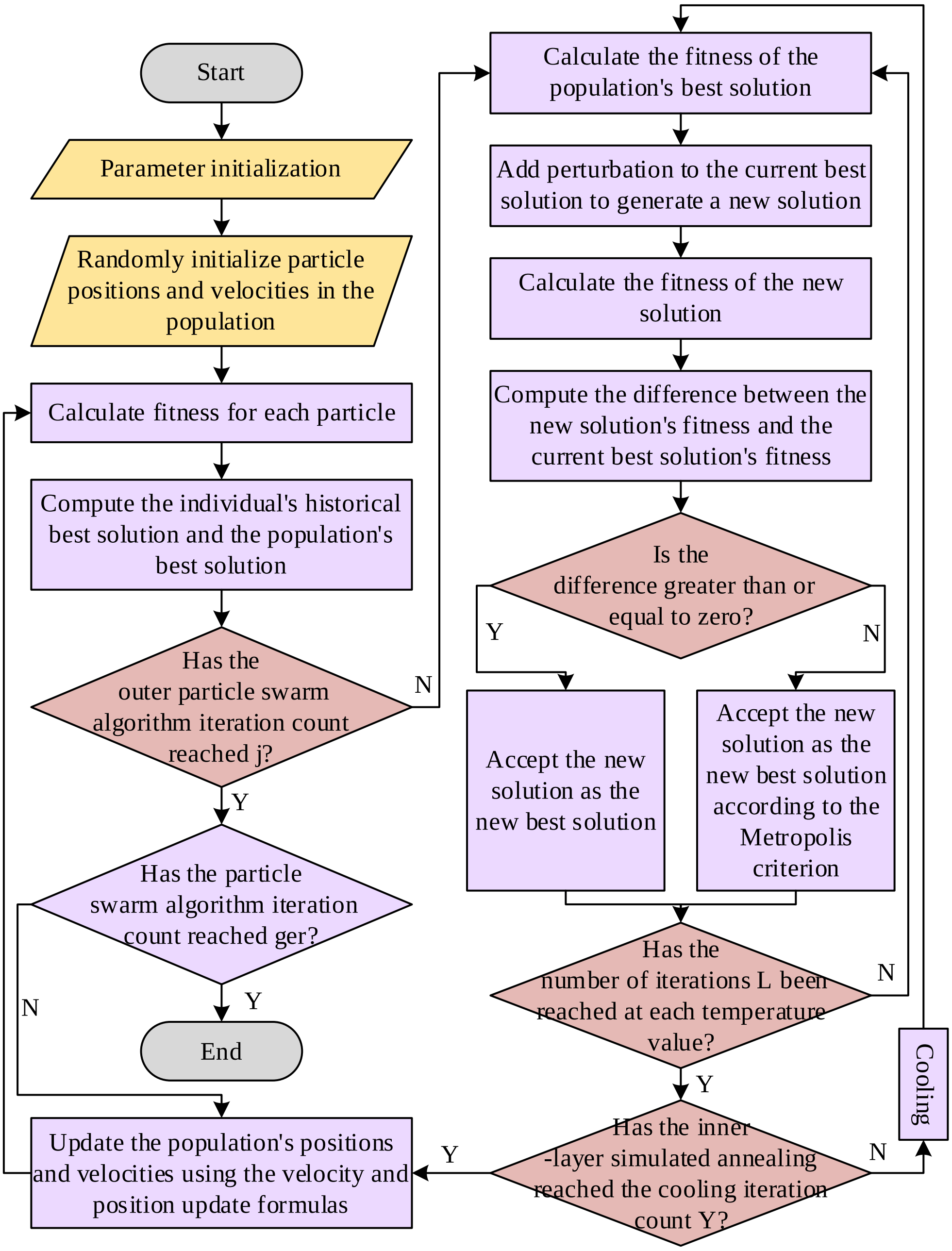


Figure 2: Model solution process based on ISA-PSO algorithm

4 Validation of the efficiency of interdisciplinary collaboration and the effectiveness of resource scheduling

In the era of open science, the trend of scientific research breaking through the limitations of a single discipline towards interdisciplinary research mode has become more and more obvious, and changes in the scientific research environment have also prompted the development of scientific research in the direction of cooperation. In this context, interdisciplinary scientific research cooperation has become an important trend in academic research and a key form of promoting the national innovation-driven development strategy. Carrying out academic research activities through different forms of cooperation, realizing knowledge sharing and integration, and producing valuable research results are important ways to truly promote disciplinary innovation, knowledge discovery and scientific progress.

4.1 Bibliometric measures of the efficiency of interdisciplinary research collaboration

4.1.1 Research data sources and processing

This article uses China National Knowledge Infrastructure (CNKI) as the data source. Among the search methods in the CNKI database, the literature source is selected as "journals", the search mode is chosen as "professional search", and the search formula is JN = 'Education Research' + 'Higher Engineering Education Research' + 'Higher Education Research' + 'China Higher Education Research' + 'China University Teaching' + 'Education Development Research' + 'High Education Exploration' + 'China Higher Education' + 'Modern Educational Management' + 'Modern University Education' + 'Degree and Graduate Education' + 'University Education Science' + 'High Education Development and Evaluation'. The search period is from 2010 to 2024, and a total of 23,900 academic journals were obtained. Additionally, the composite impact factor of the above-mentioned Chinese core journals can be obtained from CNKI.

Firstly, 98740 papers that had been obtained were screened. After eliminating papers such as non-academic papers, papers in non-higher education fields, papers from non-Chinese mainland universities, and papers combining records of documents with different signatures from the same institution, 21,475 academic journals were obtained. Second, the number of papers published in different journals by different schools (in preparation for further standardization of the number of papers) was collected from the existing data table, and the total number of papers published by each school and the average citation frequency of each paper were calculated, based on which, the number of standardized papers by each school could be obtained by multiplying the composite impact factor of the journal by the number of papers published by that school in that journal. Thirdly, the number of highly cited papers per year was extracted from the original database by first selecting the year and then selecting the top 1% of the total number of papers in that year according to the order of citation frequency.

4.1.2 Scale analysis of interdisciplinary cooperation

Based on the data obtained in the previous section, the top five higher education institutions in terms of compound impact factor, namely QH University, BJ University, HZ University of Science and Technology, XM University and FD University, are selected as samples to be analyzed in this paper. The journal data of the above five higher education institutions during the period from 2010 to 2024 are selected from the previous data, and the status of interdisciplinary research cooperation among the above five institutions is evaluated from the perspective of the scale of cooperation.

(1) Overall collaboration scale and individual collaboration scale

By integrating the journal data of the five selected institutions of higher education, the trend of interdisciplinary research cooperation between the five institutions of higher education is shown in Figure 3. As can be seen from the figure, the overall publication volume of the five higher education research institutions shows an upward trend, and their total publication volume rises from 127 articles in 2010 to 194 articles in 2024, with an overall average annual growth rate of 3.07%. On the whole, the total number of publications increased sharply in the time periods of 2012 to 2015 and 2021 to 2024. The value of HZ University of Science and Technology is higher than the other four institutions, indicating that the total number of publications is higher than that of the other four institutions.The curve of the number of publications of interdisciplinary collaborations of XM University is almost straight line, with small changes almost every year, the total number of publications of QH University is the lowest in most of the years, and the overall fluctuation of FD University is larger, indicating that the scale of its interdisciplinary collaborations is more varied.

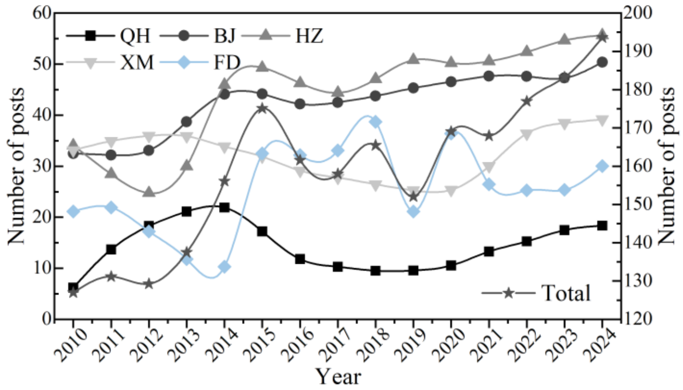


Figure 3: The trend of the development of scientific research cooperation

(2) Relative cooperation scale

Taking the proportion of the number of academic journals published by each higher education institution to the overall number from 2010 to 2024 as the horizontal coordinate, and taking the proportion of the number of interdisciplinary scientific research cooperation papers issued by each higher education institution to the overall number of interdisciplinary cooperation papers issued as the vertical coordinate, the analysis of the relative scale of cooperation is carried out, and the closer the distance to the central trend line indicates that the higher the relative scale of cooperation is, and the higher the degree of participation in interdisciplinary cooperation is. Figure 4 shows the distribution of relative cooperation scale data of five higher education institutions. As can be seen from the figure, the data of QH University is closest to the center line, which indicates that it has a larger relative cooperation scale of interdisciplinary research cooperation and a higher participation in interdisciplinary cooperation.The relative cooperation scale of BJ University and HZ University of Science and Technology is almost equal, but the scale of interdisciplinary cooperation of HZ University of Science and Technology is a bit larger in comparison.The relative cooperation scale of FD University is in the middle of QH University and XM University, but is higher than that of BJ University and HZ University of Science and Technology. XM University is the furthest away from the centerline, indicating that this higher education institution's participation in interdisciplinary collaboration needs to be further improved.

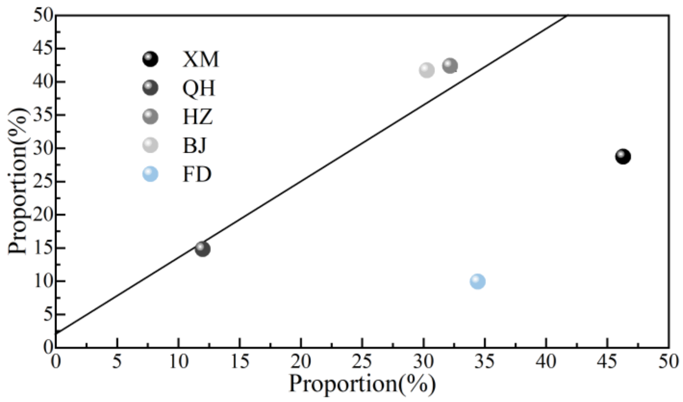


Figure 4: Data distribution of relative cooperation scale

4.1.3 Evolutionary characteristics of interdisciplinary cooperation

After analyzing the scale of interdisciplinary collaborations in five higher education institutions, this paper further enlarges the research sample to dual-tier universities and selects the number of interdisciplinary collaborations' publications in SCIE journals to be analyzed, which is classified into four different SCIE journal grades.The longitudinal evolution characteristics of interdisciplinary collaborations' publications in different journal grades of dual-tier universities from 2010 to 2024 are shown in Figure 5. The vertical evolution of interdisciplinary collaborative publications in different journals of double top universities from 2010 to 2024 is shown in Figure 5.

As can be seen from the figure, the growth in the number of interdisciplinary collaborative publications in the four different grades of SCIE journals of double first-class universities has roughly gone through four stages. In the first stage from 2010 to 2013, the number of university-enterprise co-authored SCIE papers published in the four grades of journals by double first-class universities was basically equal and showed a slow growth trend. In the second stage, from 2014 to 2017, the number of papers published in Bottom grade journals by double first-class universities began to show substantial growth, while the growth momentum of the number of journals published in Top grade journals gradually weakened. Among them, the number of journals in 2016 and 2017 was even lower than the number of journals in Second and Third ranks. In the third stage from 2017 to 2021, the number of interdisciplinary co-authored SCIE journals published on the Bottom rank in dual-tier universities has been far ahead of the number of papers in other three ranks. At the same time, the proportion of journals published in Top rank to the total number of papers has reached the lowest, indicating that the phenomenon of “weight but not quality” of journals of double first-class colleges and universities is the most prominent in this stage. In the fourth stage from 2021 to 2024, the overall growth of interdisciplinary co-authored journals published in SCIE journals by top-tier colleges and universities has not weakened. At the same time, the proportion of journals published in Top rank in this stage is increasing, and the number of journals published in Second and Third rank is also increasing, and the gap with the number of journals published in Bottom rank is narrowing, indicating that the quality of interdisciplinary co-authored papers published in SCIE journals by double first-class universities is improving, and the international influence of the journals is also increasing. This indicates that the quality of interdisciplinary co-authored papers published in SCIE journals is improving, and the international influence of journals is also increasing. However, since the proportion of journals with Bottom rank is still large, how to effectively improve the quality of SCIE papers while increasing the scale is still an important issue for interdisciplinary cooperation in higher education.

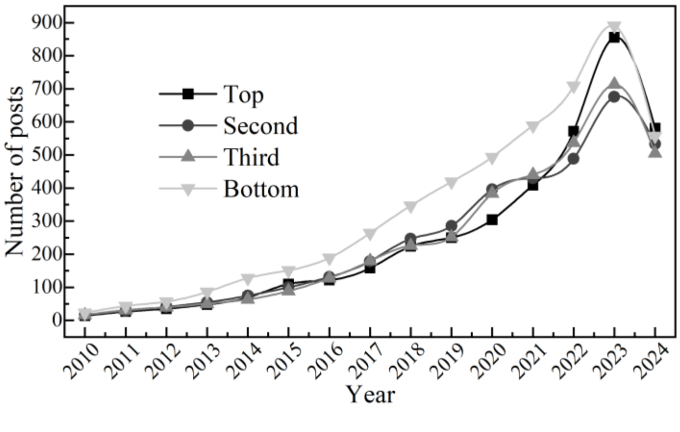


Figure 5: The characteristics of the evolution of interdisciplinary cooperation

4.2 Validation of interdisciplinary collaborative research resource scheduling

4.2.1 Performance of the ISA-PSO algorithm

In order to verify the performance of ISA-PSO algorithm, according to the scientific research resource scheduling model of interdisciplinary cooperation platform created in this paper, combined with the ISA-PSO algorithm, the MATLAB programming is used for the operation, the initialization parameter settings, and the proposed ISA-PSO algorithm and the traditional SA algorithm are compared and analyzed in terms of their performance, and the change curves of the normalized objective function are shown in Fig. 6, and the results of the algorithm operation comparison are shown in Table 1.

From the comparison of the table, it can be seen that in the case of running 120 times respectively, the average value of the number of iterations to find the optimal solution of ISA-PSO algorithm and traditional SA algorithm is 32 times and 66 times respectively, and the performance of ISA-PSO algorithm is more than one times higher than that of traditional SA algorithm, and the average value of the optimal solution is 15.215 and 15.327 respectively, which indicates that the accuracy and stability of ISA-PSO algorithm have been greatly improved in comparison with the traditional SA algorithm. It shows that the accuracy and stability of ISA-PSO algorithm are greatly improved compared with the traditional SA algorithm. ISA-PSO algorithm can find the global optimal solution 15.213 faster, and the accuracy is significantly higher than the traditional SA algorithm, whereas the traditional SA algorithm can only find the local optimal solution 15.258, and the optimal solution obtained is unstable and of poor quality. In addition, as the number of iterations increases, both the traditional SA algorithm and ISA-PSO algorithm converge and become stable, because the ISA-PSO algorithm carries out simulated annealing on the current search results, and replaces the optimal particles at the end of the annealing, which makes the algorithm converge quickly at the beginning of the iteration and accumulate the good results, and then find a suboptimal solution that is close to the optimal one around 30 iterations, at which time, the mean of the solutions in the population converges to the optimal one and individual solutions are more accurate than the traditional SA algorithm. At this point, the mean value of the solutions in the population tends to the optimal solution and has a high degree of adaptation among individuals. In the late iteration, the standard particle position update increases the search space of the algorithm to jump out of the local optimization and find the global optimal solution in about 32 iterations. In contrast, the traditional SA algorithm adopts a single simulated annealing strategy, which keeps one layer unchanged throughout the iteration process, and thus converges slowly at the beginning of the iteration, and finds the local optimal solution only after about 60 iterations. Moreover, the mean value of the solutions in the population is relatively high and the adaptability between individuals is low, while in the late iteration, the search space cannot be increased by effective mutation, which leads to the failure to find the globally optimal solution and the trapping in the local optimum.

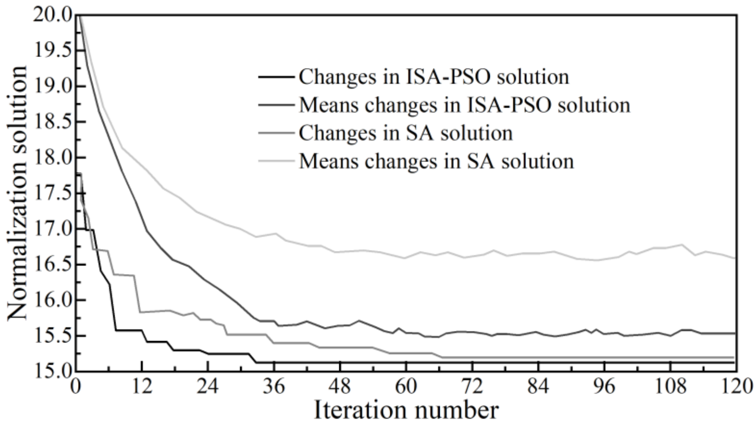


Figure 6: Normalized target function curve

Table 1: Comparison results of algorithm operations

Algorithm	Number of runs	Optimal solution	The mean of the optimal solution	Find the mean of the genetic algebra for the optimal solution
ISA-PSO	120	15.213	15.215	32
SA	120	15.258	15.327	66

4.2.2 Task Prioritization Performance Impacts

In this section, simulations are utilized to verify the superiority of the designed ISA-PSO algorithm in solving the task of research resource scheduling on an interdisciplinary collaboration platform. Consider a certain fixed interdisciplinary collaboration platform with the number of tasks set from 20 to 240. In this section, we will compare the ISA-PSO algorithm with the existing PSO algorithm and SA algorithm under different numbers of tasks, and analyze the processing delay of each algorithm, so as to determine the advantages and disadvantages of each algorithm when carrying out the implementation of the scientific research resource scheduling task on the interdisciplinary cooperation platform. Figure 7 shows the performance comparison results of the three algorithms without considering the task priority.

From the figure, it can be seen that when the number of research resource scheduling tasks is low, the difference in the total task processing delay obtained by the three algorithms is not very large. When the number of tasks increases, the algorithms deteriorate severely due to the PSO algorithm and the SA algorithm due to the fact that they are caught in the situation of searching for local optimal solutions. However, the ISA-PSO algorithm also borrows the particle update of the PSO algorithm to jump out of the local optimal solution situation on the basis of ensuring the convergence speed, and the increase in the number of tasks of scientific research resource scheduling has a relatively small impact on the algorithm. Therefore, when implemented in the actual interdisciplinary cooperation platform, the algorithm designed in the paper has a smaller processing delay, thus the user experience is improved.

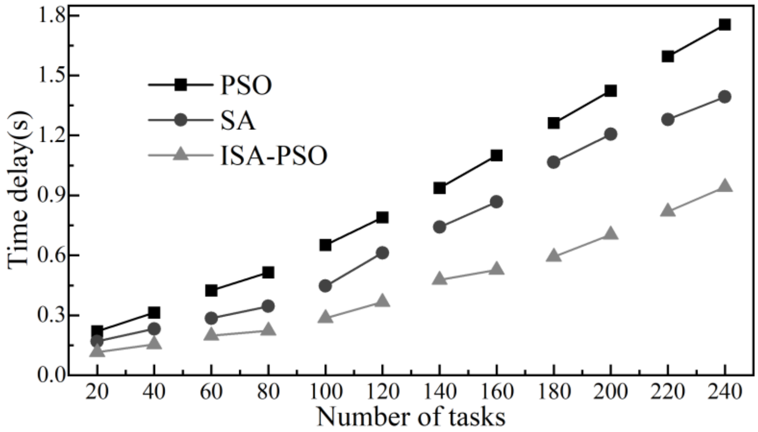


Figure 7: The performance comparison of three algorithms without priority

The processing latency of the three algorithms compared under the consideration of task prioritization is shown in Fig. 8. From the figure, it can be seen that the performance of PSO algorithm and SA algorithm degraded significantly compared with the case of not considering the task priority, and their processing latency reached the highest of 3.96s and 2.33s respectively when carrying out the scientific research resource scheduling task, while the ISA-PSO algorithm proposed in the paper considered the priority of the scientific research resource scheduling task processing in the beginning of its design, and its processing latency was lower than 1.0s, which is significant for ensuring the service quality requirements of higher education research organizations is of some significance. Therefore, the ISA-PSO algorithm has the advantage of reducing the processing delay when implemented in the interdisciplinary cooperation platform of higher education.

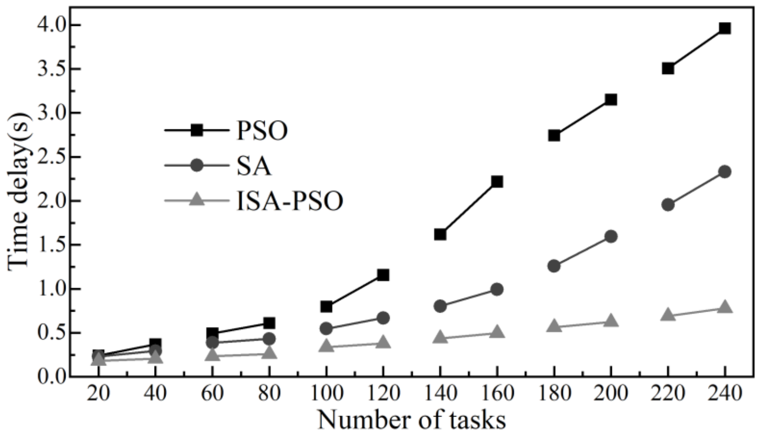


Figure 8: The performance comparison of three algorithms with priority

4.2.3 Equilibrium in relation to resources

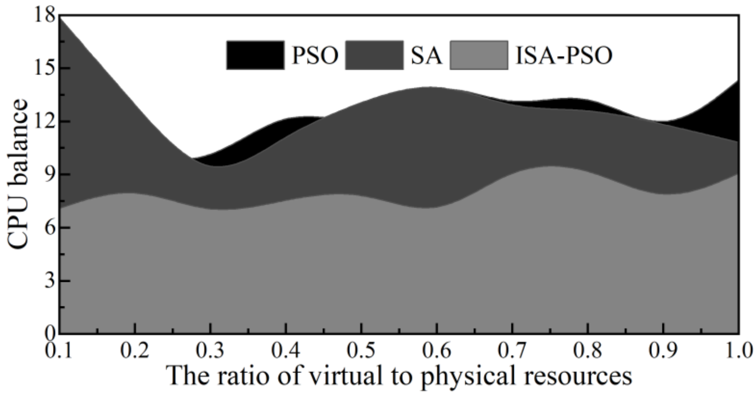
In order to test the effectiveness of the research resource scheduling model based on the ISA-PSO algorithm on an interdisciplinary cooperation platform, GirdSim software is used to simulate a local domain of research resources on an interdisciplinary cooperation platform. In order to measure the advantages and disadvantages of the scheduling scheme of ISA-PSO algorithm, PSO and SA algorithms are still used as a comparison. In the interdisciplinary cooperation platform, the CPU value ranges from 250 to 2500, the memory value ranges from [20, 1200], the bandwidth value ranges from 10 to 180, and 1200 physical research resources are randomly generated and then virtualized, which ensures the complexity of the research resources and the diversity of the virtual tasks under the interdisciplinary cooperation platform.

Each algorithm is run 50 times, and then the average value is taken as the final result of the algorithm. The balanced comparison results of the three algorithms are shown in Fig. 9, where Figs. 9(a)~(c) show the balanced comparison results of CPU, memory and bandwidth, respectively.

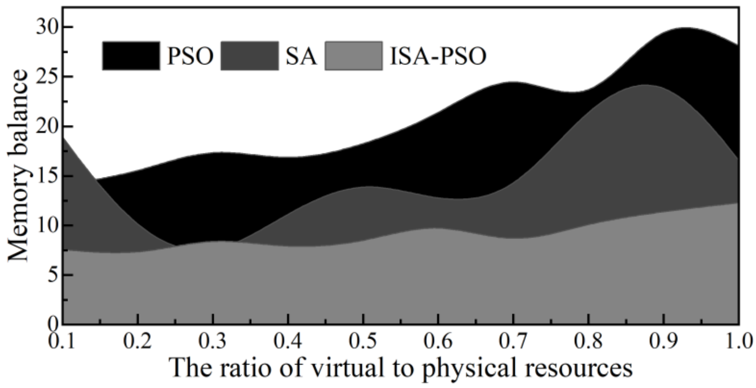
Analyzing and comparing the results of the three scheduling algorithms, the results can be obtained as follows:

(1) Among all the algorithms, the ISA-PSO algorithm has the best average performance and the PSO algorithm has the worst performance. This shows that the ISA-PSO algorithm can well reflect the characteristics of large-scale, shared and dynamic nature of scientific research resources under the interdisciplinary cooperation platform, and it can be well divided into scientific research resource scheduling tasks and allocate computational resources on it, which is an effective scientific research resource scheduling algorithm.

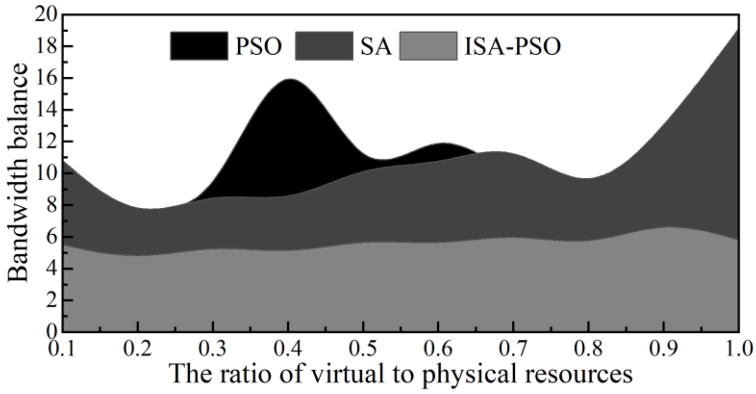
(2) Compared with SA algorithm, ISA-PSO algorithm has a more stable performance and can obtain a better research resource scheduling scheme. This is mainly due to the fact that the ISA-PSO algorithm makes full use of the advantages of the SA algorithm and the PSO algorithm, ensures the diversity of particles, and prevents the phenomenon of falling into a local optimum at the late stage of the search. This shows that the introduction of the PSO algorithm to improve the simulated annealing algorithm is effective, which further improves the convergence of the algorithm, increases the utilization rate of scientific research resources under the platform of interdisciplinary cooperation in higher education, and boosts the innovative development of scientific research results.



(a) CPU balance and Scientific resources



(b) Memory balance and Scientific resources



(c) Bandwidth balance and Scientific resources

Figure 9: The comparison results of the algorithm's balance

5 Conclusion

Based on the ecosystem theory, the article establishes the collaboration model of interdisciplinary cooperation platform in higher education, designs a multi-objective optimization model of scientific research resource scheduling task for interdisciplinary cooperation platform, and solves the model by ISA-PSO algorithm. Based on the data from China Knowledge Network, the current scale and evolutionary characteristics of interdisciplinary research cooperation in higher education are analyzed, and the feasibility of ISA-PSO algorithm in interdisciplinary research resource scheduling task is analyzed through simulation experiments. It is found that the scale of interdisciplinary research cooperation in higher education shows a rising trend year by year, and the overall interdisciplinary co-authored journals are developing in the direction of “quality-oriented”, and the ISA-PSO algorithm has higher scheduling efficiency when scheduling interdisciplinary scientific research resources, and the interdisciplinary cooperation platform is well-balanced with scientific research resources, which provides a new way to promote interdisciplinary collaboration in higher education. The ISA-PSO algorithm has higher scheduling efficiency when scheduling interdisciplinary research resources, and good balance of research resources in the interdisciplinary cooperation platform, which provides a new research perspective for promoting interdisciplinary collaboration in higher education.

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