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Underwater Pier Algorithm: Nested Civilizations and Complex Economies in a Multilayered Trade Network in Historical Geographical Perspective

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***Abstract*—Underwater Pier Algorithm (UPA) is a new meta-heuristic swarm intelligence algorithm based on differential evolution algorithm that takes into account the whole process of geo-data infrastructure, trading behavior, road network generation, and city construction in the process of social computing, by constraining the behavior of trading routes, trade kinds of data conditions and expansion laws, social mechanisms that attract data exchange and sharing, data normative standard establishment and the process of common knowledge evolution. The proposed algorithm can realize the organization category, classification index and alternative metric calculation of node data resources by testing the function, so as to realize the analysis observation of core nodes in multi-layer trade networks, significant improvement on the inference ability for local events, fast convergence, strong global search ability and high solution accuracy.**

Keywords-Underwater pier algorithms; intelligent evolution; social computing; multilayer networks

I. Introduction

To address the shortcomings of the ALO algorithm in terms of low convergence accuracy and the tendency to fall into local optima, this paper proposes a dual feedback mechanism, introducing the nested characteristics of trade demand and trade product categories as dual feedback information into the algorithm, and realizing an evidence-based research paradigm on the ecology of the Silk Road geo-trade network by introducing a spatio-temporal chaos exploration strategy and a rule improvement elite variation strategy. A dynamic adaptive feedback adjustment strategy is used to dynamically adjust the attractiveness of trade nodes to improve convergence accuracy; a spatio-temporal chaos exploration strategy is used to improve the global search ability and avoid the algorithm from falling into local optimality; a diversity feedback Gaussian variation strategy is used to enhance the diversity of trade behaviors and avoid premature maturity of the algorithm.

As a bridge for cultural, trade and political exchanges between the East and the West, the Silk Road was affected by changes in geography, ethnic relations, political changes and other factors, and can reflect the overall value and dynamic characteristics of civilizational exchanges on a large scale, across regions and over a long period of time. The Silk Road is a high-quality resource for studying the production of social data in the process of social evolution, and the Silk Road data is the data basis for the construction of a multi-layered trade network in this paper. Using this as a case study to carry out research helps to achieve a mathematical interpretation of the co-evolutionary behaviors of civilizations between geo-regions.

The remaining work of this paper is as follows: the second part of the article presents the motivation of the research problem, the third part presents the algorithm design principles and improvement goals, the fourth part presents the mathematical model of the algorithm, the fifth part presents a case study using the Silk Road as an example, and finally summarizes the conclusions and discusses future directions.

II. Motivation

A. Underwater Pier Algorithm

When building a bridge over water, the piers are constructed deep underwater, commonly with pile foundations, expanded foundations and sinkholes, 1) pile foundations: higher bearing capacity, suitable for areas with more rock layers underwater, consisting of a pile platform with multiple fine piles nailed to it, the only part exposed to the water is the pile platform; 2) expanded foundations have less force on the soil and low strength requirements for the soil layer, then they are suitable for the seabed with more soft and powdery soils underground, consisting of a wide base and then many fine columns, the base is buried deeply into the soft soil of the water bottom; 3) the sinkhole method first places a well-like hollow column on the sea (river) bed, then does a good job of sealing the bottom of the well, drains all the water from the well, then digs deeper into the well, waits for a better layer of soil before driving piles, and finally seals them.It is suitable for areas where the bearing capacity of the surface foundation is insufficient and further down is a rock formation.

Underwater piers are the basis for supporting bridges and bridge decks, the infrastructural guarantee of road access, and the continuous fulcrum built under geo-constrained conditions. Similarly, in the process of studying complex networks of trade need to be analyzed for the basis of building road networks, the basic idea of which originates from genetic algorithms, which like other evolutionary algorithms also operate on populations of candidate solutions, rather than on a single solution. Due to the existence of self-propagation and optimization, variation, crossover and fusion of different trade nodes, an evaluation is introduced as to how to identify their value and the value that is given to them.

The underwater abutment algorithm is a type of DE algorithm that uses a vector of real parameters as a population

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for each generation, and the self-referential population reproduction scheme is different from other optimization algorithms. This operation is called "variation"; then the parameters of the variation vector are mixed with the parameters of another pre-determined target vector according to certain rules to produce sub-individuals, this operation is called "crossover"; the newly produced sub-individuals are replaced only when they are better than the target individuals in the population, this operation is called "selection This operation is called "selection". The selection operation of the algorithm of underwater piers is to compete with the newly generated candidate individuals one by one after the completion of mutation and crossover, so that the child individuals are always equal to or better than the parent individuals, that is, the new trade point or the original trade point in the road network is developed. Moreover, the DE algorithm gives all individuals of the parent generation an equal opportunity to enter the next generation without discriminating against inferior individuals.

B. Limitations of the DE algorithm and targets for improvement

The DE algorithm as the object of study can only achieve global search through trade demands around random calculations at randomly selected nodes. The adaptive contraction of boundaries by nodes to achieve local exploitation is far from being able to accurately characterize the behavior of dynamic objects in the research area.

The algorithm takes a certain proportion of the differential information of multiple individuals as the perturbation number of individuals, making the algorithm adaptive in terms of jump distance and search direction. In the early stages of evolution, because of the large variability of individuals in the population, the amount of perturbation is large, which allows the algorithm to search over a large area with a strong exploration capability; in the later stages of evolution, when the algorithm tends to converge, the variability of individuals in the population is small and the algorithm searches near the individuals, which allows the algorithm to have a strong local exploitation capability. It is the ability of this algorithm to learn from individuals in the population, due to its origin in differential evolutionary algorithms, that gives it an advantage in explaining evolutionary laws.

C. Trade categories - road networks - geo-data and nodes - trading - profitability Analysis

Complexity analysis of multi-layered trade networks from a historical-geographical perspective is an important reference for quantifying the competitiveness of individual countries to predicting the collective evolution of the world economy. In recent years, significant progress has been made in the use of complex network analysis to reveal the formation and evolution of modern international trade [1], but research on international trade from a historical-geographical perspective with long time horizons and multiple time phases is still lacking.

Firstly, trade is spontaneously coordinated by individual countries (regions) to promote trade exchange and wealth accumulation in a semi-managed and semi-promoted manner. The process is simplified as follows: firstly, a country (region) obtains trade demand, information about the trade network and the organization of its own trade products through a power center, buys and sells goods at each node of the known network, and collects wealth by means of exchange, plunder and monopoly. Then, through the next node or the final target place to attract or constrain commercial behavior, in order to incentivize or punish the completion of the whole network road trade transactions wealth absorption. At the same time segment, the same pattern of data collection, collation, exchange, verification, iteration, release continues to occur until the trade road network data and trade behavior coupling, along the trade nodes and trade types of demand traversal completed.

And the study of modelling, observation and prediction of multi-layer trade networks by scholars in the West has led to a new field of research - complexity economics. Complexity economics understands the complex behavior in economic systems through tools developed in complexity science. In the modelling of complex economic networks, international trade networks are often modelled using country-product dichotomous networks, where links represent trade exchange relationships of products between countries [2], and the network exhibits a distinct nested structure [3].

The nested structure of country-product networks has profound implications for economic theory and has been studied quantitatively and analytically by numerous scholars from multiple perspectives. Issues include exploring the nested nature of observation networks [4] and predicting the evolution of industrial ecosystems [5]. Clearly, the mere use of linked data norms originating from the industrial era and representing international trade data with country-product dichotomous networks oversimplifies the system and compromises the robustness of conclusions. Only by treating historical international trade networks as constructs of complex network studies, coupled with long time series of geographical region (country)-civilizational evolution (demand)-trade product (economy) triadic relationships, can the demand, market, cost and value information of trade exchange that has been neglected in earlier studies be compensated for and effectively calculated. Among them, the multi-layered trade network not only consists of products imported and exported by each country, but also contains multiple heterogeneous piers-type data such as geo-constraints, road network ecology, and civilization supply.

This paper attempts to construct a GIS-based Silk Road: Chang 'an-Tianshan corridor trade road network data and trade category set to describe the multi-layer trade system, with each layer representing cross-regional trade relationships over a specific time span. In addition, an attempt is made to add effective support nodes to the constructed GIS multi-layered data network by growing cities and road networks as dynamic nodes to serve trade industry data (layer data). The underwater piers algorithm addresses the evolutionary needs implicit in trade behavior, in line with the consensus on trade values and the laws of technology diffusion in the evolution of civilization. Therefore, the study uses the mathematical modalities of pile and sinkhole construction in the construction of underwater piers for the organization of node data resources in terms of categories, classification metrics and alternative metrics calculation, which leads to the analytical observation of core nodes in multi-layer trade networks. Through the observation of core nodes in the trade network, the evolution of the economic trade network during the Han and Tang dynasties is explored and the symbiotic relationship between the nestedness index and economic growth is summarized. In addition, it is important to note that the size of trade nodes is positively correlated with the military-economic-political strength of a country (region). Typically, the more trade nodes and the shorter the route spacing area, the greater the density of trade numbers and transactions, and the more efficient the capture of gains and technological synchronization.

III. Principles and Improvement Goals

Drawing on the idea of parametric closed-loop control, this paper introduces the characteristics of trade node capacity and trade type improvement rate as dual feedback information into the algorithm, and uses a dynamic adaptive feedback adjustment strategy to take into account diversity feedback variation.

A. Dynamic adaptive feedback adjustment strategy

Trade point size does not become steadily larger with iteration, and the possibility of solidification, shrinkage, or even phased disappearance and complete destruction following changes in the focus of the area explored, under the influence of risks of human damage and natural disasters, requires a dynamic response to the ability of trade points to supply trade goods and absorb them. In this paper, local records are collected from publicly available databases, and datasets for different products are grouped by year. Trade flows are used to construct a multi-layered network, where each layer is a directed network and where multiple trade in and out records exist between each region and each other. The different layers of this regional trade network are represented, corresponding to livestock, iron, currency, tea and rice, and silk.

Historically, technological barriers have been widespread in world trade from ancient times to the present day, due to the evolutionary continuity of civilizations in some countries (regions), the uniqueness of their natural resources and the sophistication of their technological production. Complex products were produced by a few countries (regions) and exported to other countries (regions) that did not possess the technology. This means that the higher degree countries in the higher nested levels are the ones with advanced technology.

Previous research has shown that trade networks for complex products are more concentrated and nested [6], so we use the nestedness of the network layers to quantify the complexity of the corresponding products. Livestock resources, consisting of cattle, sheep and horses, are low-complexity products and due to geo-spatial similarities, there are no strong production barriers and therefore almost all regions along the route can produce and export them. In this case, the structure of the trading network is largely determined by geographic location and no nested structures are expected to emerge. However, for products of high complexity, which must rely on civilizational fallout and long-distance trade, only national (regional) civilizations with advanced technology can produce and export to other countries (regions).

B. Trade type variation strategy

The multi-layered trade in the Silk Road corridor was extensive, with goods traded including silk, tea, sugar, silk, porcelain, paper, mother-of-pearl, camphor, cinnamon, copper, iron, alum, gold and silver, silk products, lacquer, vegetable oils, bamboo, rhubarb, etc. from the East to the West, and cotton, wool and products, Arabian horses, iron, lead and zinc, diamonds, statues, coral, amber, glass The grapes, grapes, pomegranates, walnuts, sesame seeds, cucumbers, garlic, carrots and figs, as well as horses, shark fins, pearls and rice.

To achieve data substantiation, this paper has prepared an index of technological achievement for trade in the study's ancient region with reference to the Technology Achievement Index (TAI), which is widely used by the United Nations Development Program to measure a country's technological innovation capacity [7]. To validate the nestedness as a measure of product complexity, we compared the average nestedness values for different types of products. Searchable Silk Road trade products (including technology) were classified into nine categories according to the Standard International Trade Classification (SITC), and the product distribution for each category was given.

We calculated the top country (region) trade categories in each category and it is clear that products in the highly nested trade network are exported from high technology countries (regions) to other countries (regions). In addition, high technical barriers in international trade will lead to high asymmetries in highly complex product networks. Furthermore, the highlight of the data analysis is the average asymmetry of products belonging to different industries, with highly nested fine processing and bulk goods being more asymmetric than less nested raw materials (e.g. livestock, minerals, animal and vegetable oils, fats and waxes). The above analysis suggests that the nestedness of the trading network is closely related to the complexity of the products traded.

IV. Underwater Pier Algorithm

A. Trade individual coding methods

The DE algorithm uses a real number encoding approach where the solution $x_1, x_2, \cdots, x_n$of the optimisation problem are directly formed into individuals $X_{i,G} = (x_1, x_2, \cdots, x_n), i = 1,2, \cdots, NP$. Each individual is a candidate solution in the solution space and the dimensionality of the variables D of the individual is equal to the dimensionality n of the decision variables of the objective function, i.e. $D = n$.

B. Trade behavior initialization

The initial population is generated by a random method as

$$x_j = x_j^L + rand \cdot (x_j^U - x_j^L) \quad j = 1,2,\cdots,D \tag{1}$$

where rand is a random number between [0,1]. The population size NP directly affects the convergence speed of the algorithm and is usually taken to be 3~10 times the dimensionality of the problem (the number of vector parameters)."

C. Variant operations in trade behavior

The main difference between the DE algorithm and other evolutionary algorithms is the mutation operation, which is also the main step in generating new individuals. The intermediate individual $V_{i,G+1}$ obtained after the mutation operation is denoted as

$$V_{i,G+1} = X_{r_1,G} + F \cdot (X_{r_2,G} - X_{r_3,G}) \tag{2}$$

$r_1, r_2, r_3 \in \{1,2,\cdots,NP\}$ and $r_1 \neq r_2 \neq r_3 \neq i$; $F \in [0,1]$ is the variance factor, which is the magnitude of the DE algorithm controlling the difference vector, also known as the scaling factor, usually F takes the value of 0.3~0.7, the initial value can be $F = 0.6$; $X_{r_1,G}$ is the base point vector.

Its inter-individuals are generated by adding the weighted difference vector between two individuals in the population to the base point vector, which is equivalent to adding a random deviation perturbation to the base point vector. Also, as all three individuals are randomly selected from the population, there are a variety of combinations between individuals, which gives the DE algorithm good population diversity. The large variation of the population early in evolution makes it more capable of exploration and less capable of exploitation in the early stages, while as the number of evolutionary generations increases, the variation of the population decreases, making it less capable of exploration and more capable of exploitation in the later stages, resulting in an adaptive program with very good global harvesting properties.

The variation factor F is the ratio of variance values added to the perturbed vector in the variation operation and serves to control the magnitude of the difference vector. Hence, it is also known as the scaling factor.

D. Cross-operations in trade practices

The variation factor F is the ratio of variance values added to the perturbed vector in the variation operation and serves to control the magnitude of the difference vector. Hence, it is also known as the scaling factor.

The crossover operation was performed by crossing the intermediate individual $V_{i,G+1} = (v_{1i,G+1}, v_{2i,G+1}, \cdots, v_{Di,G+1})$ obtained by mutation with the target individual $X_{i,G} = (x_{1i,G}, x_{2i,G}, \cdots, x_{Di,G})$, as shown in equation The candidate individuals $U_{i,G+1} = (u_{1i,G+1}, u_{2i,G+1}, \cdots, u_{Di,G+1})$。 of the target individual were obtained after hybridization.

$$u_{ji,G+1} = \begin{cases} v_{ji,G+1} & (randb(j) \leq CR) \ or \ j = rnbr(i) \\ x_{ji,G} & others \end{cases} \tag{3}$$

where $i = 1,2,\cdots,NP, j = 1,2,\cdots,D$; $rnbr(i)$ is a random integer in the range [1, D] used to ensure that candidate individuals $U_{i,G+1}$ are taken from $V_{i,G+1}$ in at least one dimensional variable; $randb(j) \in [0,1]$ is a uniformly distributed random number; the crossover factor $CR \in [0,1]$ is an important parameter of the DE algorithm , which determines the probability of the intermediate individual component value replacing the target individual component value. A larger CR value indicates a higher probability of the intermediate individual component value replacing the target individual component value and a faster individual update rate. The crossover factor CR is generally chosen in the range [0.3, 0.9], and the initial value of CR is usually 0.5.

E. Selection operations in trade behaviors

Candidate individuals $U_{i,G+1}$ are evaluated for fitness and then a decision is made whether to replace the current target individual with a candidate in the next generation according to equation .

$$X_{i,G+1} = \begin{cases} U_{i,G+1} & f(U_{i,G+1}) \leq f(X_{i,G}) \\ X_{i,G} & others \end{cases} \tag{4}$$

The fitness function is used to assess the relative magnitude of an individual's strengths and weaknesses relative to the group as a whole. There are two ways in which DE can select a fitness function.

F. Adaptability functions in trade behaviour.

1) The objective function of the optimisation problem to be solved is directly used as the fitness function. If the objective function is the maximum optimisation problem, the fitness function is chosen as

$$Fit(f(x)) = f(x) \tag{5}$$

If the objective function is a minimization problem, the fitness function is chosen as

$$Fit(f(x)) = \frac{1}{f(x)} \tag{6}$$

2) When the objective function of the problem is used as the individual fitness, the objective function must be converted to a form that seeks the maximum value and ensures that the objective function value is non-negative. The conversion can be carried out in the following way. If the objective function is a minimization problem, then

$$Fit(f(x)) = \begin{cases} C_{max} - f(x) & f(x) < C_{max} \\ 0 & others \end{cases} \tag{7}$$

where C_{max} is the maximum estimate of *f(x)*, which can be a suitable losing value, or the maximum value of *f(x)* in the process so far or the maximum value in the current population can be used, and of course C_{max} can be the maximum value of *f(x)* in the previous *K* generations. Clearly, there exist multiple ways to choose the coefficient C_{max} , but preferably independent of the population itself.

$$Fit(f(x)) = \begin{cases} f(x) - C_{min} & f(x) > C_{min} \\ 0 & others \end{cases} \quad (8)$$

Where C_{min} is the minimum estimate of $f(x)$, C_{min} can be a suitable infant value, or the minimum value of $f(x)$ in the current generation or *K* generations, or it can be a function of the population variance.

G. Overall update due to disruptions

Using the best adapted trade behavior as a benchmark, which will be the indicator to evaluate all trade behaviors when the variability due to historical turbulence can seriously interfere with the calculations. Then the absolute value of the best trade-point adaptation value obtained from this iteration to the previous best trade-point adaptation value needs to be introduced, and the ratio of the best trade-point adaptation to the current best trade-point adaptation, within the Δrange, then the population improvement does not reach the expected value, then Gaussian variation is performed.

$$\frac{|fit[x_{best}(t)] - fit[x_{best}(t-n)]|}{fit[x_{best}(t)]} \leq \Delta, t \geq 10 \quad (9)$$

$$x_{best}(t) = x_{best}(t) + Bn(0,1) \quad (10)$$

where β is the coefficient and $N(0,1)$ is the standard Gaussian variance random number.

V. Case and Evaluation

Link relationships commonly exist between samples in a dataset, and implicit target mining is an emerging area for research related to link relationships. Link prediction belongs to the category of link mining, and the task is to predict the possibility of link existence based on the existing data and related information. Link prediction models can currently be applied to social network relationship mining, personalized recommendation and other fields. On the Internet-based social network, the most basic element is social relationship, and the analysis of social link relationship using prediction models is an important direction of link prediction research.

For the study of link prediction problems, a matrix describing the similarity between nodes in a network is usually defined, and the probability of link existence is described by the similarity matrix, which can be obtained by analyzing and mining the known network data. Therefore, in this paper, the number of households, population, and number of victorious soldiers (military forces) from historical records of the 36 tribes of western regions (multi/single-ethnic inhabited regions) during the Han Dynasty are selected and categorized and recorded, where geopolitical constraints (number of bifurcations of transportation road network nodes) are added to form a link prediction dataset. The main task is to design a model for predicting the existence of links in unknown parts using the relationships between observable nodes. This link prediction model can be used for both static, single-objective data analysis and can be extended to dynamic multi-objective social computing to predict social development trajectories and ethnic integration symbiosis before and after longer time periods.

The problem to be solved in this paper is to deduce the possible implicit knowledge in the historical literature based on the known existence of link data and to achieve the validation of the phenomenon of underwater piers (sustainable development goals in key areas of social and economic growth). This is also used to predict subsequent social change trends. Data-based link prediction requires relying on the similarity matrix as data and outputting the probability of the existence of a link between any two nodes in the network through the process of model optimization solving. Therefore, constraints on the global structure and local characteristics of the similarity matrix are needed in the construction of the solution model to facilitate the estimation of the solution by the optimization algorithm. For the global structure constraint of the similarity matrix construction, the two more effective ones are low rank and sparse. Since all relationships have the characteristic of "things are clustered together", it can actually be transformed into the low-rank structure of the matrix, which can effectively predict the possibility of linking relationships. At the same time, adding sparsity constraints to the model can effectively reduce the influence of noisy data and missing values, making the similarity matrix more closely resemble the sparsity characteristics of large-scale data prediction.

A. Experiment Proceedings

1) 50 sets of regional population data from the retrievable dataset are extracted. Due to the collation of the Han Dynasty household registry, the number of minors and females was not recorded, and this data had a certain rate of deviation. Individual regions have local missing information, which needs to be filled in by applying weight parameters after the overall data analysis and traversal verification.

2) The number of households is compared with the number of population to extract the number of each household per capita; the number of population is compared with the number of recruitment to extract the proportion of recruitment; the number of households is compared with the number of recruitment to extract the proportion of each household's military contribution. (b) Due to the existence of a mixed ancient social state of basic animal husbandry, agro-pastoralism and nomadism, finer comparative parameters can be obtained in combination with geo-road network constraints.

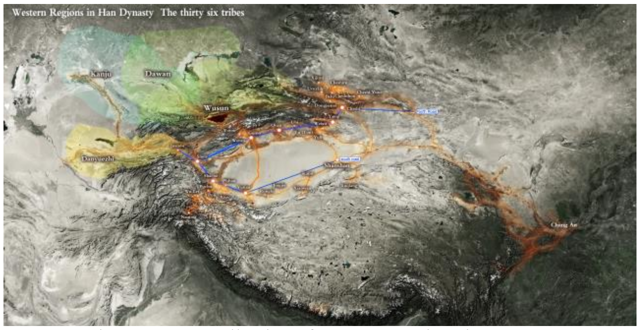

Figure 1. Data collection of Western Regions in Han Dynasty

B. Calculation Results

The results are shown in the following figures(Figure1 and Figure2).

Place name	Households	Population	Soldiers	Soldiers per household	Persons per household	Recruitment Ratio	Roads
Qiuzi	6970	81317	21076	3.02	11.67	0.26	6
Zihe	350	4000	1000	2.86	11.43	0.25	3
Yuli	130	1480	150	1.15	11.38	0.10	2
Ubi	110	1200	300	2.73	10.91	0.25	3
Puchu	100	1070	334	3.34	10.70	0.31	2
Yanqi	5000	52000	20000	4.00	10.40	0.38	3
Shanshan	1570	14100	2912	1.85	8.98	0.21	5
Cheshi Yutu	40	333	84	2.10	8.33	0.25	3
Yu (Ton)	1200	9600	2000	1.67	8.00	0.21	2
Puli	650	5000	2000	3.08	7.69	0.40	2
Yutou	300	2300	800	2.67	7.67	0.35	1
Gumo	3500	24500	4500	1.29	7.00	0.18	1
Shache	2339	16373	3049	1.30	7.00	0.19	1
Wu Lei	1000	7000	3000	3.00	7.00	0.43	3
Pishan	500	3500	500	1.00	7.00	0.14	1
Jingjie	480	3360	500	1.04	7.00	0.15	2
Dule	310	2170	300	0.97	7.00	0.14	5
Yama	230	1610	320	1.39	7.00	0.20	1
Xiaowan	150	1050	200	1.33	7.00	0.19	4
Ronglu	240	1610	300	1.25	6.71	0.19	2
Dejo	100	670	350	3.50	6.70	0.52	1
Cheshihou	154	960	260	1.69	6.23	0.27	3
Nantou	5000	31000	8000	1.60	6.20	0.26	1
Belu	227	1387	422	1.86	6.11	0.30	3
Zhongyi	3340	20040	3540	1.06	6.00	0.18	2
Yutian	3300	19300	3540	1.07	5.85	0.18	3
Xijimi	332	1926	738	2.22	5.80	0.38	1
Ucuzi	41	231	57	1.39	5.63	0.25	2
Urumqi	490	2733	740	1.51	5.58	0.27	2
Enai	125	670	350	2.80	5.36	0.52	2
Wusun	120000	630000	188800	1.57	5.25	0.30	4
Kanju	120000	600000	120000	1.00	5.00	0.20	4
Dawan	60000	300000	60000	1.00	5.00	0.20	4
Danyuezhi	100000	400000	100000	1.00	4.00	0.25	2
Xiye	2500	10000	3000	1.20	4.00	0.30	4
Ruqiang	450	1750	500	1.11	3.89	0.29	2
Wensu	2200	8400	1500	0.68	3.82	0.18	2
Cheshi	4000	15000	3000	0.75	3.75	0.20	3
Kumi	2173	7251	1760	0.81	3.34	0.24	2
Yizhi	1000	3000	1000	1.00	3.00	0.33	2
Weixu	380	1100	500	1.32	2.89	0.45	3
Juandu	380	1100	500	1.32	2.89	0.45	4
Huizhong	358	1030	480	1.34	2.88	0.47	1
Cheshire	1500	4000	2000	1.33	2.67	0.50	4
Yuming	32000	83000	30000	0.94	2.59	0.36	4
Puchuan	800	2000	700	0.88	2.50	0.35	2
Belu	462	1137	350	0.76	2.46	0.31	3
Dongjamei	3000	5000	2000	0.67	1.67	0.40	1
Shule	21000	83000	30000	1.43	3.95	0.36	4

Cities with more than 50000 people
A city with 10000 to 50000 people
A city o rTribes with 5000 to 10000 people
Tribes with less than 1000 peopl

Figure 2. Calculation of household, population, soldiers and related data of Western Regions in Han Dynasty

C. Analysis

Areas with more than 50,000 inhabitants, governance structures, trade structures and military organizational capabilities have formed urban forms, and the evolution of social structures resulting in economic pluralism, ethnic integration, and cultural mutual-reference already have a large room for growth. But at the same time, due to the limited geographical supply, the increase in population exacerbates the trend of social instability and hidden dangers. In order to obtain sufficient revenue, most of them adopted the expansion of nearby nomadic areas and the extraction of taxes from the trade road network, and transformed the benefits into a cycle of promoting trade and strengthening military equipment. In this way, the geo-geopolitical advantages of the region were secured for a short period of time (around a century).

Urban prototypes of 10,000-50,000 inhabited areas, most of which are in a stable area in terms of recruitment ratio, severely limited by economic and production supply capacity, unable to rely on their own population base to accomplish their development goals, and due to similar production methods, the high density of conflicts among them, frequent affiliation and division of ethnic groups, cannot constitute a driving force to promote positive regional development.

The number of households and the proportion of recruits are extremely high in the 0.5-10,000 inhabitants area. As this type of area mostly exists in nomadic form, it can only find living space between larger groups and cities, and production materials such as salt and iron cannot be supplied outside the trading network, so it is mostly parasitic in the form of attachments.

There are a large number of nomadic tribes, with low populations, mixed military and civilian, dependent on the above-mentioned areas for supply, while also maintaining sufficient spatial distance to avoid annihilation and annexation, have little chance of independent development and growth.

In summary, in the road network of western regions, as a bridge for two-way interaction between the east and west, the core city (node) completed the construction of the underwater piers with the intention of objective economic adsorption capacity and military security capacity to provide for the survival of the road. However, when the development goals of the node there exceed its own supply capacity, governance capacity, manpower security and military late capacity, a large number of human and financial resources were consumed in a disorderly manner, triggering the intensification of conflicts and contradictions around the region, leading to serious instability in the region, objectively causing a sharp decline in the support capacity of the node's underwater piers stable bridge, eventually leading to the collapse of the bridge (economic road network).

D. Evaluation

The algorithm in this paper can ensure computational scalability in large-scale network data link prediction problems by the partitioning method of matrix chunking solution. The experimental results on several real network data sets illustrate that the link prediction algorithm based on low-rank structure and local feature constraint matrix estimation in this paper can achieve better results than the benchmark algorithm, has robustness and effectiveness, and has strong scalability for complex network structure data with high noise. With the increase in data size, the link prediction optimization problem model with local structural constraints and local feature constraints can be solved by using the iterative optimization method proposed in the framework of the extended Lagrange multiplier method. Based on the ideas in this paper, designing link prediction models for multi-source fusion problems is the next research goal.

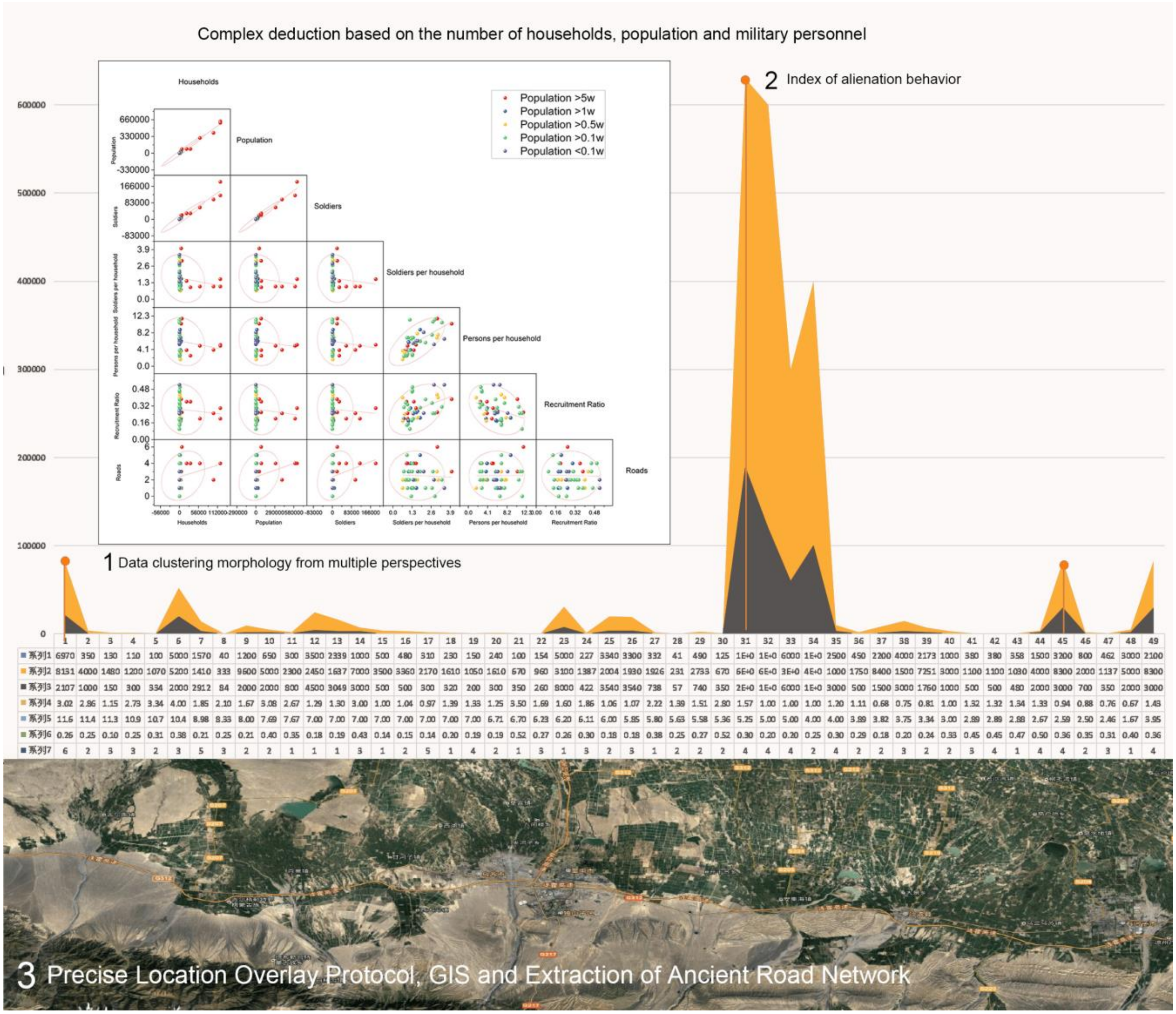

Figure 3. Complex deduction based on the number of households, population and military personnel

VI. Conclusion

Economic networks of trade derived from data mining, organization and analysis, containing theories with appropriate descriptions of economic agents and their interactions, allow for a systematic understanding of the full domain effect from the perspective of a single network, and while these works provide indicators that can quantify economic complexity through information on network structure, a single network oversimplifies the international trading system. As an improvement, we constructed a multi-layer network in which the trading relationships for each product are represented in the corresponding layers, such as the time series layer, the geo-structure layer, the trading road network layer, and the population data layer. We constructed a multi-layered Silk Road trade network [8] using the set of transactional trade data categories (including import and export relationships). We observe that each layer of the multilayered world trade network immediately reveals nested structures within each layer and is tied to the self-propagation of trade nodes, allowing us to measure the complexity of inter-country (regional) behaviour.

It is found that the civilisation-nesting structure in the network layers seems to be related to asymmetric trading relationships due to trade barriers, the evolution of product complexity is studied through the degree of nesting and the product types with the highest degree of nesting are selected at different levels, in addition, we show that the competitiveness of a country (region) can also be measured according to the degree of nesting of its export products. In this paper, we compare civilization-trade competitiveness and discuss a review to explore the evolution of economic trade networks during the Han and Tang dynasties [9] and to summarize the symbiotic relationship between the total nestedness index and economic growth.

The underwater piers algorithm can then compensate for the civilizational nestedness and economic complexity of the trade demands of nodal regions in a multi-layered world trade network and enrich numerous extensions. As our description of the algorithm shows, calculations for nodes can reveal their self-propagation and optimization, variation, crossover, and convergence, can characterize product complexity, and can provide analytical inference empowerment for other economic systems in observation and modelling. How to design better metrics to more accurately dissect historical trajectories that have disappeared and, in the present, the many emerging barriers to trade due to political conflicts or epidemics, algorithmic interventions can provide a way to think about the structural characteristics of trade data.

The underwater piers algorithm focuses on the study of feedback strategies for trade, production and circulation behavior, and there is a need for continued evolution in the fine-grained and reusable nature of the study, for example, traffic forecasting can be used for business behavior that lacks geo-road network information and new and scarce types of trade products, with cyclic iterations until convergence or the maximum set number of cycles of the model is reached, with iterative calculations of travel costs introduced in the cycle calculation process The iterative calculation of travel costs is introduced in the loop calculation. At this stage the algorithm is facing the long time, multi-objective dynamic path planning research although in the organization of data samples and phenomenological deduction of significant results, but in the increasingly complex data class, the amount of data urgently needs to surge, the challenge of more fine-grained target partition, directly applied to the global comprehensive traffic model analysis, the running time will be unacceptable, in the rapid response to the problem is particularly prominent, for this reason it is necessary to the algorithm model structure Further optimization of the algorithm model structure is necessary to seek higher model efficiency.

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