Design and Implementation of a Geographic Scenario Computation System Based on Knowledge Base

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Keywords: Geographic Scenarios, GIS, Geocomputation System

Abstract

The promotion and expansion of Geographic Information System (GIS) applications have increased the complexity of geocomputation. The concept of a geographic scene, which encompasses both geographic entities and complex spatial interaction relationships, serves as a means of organizing and expressing geographic information. Existing methods of organizing and computing geographic scenes often focus on single geometric elements or single-category objects, neglecting the complexity of the geocomputation process and leading to biased results. To address this issue, this study designs and implements a geographic scenario computation system based on WebGIS to overcome the lack of integration of knowledge elements in traditional geographic scenario computation methods. The system consists of a data management module, a geographic scenario visualization module, and a geographic scenario computation module. It not only realizes the visualization of geographic scenarios but also introduces a knowledge base into the geographic scenario computation process, enabling accurate management of geographic scenarios. This paper uses a farmland scenario in Shandong Province, China, as a case study to verify the effectiveness and feasibility of the system. The application of this system provides new technical support for the computation process of geographic scenarios, promoting the refinement and intelligent development of geographic scenario management. This method can also be applied to similar applications of intelligent sensors and the Internet of Things in the organization and management of sensing information in the future.

1. Introduction

In the context of the big data era, the theory and technology of Geographic Information Systems (GIS) have developed rapidly. Research and analysis have gradually shifted from abstracting and analysing based on the real world to digital abstraction and analysis based on data and models. A medium is needed to integrate and express geographic phenomena and geographic laws. The geographic scene, which provides a novel solution through the integrated expression of the six elements of geographic information using a unified data model of geometric algebra, meets this need. A geographic scene refers to the objectively existing natural or human landscape in the real world, including terrain, urban space, and more. It is a comprehensive regional entity with specific structures and functions formed by the interaction of various natural and human elements within a certain spatiotemporal range(Lü et al., 2018b). Geographic scenes can simulate the evolution of geographic events, express geographic laws, and facilitate geographic knowledge discovery(Lü et al., 2018a). With the development of cartography, the concept of geographic scenes has been applied in many fields, such as emergency mapping (Liu et al., 2022)and digital scene description(Du et al., 2019), achieving remarkable results. To achieve precise management of geographic scenes, it is necessary to organize and compute the elements within the scenes. Therefore, conducting research on geographic scene computation is essential. To realize geographic scene computation and simplify the cognitive process of geographic scenes, an increasing number of scholars are studying geographic scene computation techniques, aiming to transform the computation process of geographic scenes into a more user-friendly form, rather than just textual descriptions or formulas. Through geographic scene computation, precise management of the elements within the scenes can be achieved.

Although there are currently various methods for geographic scene computation, existing methods often focus on single geometric elements or single-category objects as research subjects. This approach overlooks the complexity of the geocomputation process, leading to biased results. Additionally, these methods generally have limited interactivity, are difficult for users to operate, and do not demonstrate the geocomputation process. To address these issues, this study designs and implements a WebGIS-based geographic scene computation system to compensate for the lack of integration of knowledge elements in traditional geographic scene computation methods. This system comprises a data management module, a geographic scene visualization module, and a geographic scene computation module. It not only realizes the visualization of geographic scenes but also incorporates a knowledge base into the geocomputation process, enabling precise management of geographic scenes.

The main contributions of this paper are as follows: (1) A geographic scene visualization system based on WebGIS technology was developed, which enables the creation of geographic scenes and visualization of interaction processes among internal elements. It also allows users to add or delete elements within the scenes according to actual needs, achieving the purpose of multi-element management and visualization within geographic scenes. (2) A knowledge base was integrated into the geographic scene computing system, and the calculation processes of entities within the scenes were demonstrated through a computational model. The feasibility and superiority of the system were validated using the high-standard farmland in Shandong Province, China as a case study.

2. Related Work

To gain a deeper understanding of geographic scenes and the elements within these scenes, many scholars have conducted research on geographic scene computation. These studies primarily focus on the representation methods of geographic scenes and the computation methods of elements within the scenes. The aim is to achieve the computation and visualization of geographic scenes through more efficient expression frameworks. Huang (Huang, 2021) addressed the difficulty of traditional "attribute-location-set" based expression methods in depicting the hierarchical structure and relationships of geographic scene elements. He proposed a unified expression framework for geographic scene features centered on "state-relation-process," which overcomes the limitations of traditional methods in depicting the evolutionary process of multiple elements. Pu (Pu, 2020) proposed a geographic data reconstruction method tailored to geographic scenes, constructing a multi-level nested structure for geographic scenes and reconstructing diverse geographic data structures and relationships. This provided a new solution and led to the development of a geographic scene visualization system based on the Neo4j database. Cao (Cao et al., 2018) and colleagues proposed a process-centric ontology model to visualize the geographic environment from three perspectives: geographic scenes, geographic processes, and geographic elements. This model also visualized the connections between geographic entities and geographic processes through a graphical model. Additionally, some scholars have studied how to achieve the visualization of geographic scenes through symbolic expressions. Wu (Wu, 2022) introduced the concept of multi-granularity into the creation and application of geographic scene symbols, designing a multi-granularity expression method for geographic scene symbols. This method resulted in a collection of symbols with multi-granularity spatial versions, temporal versions, and semantic levels, making the full process framework of symbolic expression more comprehensive and flexible. With the development of three-dimensional technology, an increasing number of scholars have achieved the visualization of geographic scenes through 3D technology. Zou and others(Zou et al., 2017) proposed a method for calculating large-area true 3D geographic scenes using spherical great circle arc octree subdivision tiles, taking into account the curvature of the Earth and overcoming projection distortion issues. Liu(Liu et al., 2015) and others designed and implemented a 3D geographic scene display system for mobile devices based on OpenSceneGraph, using an edge collapse model to calculate 3D models of scene objects with varying levels of detail, thereby reducing hardware resource usage.

Overall, despite the significant progress made by the aforementioned studies in the computation and visualization of various elements within geographic scenes, accurately conveying information within scenes and achieving computations based on scene elements, some limitations still exist. Notably, these limitations pertain to the interactivity of scene elements and user operability. The current computational methods do not fully demonstrate the computational processes between elements within the scenes, thereby limiting users' ability to interact with scene elements. This limitation may hinder users' in-depth understanding of the complex relationships and functionalities within the scenes.

With the development of WebGIS technology, an increasing number of scholars have begun to achieve the computation and visualization of geographic scenes through WebGIS. This method has the advantage of quickly building an interactive system with rich resources for scene computation and visualization. Pessina (Vera Pessina and Fabrizio Meroni, 2009) developed a WebGIS-based tool for earthquake risk scenarios and risk analysis, enabling users to perform risk assessments based on different earthquake scenarios. This includes calculating earthquake hazard assessments, predicting damage to buildings and infrastructure, and assessing potential economic losses. Li (Li et al., 2020) constructed an LOD (Level of Detail) storage structure for point cloud tiles based on an octree and, combined with the Cesium JS 3D rendering engine, implemented the loading of 3D point cloud data on the web, achieving an integrated display of geographic scenes. Miao (Miao et al., 2017) used WebGL technology to display 3D scenes in the browser and employed a method to preload geographic scene data that users might be interested in by calculating user trajectories, thereby improving the smoothness of visualization. Some scholars have also achieved the dynamic process computation of elements within scenes through WebGIS. For example, He (He et al., 2021) and colleagues established a spatio-temporal dynamic expression model that emphasizes geographic process events and developed a visualization method for typhoon dynamics by integrating Cypher and the Neo4j database.

However, despite existing studies achieving the computation and visualization of geographic scenes through WebGIS technology, these studies often focus only on the computation of single elements without integrating computations with other elements within the scene. In the real world, geographic entities exhibit diverse interactions, and relying solely on the computation of single elements is insufficient for managing geographic scenes. Additionally, the comprehensive computation of different types of elements within scenes has not yet been realized. Therefore, to better achieve the computation of geographic scenes, these issues need to be studied in greater depth.

3. Design of System and Functional Modules

3.1 Design of System Architecture

The system utilizes a three-tier architecture aligned with industry standards, as shown in figure 1, this system comprising the presentation layer, support layer, and data layer. In this setup, the data layer pre-processes map and SHP data, subsequently storing it in PostgreSQL. On the support layer, the Spring Boot framework serves as the foundation for data processing conducted via Python, with the processed data then relayed to the presentation layer. This final layer is where the system's outputs are showcased, offering users an intuitive visualization of geographic scenes. It leverages front-end visualization technologies such as React, Leaflet, and Ant Design to facilitate this visual presentation.

3.2 Design of Functional Module

To enhance the visualization of geographic scenes and the computational processes of their internal entities, and in line with the system's overarching design outlined in Section 3, four specialized functional modules were developed. These modules are the knowledge expression module, computational model module, geographic scene module, and interaction process visualization module. The integration of these modules

https://doi.org/10.5194/isprs-archives-XLVIII-4-2024-177-2024 | © Author(s) 2024. CC BY 4.0 License.

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To better achieve the visualization of geographic scenes and the computational processes of their internal entities, and in line with the overall design of the system outlined in Section 3, four specialized functional modules were developed. These modules are the knowledge expression module, computational model module, geographic scene module, and interaction process visualization module. Through the integration of these four modules, the visualization of geographic scenes and their computational processes has been realized.

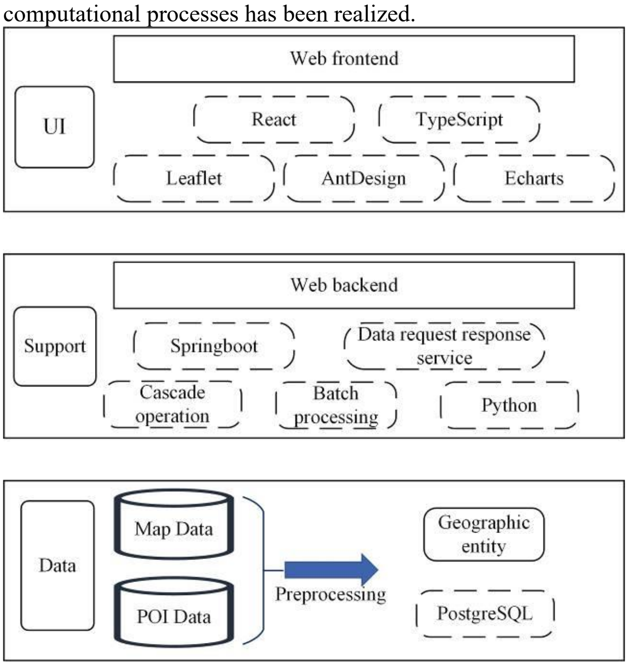

Figure 1. Design of System Architecture.

3.2.1 Geographic Scene Module: The geographic scene module primarily serves to facilitate the creation and deletion of geographic scenes. Through this module, can visually inspect the current geographic scenes within the system and their initiation and conclusion periods, aiding in the swift and precise management of geographic scenes.

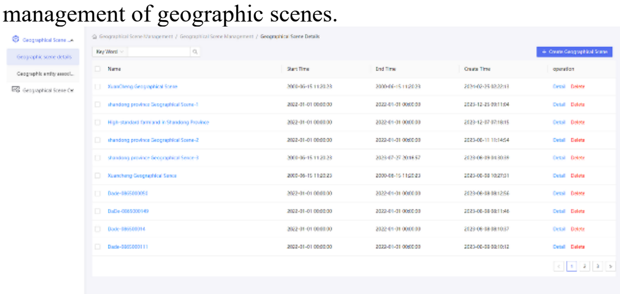

Figure 2. Geographic Scene Module.

3.2.2 Knowledge Expression Module: In the geographic realm, knowledge expression denotes the objective portrayal of an object's attributes and its latent capabilities within a scene. This expression can synergize with other objects and knowledge to accomplish specific functionalities. The formalized expression of knowledge may encompass empirical knowledge and systematic scientific theories. The knowledge expression module can be utilized for the management and storage of knowledge. Users have the capability to upload or delete knowledge repositories. As illustrated, clicking the button facilitates the uploading of knowledge repositories stored in CSV format. Clicking the delete button allows for the removal of the repository. Clicking on the name of the repository enables the viewing of detailed information.

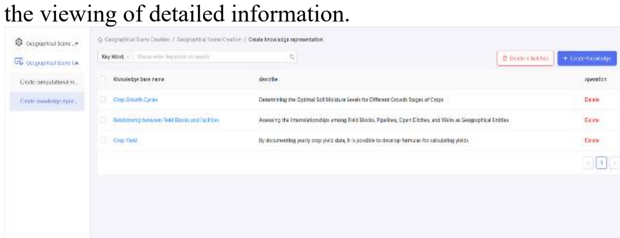

Figure 3. Knowledge Expression Module.

Geographic scene often encompass a plethora of diverse knowledge, each with its own unique expressions and interpretations. Therefore, in order to achieve a more refined visualization of knowledge within scenes, this paper broadly categorizes knowledge into relational and regulatory types. The relational type pertains to the intricate interconnections among entities within geographic landscapes, represented in this system through graph modelling. Here, nodes symbolize entities within scenes, while edges represent the relationships between these entities.

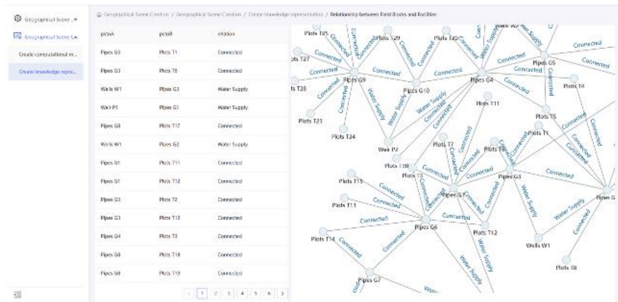

Figure 4. Relational Knowledge Database.

Regulatory classes refer to certain immutable attributes within a scenario, such as the height or volume of an object, or demographic details like population numbers and population density per area. To intuitively convey this information, the system employs a two-dimensional table to display a knowledge base of these regulatory elements.

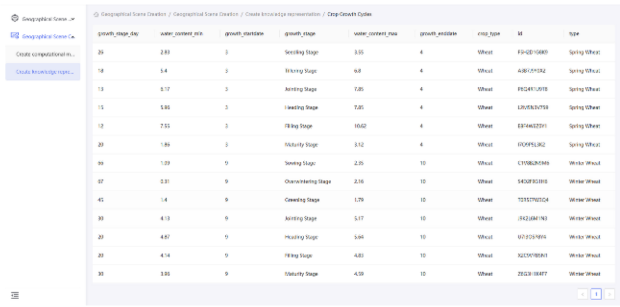

Figure 5. Rule-Based Knowledge Database.

3.2.3 Computational Model Module: Furthermore, to visualize the interaction processes among entities within the scenario, it's essential to devise a model that mirrors the interaction processes in the real world. Consequently, this study has designed computational models based on real-world scenarios and developed a module for managing and viewing these models. By clicking on the model name, one can access detailed information about the model, including its type, function, and required parameters, thereby facilitating a deeper understanding for the user.

Figure 6. Computational Model Module.

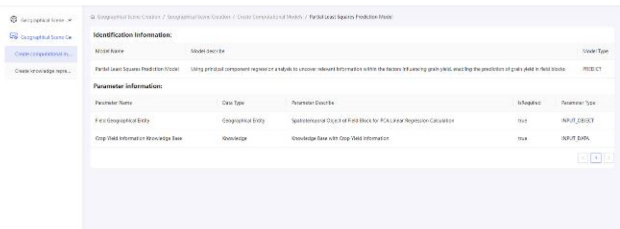

Figure 7. Detail Page of Computational Model.

3.2.4 Geographic Scene Computation Visualization Module: The geographic scene computation process visualization module is primarily used to achieve complete visualization of the computation process and to display the geographic entities, knowledge expressions, and computation models within the scene. Users can create geographic scenes in the system and add or remove entities, knowledge, and models within the scenes. As shown in the diagram, the left side of the page displays the knowledge and models within the scene. Users can add or remove various elements such as geographic entities, knowledge expressions, or computation models by clicking buttons. The right side of the page shows the actual boundaries of the entities, allowing users to intuitively understand the geographic entities within the scene. This module also visualizes the element computation process, reflecting the changes within the scene.

Figure 8. Detail Page of Computational Model.

4. Application of the System

4.1 Data Introduction

This research focuses on a high-standard agricultural field located in Shandong Province, highlighting its significance in boosting overall agricultural productivity and securing food safety. The development of such advanced agricultural infrastructures meets crucial national strategies and immediate needs. The field in question is equipped with numerous facilities, including plots, wells, water pumps, and pipelines, all interconnected in a complex network that necessitates extensive daily interactions, making manual management impractical. This paper examines the feasibility and benefits of employing this field as a case study, introducing the various entities, knowledge, and models involved.

4.1.1 Geographical Entities: Initial field surveys were conducted to identify and categorize the geographical features within the study area, resulting in a total of 44 entities across four main categories: plots, pipelines, wells, and weirs. This includes 30 plot entities, 10 pipeline entities, 2 well entities, and 2 weir entities, thus encompassing the entire geographical landscape of the area. Data collected encompasses basic information such as the area and boundary coordinates of these entities. Moreover, each category of entity possesses unique characteristics; for example, plot entities detail the type of crops grown, their growth cycles, and water content, whereas weir entities specify the water storage and maximum capacity of reservoirs.

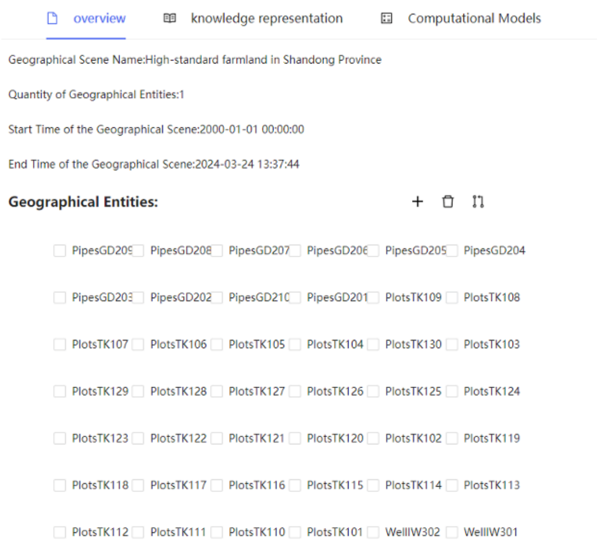

Figure 9. Geographic Entities in the High-Standard Farmlands of Shandong Province.

4.1.2 Knowledge: To enhance management within this region, extensive field research and needs analysis led to the development of two forms of knowledge representation: a relational database detailing the relationships between facilities, and a rule-based knowledge base outlining crop growth cycles and yields. The facility relationship database captures the interconnections among all geographical entities in the scenario, illustrating, for example, the linkages between specific pipelines and plots or between wells and weirs. The crop growth and yield database details the water demands of various crops at different stages, enabling an understanding of the optimal moisture content for crops in the fields at various times and offering data support for future irrigation and drainage strategies.

growth_stage_day	water_content_min	growth_startdate	growth_stage	water_content_max	growth_enddate	crop_type	id	type
26	2.83	3	Seedling Stage	3.55	4	Wheat	F5H2D1G8K9	Spring Wheat
18	5.4	3	Tillering Stage	6.8	4	Wheat	A3B7J9Y0X2	Spring Wheat
13	6.17	3	Jointing Stage	7.85	4	Wheat	P6Q4R1U9T8	Spring Wheat
15	5.96	3	Heading Stage	7.85	4	Wheat	L2M5N3V7S9	Spring Wheat
12	7.55	3	Filling Stage	10.62	4	Wheat	E8F4W6Z0Y1	Spring Wheat
20	1.86	3	Maturity Stage	3.12	4	Wheat	I7O9P5L3K2	Spring Wheat
66	1.09	9	Sowing Stage	2.35	10	Wheat	C1V8B2N9M6	Winter Wheat
67	0.31	9	Overwintering Stage	2.16	10	Wheat	S4D2F9G1H6	Winter Wheat
45	1.4	9	Greening Stage	1.79	10	Wheat	T0R5E7W3Q4	Winter Wheat
30	4.13	9	Jointing Stage	5.17	10	Wheat	J9K2L6M1N3	Winter Wheat
20	4.87	9	Heading Stage	5.64	10	Wheat	U7I3O5P8Y4	Winter Wheat
20	4.14	9	Filling Stage	4.83	10	Wheat	X2C9V7B5N1	Winter Wheat
30	3.96	9	Maturity Stage	4.59	10	Wheat	Z6G3H1K4F7	Winter Wheat

pstoA	pstoB	relation
Pipes G3	Plots T1	Connected
Pipes G3	Plots T6	Connected
Wells W1	Pipes G3	Water Supply
Weir P1	Pipes G1	Water Supply
Pipes G8	Plots T17	Connected
Wells W1	Pipes G2	Water Supply
Pipes G1	Plots T11	Connected
Pipes G1	Plots T12	Connected
Pipes G3	Plots T2	Connected
Pipes G3	Plots T12	Connected
Pipes G4	Plots T3	Connected
Pipes G8	Plots T18	Connected
Pipes G8	Plots T19	Connected

Figure 10. Knowledge Base of High-Standard Farmland in Shandong Province.

4.1.3 Model: To integrate data and knowledge within the scene and achieve the computation of geographic scenes, this paper designs several computational models based on real-world needs and on-site conditions. These models enable the linking of entities and knowledge as well as the modification of the current attributes of geographic entities. Taking the integrated irrigation model as an example, this model uses geographic entities and knowledge as inputs, calculates the optimal irrigation and drainage route from pond-dam to pipeline to field plot through the relational knowledge base, and determines whether to irrigate and the amount of irrigation based on the crop growth cycle knowledge base, thus realizing intelligent irrigation and drainage decision-making. The diagram below shows the parameters required for the irrigation integration model needed for the irrigation and drainage process.

Figure 11. Parameters Needed for the Integrated Irrigation Model.

4.2 Visualization of the Irrigation Process

To verify the functionality of the system for visualizing the computation process of geographic scenes, this paper takes the irrigation process of field plots as an example. During the crop growth stages, to maximize yield, it is essential to ensure that the soil moisture content in the field plots remains within an optimal range. Given the presence of numerous irrigation and drainage facilities such as wells, pipelines, and ponds in the scene, making the best irrigation and drainage decisions manually is challenging. Therefore, this paper uses the irrigation and drainage process in the geographic scene of high-standard farmland in Shandong Province as an example to achieve the visualization of the computation process.

Through the irrigation model, irrigation decisions for field plots were achieved. Taking plot TK106 as an example, the soil moisture content before irrigation was 0.85, indicating a water-deficient state, thus necessitating irrigation. The operational process in the system is illustrated in the following diagram. First, based on the requirements of the computational model, geographic entities and knowledge bases are input. Upon confirming the input, the model automatically formulates and executes the optimal irrigation and drainage decisions. This ensures the crops have the most suitable growing environment while reducing the time and financial costs of the irrigation and drainage process. The visualization of the geographic scene computation process demonstrates the feasibility and superiority of the method.

In this specific case, visual analytics reveal that field TK106 suffers from inadequate moisture levels, leading to the decision to irrigate. The model, drawing on the relationship knowledge base of geographical entities and the attributes of decision-involved entities, autonomously determines the most effective watering route. Leveraging the crop attribute knowledge base, it calculates the precise volume of water needed. The decision is then executed automatically, ensuring the field's moisture content is adjusted to an ideal level.

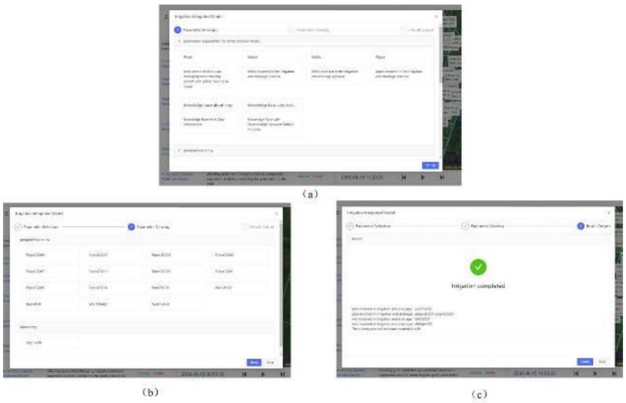

Figure 12. Irrigation Processes and Outcomes within the System.

5. Discussion and Conclusions

The geographic scene computation visualization system developed in this paper addresses the shortcomings of existing visualization systems: Firstly, traditional geographic scene visualization systems mostly focus on the computation of single elements within a scene without considering their overall integration, and they do not achieve the interactive visualization of computation processes within the scene. The geographic scene computation process visualization system developed in this paper not only realizes the comprehensive display of different types of elements within a scene but also links the knowledge and entities within the scene through computational models. This makes the elements within the scene dynamic, allowing different entities to interact with each other, which better reflects real-world scenarios and enhances the visualization effect. Additionally, the computational models update and modify the status of entities within the scene, and by integrating knowledge bases, the accuracy of the model output is increased, ensuring that each adjustment optimizes the state of the objects. This system also effectively improves response speed while enhancing the intelligent management of geographic scenes. The system uses a front-end and back-end separation architecture, improving maintainability. The back-end adopts the mainstream Spring Boot framework combined with PostgreSQL as the knowledge base storage solution, dividing each knowledge base into main and sub-tables for storage and adding indexes to optimize query performance. The system also integrates Python algorithms to achieve efficient response speed. The front-end is based on React and TypeScript, and uses Leaflet components to visualize geographic entities, ensuring system efficiency and maintainability while providing good browser compatibility.

This paper proposes a knowledge base-based geographic scene computation visualization system to address the limitations of existing computation systems, which often overlook interactions between entities and cannot comprehensively describe the geocomputation process. This system provides users with the ability to create and edit geographic scenes and enables the computation of entities within the scene. Users can also update entity attributes through computation models, achieving intuitive visualization of the computation process and intelligent decision-making. The results show that this system can intuitively display the computation processes of entities within the scene, helping users gain a deeper understanding of geographic scenes and enabling a certain level of intelligent scene management. Although this paper uses a high-standard farmland area in Shandong Province as a case study, the complexity and high-frequency interactions of this scene demonstrate the system's broad application potential.

Acknowledgements

This research was supported by grants from the National Key Research and Development Program of China (Grant #2021YFB3900902)

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