Chapter 9
Classification and Description of Geographic Information: A Comprehensive Expression Framework

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Abstract Geography is a comprehensive discipline that studies spatial–temporal patterns, evolution processes, and interaction mechanisms of geographic objects and phenomena. With the evolution of the world from a binary space to a ternary space, it is urgent to deepen and expand the understanding, expression, and mining of geographic information. Most current GIS models use the geometry + combination to express geographic information. Geographic processes, including interplay among features, cannot be directly modeled under the above notion. Geography analyzes spatial and temporal structure of macroscopic patterns as a whole and studies evolutionary processes from the perspective of comprehensive integration, and reveals system structures from the perspective of the integrated role of

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multiple elements. Based on the concept of ternary space, we identify seven dimensions of geographic information elements, which include semantics, spatial location, geometric structure, attribute, interrelationship, evolution process, and interplay mechanism. We also discussed how such representation framework can be employed under a geometric algebra approach to represent geographic scenes and to achieve a unified representation of the seven dimensions.

Keywords Geographic information · Ternary space · Elements of information · Dimensions of geographical description · Geographic information classification

9.1 Introduction

With the rapid development of ICT (Information, Communication and Technology), such as cloud computing, internet of things, virtual reality and other technologies, great progress and improvement have been made on the acquisition, analysis, and display of geographic information. Geographic information has become interlink, dynamic and ubiquitous. With the continuous increase of the heterogeneity of geographical information, the traditional geographic information description schema is prone problems, such as incomplete attribute, inaccurate semantics, and unclear evolutionary processes. How to build a comprehensive description framework of geographic information for the era of ICT is a frontier scientific problem.

Geographical information contains a variety of physical, human, social, and many other aspects. Geographic information can capture comprehensive properties of earth processes and phenomena that are multidimensional, and dynamic. In recent years, the description of geographic space has changed from a binary space (physical, and social-human world) to a ternary world (physical, social-human, and information world). In this context, geographic information description should include the interpretation of time, place, process, law, mechanism, and other elements. Therefore, we suggest a description framework that integrally expresses the seven dimensions: semantics, spatial location, geometric structure, attribute, interrelationship, evolution process, and interplay mechanism (Lü et al., 2017).

9.2 The Connotation of Geographic Information

9.2.1 Overall Framework

Based on the concept of a ternary world, we aim to develop an abstract mapping mechanism of the ternary world of physical, human, and information to the computer from the perspective of geography. In this chapter, a geographic information classification system is analyzed systematically, and a framework consisting of seven-dimensional descriptors of geographic information is given (Fig. 9.1). The physical,

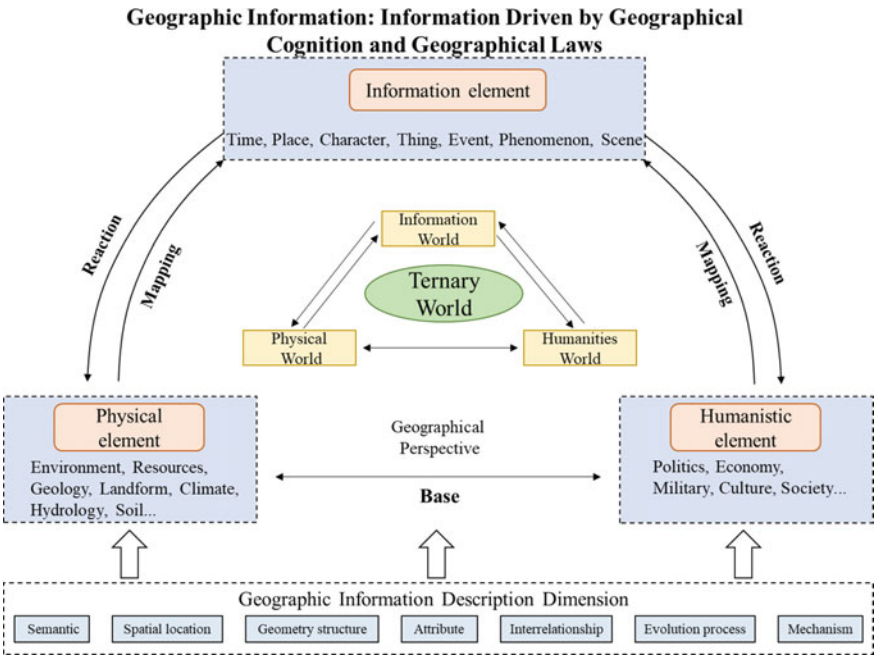

Fig. 9.1 Geographic information description framework

human, and information worlds are composed of various geographical elements. These geographical elements, which are the key concepts and expression units of geography, are interconnected and can be transformed as geographic information. The comprehensive expression of geographic information can then be organized with a unified and complete expression model. This unified expression model, as an organization of information, can provide a theoretical foundation that enables geographic information to incorporate complex geographic objects and geographic processes into geographic information systems.

9.2.2 Information Elements for Ternary Space

The traditional binary space is suited for the physical world which only perceived to be consisting of two parts: physical and human. However, with the rapid development of ICT, the word has evolved into a new generation that covers the physical world, the human world, and the information worlds (Zhou, 2015). The physical world refers to the physical environment in which humans live and the material systems contained therein; the human world refers to the sum of human behavior and social activities; and the information world is a virtual world built on the physical space and social space where the physical and human geographic information transformed from the

real world is captured, stored, managed, expressed, and analyzed in the form of a digital twin.

Based on the perspective of a ternary world, geographic elements can be divided into physical elements, humanistic elements, and information elements. Physical elements include geology, landforms, weather and climate, hydrology, soil, biology, and other elements. Human elements include political, economic, military, cultural, social, and historical elements. Information elements include time, place, character, object, event, phenomenon, scene. The information world can carry and map the physical world and the human world. Meanwhile, it can further influence and even reconstruct the physical and human worlds employing multi-situation simulation and digital twins (Guo & Ying, 2017). In this context, information organization in geographic space needs a comprehensive description of physical, human, and information in the ternary world. The physical elements are the foundation of human elements, and the information elements are further abstractions of the physical and human elements.

All physical, human, and information elements complement each other and can be expressed by information elements. The development of GIS has accelerated the mutual integration of physical, human, and information worlds. The introduction of ternary space has expanded the representation dimensions of geographic information to capture the ternary elements of the world (Guo et al., 2018). The abstraction and description of the physical and human worlds from the perspective of information elements can be summarized into seven elements, namely time, place, character, object, event, phenomenon, and scene. The seven elements of information are the top-level abstraction of the ternary world, and each element can be further divided.

9.2.3 Seven Dimensions for Geographical Information Description

Geography is a science that studies spatial patterns, temporal evolutions of the human living environment, and the interaction between humans and their environment in Earth surface systems (Chen et al., 2019). Geographical information is fundamentally different from other information, with characteristics that are often regional, multidimensional, and changing over time and space. Traditionally, geographic information description follows the schema of "location + geometry + attribute" using discrete geometric objects such as points, lines, polygons, and volumes to approximate the complex real geographic world. This schema shows weakness in organizing complex and continuous geographic objects and in modeling geographic processes.

Recently, the concept of geographic scene has been applied to the expression of geographic information. A geographic scene is a specific synthetic region comprising physical, human, and information factors and their mutual relationships and interactions. A geographic scene has a specific structure and functions and is characterized by comprehensiveness. In our previous research, we proposed a representation model

consisting of six elements of geographic scene (Lü et al., 2018): semantics, location, the shapes and attributes of geographic elements, the relationships among elements, and evolutionary processes. The ternary space model can be adopted to extend the concept of geographic scenes by refining the dimensions of shape and relationship as geometric structure and interrelationship, and by adding interaction mechanism as an additional dimension. These seven dimensions, namely semantics, spatial location, geometric structure, attributes, interrelationships, evolution processes, and interplay mechanisms, will be discussed as follows.

9.2.3.1 Semantics

Semantics refers to the geographic characteristics of information elements in geographic scenes that have been processed and recognized by humans. It is mostly indirect and obtained through reasoning. The semantic description of information elements may include definitions, classification systems, and schematic diagrams (schematics). Among them, definition is the connotation, including time, place, and scene. Classification system refers to the hierarchy of differentiating and associating diverse geographic elements in a given context. Schematic diagram is a graphical (often abstracted) representation of the connotation; it usually embodies a graphical description and decomposition of its essential characteristics.

9.2.3.2 Spatial Location

Spatial location is a description of the location of geographic entities, identifying where a geographic element is located, or where an event/process/phenomenon occurs. Coordinates are widely used to encode spatial location. More broadly, landmarks, placenames, and addresses, or even spatial relationships (e.g., near, opposite), can also provide useful references about spatial location as spatial identifiers.

9.2.3.3 Geometric Structure

Geometric structure is a description of the geometric forms of various geographic entities, including shapes, orientations, and reflections There are many types of geometric forms such as points, lines, polygons, and bodies in the existing geographic information system. In addition to traditional object descriptions, geometric descriptions and expressions can also be carried out through pixels and voxels. Pixel is a basic and atomic component of the two-dimensional grid, and a voxel can be considered as a three-dimensional volume pixel, which represents a basic and atomic component of the regular grid in a three-dimensional space.

9.2.3.4 Attribute

Attribute components are mainly dedicated to the non-spatial characteristics of spatial entities, such as land cover, temperature, and population. Attribute components can be recorded from multiple perspectives, such as geometric, physical, chemical, biological, cultural, social, and economic, among others. Note that attribute components can also evolve with temporal and/or spatial components of geographic entities.

9.2.3.5 Interrelationship

Interrelationship is used to describe the spatial and/or temporal relationships between information elements. The traditional geographic information representation model highlights spatial relationships (e.g., distance relationships, topological relationships, directional relationships), and often overlooks the interplay relationships among features. The relationships that expressed by differential equations, chemical equations, and information diagrams are also overlooked by current GIS data models. More interrelationships that focus on geology and landform, climate and hydrology, landform and vegetation and other physical elements, regions and economic development, social relations, as well as communities and other human factors could be included to form a comprehensive description of the relationships among physical, human, and information worlds.

9.2.3.6 Evolution Process

Evolution process refers to the change of information elements over time. The description of the evolution process should first include the description of the time information, including the point in time (t_i), the time snapshot (Δt, dt), or the process (∂t) description of the full life cycle. Descriptions of the state and behavior of the element at the time could also be attached.

9.2.3.7 Interplay Mechanism

Behind visual appearance, there are interplay mechanisms among geographic elements. These mechanisms mainly reveal the possible cause of material migration, energy conversion, and information transmission. The mechanism of actions among elements in the real world can be described, perceived, and analyzed through various functions such as scenes, maps, networks, and models. On the other hand, the mechanism of action can also be used as constraints and rules for the expression of geographic information.

9.3 Example of the New Geographic Information Description

For the seven-dimensional expression of geographic information, it is necessary to establish an innovative data model. Unlike traditional GIS data models that mainly focus on the organization of spatiotemporal information with related attributes, a new data model should be developed with consideration of all the seven dimensions. Thus, semantics, spatial location, geometric structure, attributes, interrelationships, evolution processes, and interplay mechanisms must be expressed structurally and unified in the data model. In our previous works, geometric algebra (GA), which is a high dimensional algebra system, is used to develop such data models. GA integrates geometric and algebraic expressions organically, and realizes the unified description of time and space, continuous and discrete, as well as unified measurement and operation in high-dimensional space through unique reversible geometric product operations and rich geometric algebra operators. The multi-dimensional unity and the coordinate independence of GA are used to construct a multi-dimensional unified expression and calculation model of geographic information, which provides high-dimensional expression and calculation support for various information elements (Fig. 9.2).

GA provides a blade and multivector structure for organizing and representing the complex structure of the ternary world and facilitates object expression and measurement through geometric product. The multivector structure provides the fundamental containers that can connect different types of elements with different dimensions. In GA, spatial location is represented as the basis of GA and the geometric structures can be developed based on the Grassmann structure and multivector structures (Yuan et al., 2012). Evolution process can be represented using versors, which can be used as calculation operators to construct differential equations or discrete dynamical

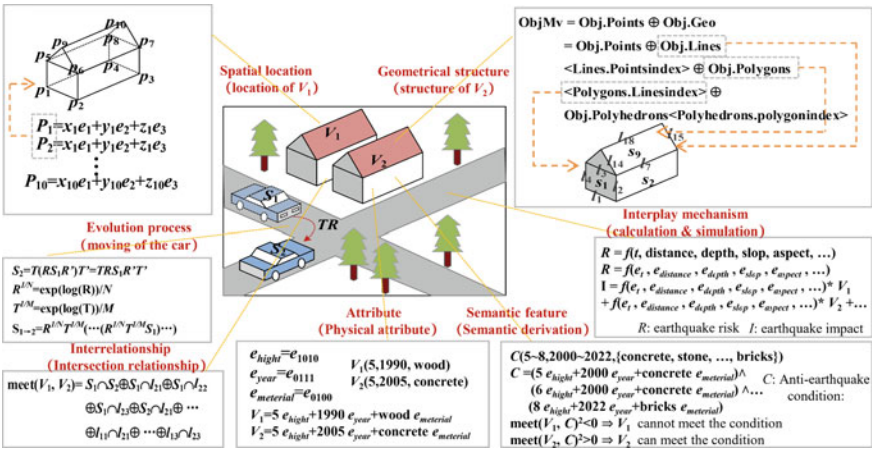

Fig. 9.2 Geographic information description with geometric algebra

representations (Yu et al., 2015, 2016). Semantics, attribute, interrelationship, and interplay mechanism are usually unstructured and cannot be represented as geometries or simple algebraic equations. To integrate these four components in the model, a GA-based distributed knowledge representation mechanism (Patyk, 2010) is used for coding them. Such integrated representation provides the mathematical and theoretical basis for integrated information modeling of geographic multi-factors (Yuan et al., 2019).

9.4 Conclusion

Based on the concept of ternary space, we proposed a seven dimensions framework to represent geographic information, which includes, semantics, spatial location, geometric structure, attribute, interrelationship, evolution process, and interplay mechanism. This representation model should enable the systematic integration of geographic information with multiple scales, dimensions, attributes, and spatial properties, which solves the problems of incomplete expression of information elements and lack of geographic characteristics. On this basis, the proposed framework expands the scope and domain of geographic information science and can serve as the basis for the development of a new generation of the geographic information system.

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