An image cube subscription service prototype based on 3D topological relationship and its case study

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Abstract: The normalization, standardization and unification of GIS image cube services support the effective sharing of geographic information data, solve problems of incompatibility and non-uniformity of image cube data services, significantly improve the sharing and socialized use of geographic information resources, and promote the development of digital earth. By reviewing and comparing various geographic information subscription and service standards in the mainstream of GIS industry, this study analyzed requirements of standardized GIS image cube data subscription services, proposed a standardized subscription service prototype considering relationships among three-dimensional entities, and explored an industrial application implementation mechanism according to case demands of specific fields.

Keywords- Image cube; subscription service; topological relationship

1. INTRODUCTION

The image cube grid, as a regular spatio-temporal phenomenon description model, is often referred to as "grid" or "array" data. Common grid cube data include three-dimensional x/y/t timing images and three-dimensional x/y/z data and 4-dimensional x/y/z/t data in the field of atmosphere, ocean, geophysics, etc. These data are widely used in nature monitoring, social management, environmental governance and et al. Under a unified standard frame, image cube subscription is not only conducive to the collection and collaborative mining of image cube data in different fields, but also enables multi-disciplinary scientific data with image cube services as carriers to expand, store, retrieve and conduct collaborative analysis more flexible and efficient. Under a unified standardized service framework, mass storage, efficient management and continuous sharing can be realized organically through the Web, and remote sensing images can be fully and effectively used, shared and integrated by the whole society[1-2]. For example, Geospatial Data Cloud [3] provides query services according to given spatio-temporal limits, keywords and sensor types. Aiming at the problem of dispersion and heterogeneity of data sets in different data centers, Zhang Jing et al. [4] proposed a method of integrating Earth Observation (EO) data based on OpenSearch and provided a keyword query service.
OpenSearch provides a method for websites and search engines to publish search results in a standard format, and allows users to access different websites and search engines conforming to OpenSearch specification in a unified way. However, the query method based on spatio-temporal limits and keywords [6-7] cannot make full use of spatial relationships between query conditions and images to ensure recall and accuracy.

In this study, Subscription query for spatio-temporal images was made up of points, lines, planes and bodies in three-dimensional space (2d + time dimension) and image data with time attributes. Accordingly, subscription query conditions based on customized 3D topological relations are used to filter the result set through standardized OpenSearch query as the carrier for RSS subscription. The remainder of this paper was organized as follows. Section 2 presented a 3D topological relation model. Section 3 introduced a standard-based subscription service. Section 4 provided a case study. Section 5 concluded the paper.

2. 3D TOPOLOGICAL RELATION MODEL

Three-dimensional topological models mainly included topological models based on graph theory and topological models based on point set topology [8]. Related study based on graph theory included Chen Jun et al. [9] proposed a description model of topological relations based on the theory that any three-dimensional spatial entity can be subdivided into several simplex dimensions ≤3. On this basis, Zhang PingFei [10] further proposed a Simplicial Complex-based Topological Relations Model(SCTRM) based on simplex complex to distinguish topological relations. However, it is still necessary to divide the boundary and interior of space entities into simplex. At the same time a large number of fragments and data may be generated in the process of segmentation, so that some topological properties of space entities were hidden by a large number of simplex [8]. The three-dimensional topological models based on point set topology mainly included the 4-intersection model DE-4IM proposed by Clementini [11] based on dimension extension and the 9-intersection model DE-9IM based on dimension extension. 4-intersection models [12] and 9-intersection models [13] described topological models by using the intersecting dimensions of internal, external and boundary of two geometric objects. Zhu TieWen et al. [14] formulated 24 topological relation judgment criteria for objects in three-dimensional space, which was not yet completed in topological relations between lines, planes, bodies in the vertical direction and planes in the horizontal direction. Zlatanova [15] proposed 13 groups of 25 negative rules for points, lines, planes and bodies defined by OGC, and summarized the relatively comprehensive topological relations among current three-dimensional space objects. On the basis, Zhang Jun [16] proposed 10 groups of 69 negative rules for objects defined by 3D Realms Data Model(3DRDM), these rules can distinguish 80 topological relationships. However, when topological relations of these models were applied to the topological query of images, it was redundant and inconvenient to operate [17].

Compared with DE-9IM, which uses a 3*3 matrix to represent 3D topological relations, Earth Observation 3-Intersection Model(EO-3IM) proposed in this study used 1*3 matrix to represent the topological relations between two objects, which can effectively reduce the complexity of the topological model and more intuitively distinguish various application scenarios in the query process.

The definition of EO-3IM proposed in this paper was as follows:

EO-3IM(x, y) = [dim(x ∩ y), dim( x ∩ y ), dim( x ∩ y )]

Where x represented the query condition, which can be a line, a polygon, or a body in a 3D space, y represents an image, and dim(x ∩ y), dim( x ∩ y ), dim( x ∩ y ) respectively represented the intersection dimension between the query condition and the interior, boundary and outside of a remote sensing image.

For each element of the EO-3IM's 3-intersection matrix, there were five ways to take the value {Ø, 0, 1, 2, 3}. EO-3IM can reduce the complexity of topological model compared to DE-9IM. However, EO-3IM's topological relationships distinguishing ability was not comparable to DE-9IM. To compensate for
this deficiency, 1 was divided into two parts, 1 (¬) represented the line and not closed, 1 (≡) represented the line and closed-loop, that is, the start point and the end point were the same points. Among them, only when \(\text{dim}(x')=2\), \(\text{dim}(x\cap y')\) had the possibility of taking 1(≡). There were 5 possible topological relations for this situation, and the others had \(5^3=125\) topological relations. There were 130 possibilities in theory. Where Ø represented the intersection in an empty set, 0 represented the intersection at a point, 1 (¬) as shown above, 2 indicated the intersection at a polygon, 3 meant the intersection at a body. In the actual topological relationship query process, EO-3IM only described the topological relationships between horizontal and vertical directions. It can distinguish 3 kinds of point/polygon relations, 8 kinds of line/polygon relations, 11 kinds of polygon/polygon relations and 7 body/polygon relations, as shown in figure 1.

| Topological Relations | 0 (Ø) | 1 (¬) | 2 (Æ) | 3 (≈) | 4 ( solving) |
|-----------------------|-------|-------|--------|-------|--------------|
| disjoint              |       |       |        |       |              |
| meet(point)           | [0,0,0] | [0,1,1] | [1,0,0] | [1,1,1] | [2,2,0]      |
| meet(line)            |       |       |        |       |              |
| meet(polygon)         |       |       |        |       |              |
| within                |       |       |        |       |              |
| cross(point)          | [3,0,0] | [3,1,1] | [4,0,0] | [4,1,1] | [5,2,0]      |
| cross(line)           |       |       |        |       |              |
| cross(polygon)        |       |       |        |       |              |
| overlap               |       |       |        |       |              |
| contain               |       |       |        |       |              |
| equal                 |       |       |        |       |              |

**Figure 1.** Semantic rules for topological relations.

3. STANDARD-BASED SUBSCRIPTION SERVICE

OpenSearch is a collection of technologies that allows websites and search engines to publish search results in a standard and accessible format for syndication and aggregation.

Solr [18] is a full-text search engine that only supports keyword queries, which is based on Apache Lucene to build an open source search engine. Solr provides a Web Service API interface, while the query results can be returned as XML and JSON format.

JTS is a Java library for creating and processing vector geometry objects. It implements the judgment function of geometric objects defined in OpenGIS Consortium Simple Feature Specification for SQL, the core operation algorithm of spatial topology, and all two-dimensional topological relations of DE-9IM. EO-3IM defines the topology model in 3D space. To make JTS and EO-3IM seamlessly connected, it is necessary to map the 3D topology object in EO-3IM into topology objects in 2D space. The specific conversion method is the horizontal direction directly performs matrix mapping according to the
topological predicate. In the vertical direction, firstly, 3D objects are subjected to dimensionality reduction processing, that is, turning the line into multi-point, turning the polygon into multi-line, turning the body into multi-polygon, and then mapping according to the horizontal direction mapping manner.

In this study, the subscription query results were stored in the database through the JTS plug-in customized topology model. Solr updated the corresponding index library and returned the subscription results in the form of keywords. The result is converted to atom format through OpenSearch, generating an RSS source, as shown in figure 2.

![Figure 2. Prototype architecture](image)

4. APPLICATION

DongShan Island is located in the southern coastal area of Fujian province, China. Its geographic coordinates are 23.55-23.78 north latitude and 117.284-117.584 east longitude. It is the largest abalone breeding base in China. With the rise of abalone breeding industry and the increasing development of salt farms, the ecological environment of the gulf has been damaged, which directly affected the length and shape of the coastline. In order to analyze the temporal and spatial variation characteristics of the DongShan Island coastline, it is necessary to obtain all image data including DongShan Island. The query geometry condition is customized according to the coordinate range of DongShan Island. Then, the topological contain condition is carried out to set off topological calculation with all data records in the metadata database. The calculated result is in the database. We set the topological semantic keyword to dongshancontain, and then sent the OpenSearch query request: http://localhost:8983/solr/OpenSearch/selectfq=dongshancontain:yes&q=*&wt=xslt&tr=atom.xsl.

Two data sources were selected for the integration, namely 38808 landsat5, 7393 landsat7 and 46990 landsat8 in the geospatial data cloud, and 720 gf-1 data in the national integrated earth observation data sharing platform. Metadata of different data sources were obtained by using Python.

The OpenSearch query response results returned all the impact records in the database that meet the query criteria, a total of 124 records, as shown in figure 3. At the same time, An RSS feed subscription can be made to the response result of the query. Once there is data update in the database that meets the requirements of dongshancontain, the update will be timely pushed to the user.
5. CONCLUSIONS

This study provided an image subscription service prototype based on the proposed EO-3IM without considering the non-plumb direction. EO-3IM can effectively reduce the complexity of topological models and the corresponding service prototype can intuitively distinguish various remote sensing image query scenarios in the subscription process by providing standardized RSS. The study proposed a weakly coupled image subscription approach to integrate data of different EO data centers in a loose way, improved the sharing and interoperability of image data, and provided reference for comprehensive query of multi-source heterogeneous EO images.

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**Acknowledgement**: Supported by Natural Science Foundation of Fujian Province of China (No.2019I0006), and National Natural Science Foundation of China (No. 41401454).