WEB-BASED INFORMATION EXPLORATION OF SENSOR WEB USING THE HTML5/X3D INTEGRATION MODEL

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ABSTRACT

We investigate how the visualization of sensor resources on a 3D Web-based globe organized by level-of-detail can enhance search and exploration of information by easing the formulation of geospatial queries against the metadata of sensor systems. Our case study provides an approach inspired by geographical mashups in which freely-available functionality and data are flexibly combined. We use PostgreSQL, PostGIS, PHP, X3D-Earth and X3DOM to allow the Web3D standard and its geospatial component to be used for visual exploration and level-of-detail control of a dynamic scene. The proposed approach facilitates the dynamic exploration of the Sensor Web and allows the user to seamlessly focus in on a particular sensor system from a set of registered sensor networks deployed across the globe. We present a prototype metadata exploration system featuring levels-of-detail for a multi-scaled Sensor Web and use it to visually explore sensor data of weather stations.

KEYWORDS

Web3D, Extensible 3D (X3D) Graphics, Sensor Web, X3DOM, HTML5

1. INTRODUCTION

While most environmental scientists rely on the sensor data portals hosted by a few large-scale government and research institutes, finding information on the Web is generally done using an ordinary text query or tree-based hierarchical text exploration interface. This approach is useful in that people routinely find sensor data from specific data portals. However, searching and exploration can be frustrating when queries return a tremendous number of sensor resources. Often the query output does not match what they are seeking. Search remains primarily textual and result lists are usually unstructured and not interactive. Therefore there is need for an efficient discovery and exploration interface for large distributed sensor resources.

In this paper, we introduce an approach for sensor metadata discovery by exploring a Web-based 3D virtual globe on which the metadata of distributed sensor systems are queried and visualized through interaction with the information seeker. In order to provide a more intuitive exposure of metadata for sensor networks, we implement a dynamic 3D scene of sensor information on the globe by interactive navigation using HTML5 and X3D integration model (X3DOM) (Behr *et al.* 2009, Behr *et al.* 2010). Multiple levels-of-detail for metadata visualization are proposed for the display of a multi-scaled sensor network. We apply the proposed approach to the exploration of metadata of personal weather stations which are deployed across the globe in order to investigate how the visualization of metadata on a 3D Web-based globe organized by level-of-detail can enhance the search and exploration of information.

2. RELATED WORK

Similar to the W3C Web standards enabling the WWW, the Open Geospatial Consortium's Sensor Web Enablement (SWE) standards enable researchers and developers to make sensing resources discoverable, accessible, and re-useable via the Web. The SWE is composed of candidate specifications including Observation and Measurement (O&M), Sensor Model Language (SensorML), and Sensor Observation Service (SOS). A reader can refer to the recent publication (Bröring *et al.* 2011) to get detail information about examples and applications of SWE.

Interactive visualizations can considerably improve the exploration of data. Graphical user interface elements can enable visual information seeking via dynamic queries (Ahlberg and Shneiderman 1994). An extension of dynamic queries can display visual overviews beyond the current query constraints and thus provides cues for how changing a query may yield a satisfying set of results (Spence and Tweedie 1998). Coordinated visualization yields deeper insights by showing the interdependencies among the information sources (Baldonado *et al.* 2000). For example, geographic information can be explored in an interface where two linked visualizations are provided for spatial and conceptual domains (Cai 2002). Coordinated information visualization query widgets that make it possible for information seekers to orient themselves within Web-based information spaces and to incrementally build complex filtering queries have been developed (Dörk *et al.* 2008).

Metadata that describe characteristics of a sensor resource are used for discovering potential datasets and evaluating their suitability for the researcher's purposes. Discovery is based on search functions relying on metadata about thematic, spatial, and temporal extents of datasets (Beard and Sharma 1997). Multiple scholars have demonstrated the usefulness of the visualization of metadata as a tool for visual analysis and reasoning and have used them to support the search for geographic resources (Ahonen-Rainio 2005, Albertoni *et al.* 2005). Exploratory visual analysis is useful for the preliminary investigation of large spatio-temporal datasets (Wood *et al.* 2007). The mapping and superimposition of metadata summaries can be used to provide a supporting context for data discovery and access by the synthesis of metadata, map and feature services (Aditya and Kraak 2007b, Aditya and Kraak 2007a, Nicula *et al.* 2008).

Previous work has shown the potential of 3D visualization using virtual globe as a tool of data exploration (Stensgaard *et al.* 2009, Tomaszewski 2011). The virtual globe is used for exploring geo-temporal differences of datasets (Wood *et al.* 2007, Hoeber *et al.* 2011) and data publication of Sensor Web (Liang *et al.* 2010). 3D thematic mapping using the virtual globe and geobrowsers (Sandvik 2008) offered a framework of 3D geo-visualization for statistical datasets. It provides an inspiration for 3D geo-visualization of metadata of Sensor Web.

Behr *et al.* (2009) introduced X3DOM, which is a model that allows to directly integrate X3D nodes into HTML5 DOM content. X3DOM eases the integration of X3D in modern web applications by directly mapping and synchronizing live DOM elements to a X3D scene model. The integration model is notably evolving and used a framework for online visualization of 3D city model (Mao and Ban 2011).

3. DESIGN OF METADATA VISUALIZATION

We extend data-oriented data registry of Sensor Web toward visual information exploration in the virtual globe on the Web, by developing interactive visualizations that provide dynamic exploration across multiple levels-of-detail. These are intuitive user interfaces for efficient information retrieval of metadata for large datasets of sensor resources across the globe.

3.1 Level-of-Detail of Metadata

In information exploration visualized on a virtual globe, the system must display not only information from the virtual globe but also metadata of sensor networks in a way that depends on the complexity of the two sets of information. For example, if the most pertinent sensor stations are deployed in a specific area while thousands of stations are recorded in the metadata registry, the local view of the 3D scene can display only specific sensor stations which are included in the viewing frustum of the current scene. However, the global view of the same information shows all the metadata in a very small region of display. If the same method of visualization is applied for both cases, the amount of information in the global view is larger than that of the local view, and there are complex occlusions among the metadata displayed in a small area. These phenomena should be avoided through the consideration of proper visualization methods for different levels-of-detail. We summarize specific visualization methods for metadata exploration.

- *Statistical visualization*: An information exploration system should be able to display a statistical visualization, which shows the distribution of sensor systems according to geographical location. It is appropriate to expose a broad view of the overall metadata registered in the system. The visualization can show a bar chart, choropleth and proportional symbol, which are geographically referenced on the globe.

- *Text tag*: A text tag shows 3D text on a specific location of the virtual globe. It shows textual information with variation of size, style, and color of the text displayed.
- *3D shape template*: A 3D shape template can be used to display any kind of 3D object on the globe. For example, a simplified 3D model of sensor system can be a template. It can be located at any specific geographical location. A 3D shape template is composed with an X3D shape object, so that any event, animation and interaction can be implemented with X3D standard node description.
- *2D dynamic sprite*: 2D dynamic sprite is a simple 2-dimensional image that is generated dynamically on the information exploration server. It is appropriate to draw summarized information of the sensor system in limited 3D space. The image is dynamically generated according to queries and mapped as a texture image on a 3D geometry in a 3D scene.
- *Graph drawing of sensor data*: Practical sensor data can be displayed as a 2D or 3D graph drawing in the 3D space of the information exploration system. It is useful to visualize the recent history of sensor values when the information seeker wants to access more detail of the sensor system after decreasing focus on a particular sensor system.

3.2 Standard Web3D Technologies

The component technologies are configured to explore the massive metadata of Sensor Web. The data, applications and communication technologies used are depicted in Figure 1.

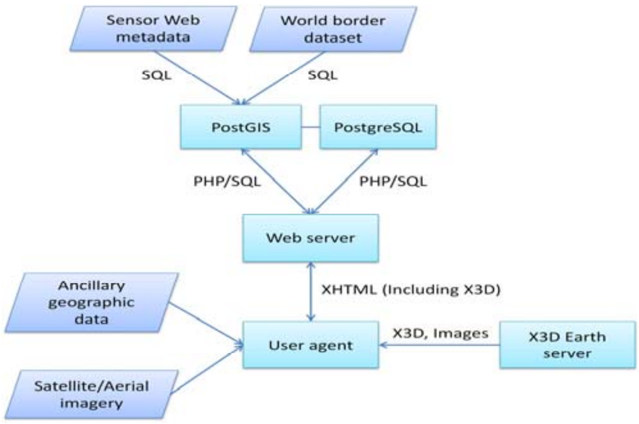


Figure 1. Data, application and communication technologies used in the proposed system.

- X3D is open standard file format and run-time architecture to represent and communicate 3D scenes and objects using XML on the Web. The X3D geospatial component provides support for geographic and geospatial applications including the ability to embed geospatial coordinates in certain X3D nodes. Google Earth, Microsoft Bing Maps, NASA World Wind and ESRI ArcGIS Explorer are well-known geobrowsers, which let the user add data layers to maps and imagery. However, a comparative review of existing geobrowsers and related technologies showed that X3D provides the largest number of competitive features in a royalty-free open standards (Yoo and Brutzman 2009).
- X3D-Earth is an open standard-based technology for publishing earth globes, which includes tools to enable users to build their own globes utilizing their own data. We can build our X3D-Earth globe instance based on the specific requirements for exploring the metadata from particular sensor networks.
- X3DOM model is an open and human-readable 3D scene-graph embedded in the HTML DOM, which extends the DOM interfaces and allows the application developer to access and manipulate the 3D content by only adding, removing or changing the DOM elements via standard DOM scripting. Thus, no specific plugins or plugin interfaces like the Scene Authoring Interface (SAI) are needed. Furthermore, this seamless integration of 3D contents in the web browser integrates well with common web dynamic techniques such as DHTML and Ajax, and the web browsers already provide a complete deployment structure (Behr *et al.* 2011).

4. IMPLEMENTATION

We implemented a Web-based system to support the visual exploration of a large collection of metadata from the distributed Sensor Web. The prototype performs online browsing of approximately 34,000 sensor systems from which datasets are accessible.

4.1 Architecture

The architecture of the visual metadata exploration system is divided into two parts: client-side and server-side (see Figure 2). On the Web server, data is processed and filtered to generate a dynamic X3D scene. We use PHP as an overall programming framework and PostgreSQL as the back-end database for storing processed metadata from the distributed Sensor Web. PostGIS is used to extend the geospatial capability of the database. Presentations and interactions are realized in the Web browser. We support the latest build of WebGL-enabled browsers. WebGL-enabled web browsers are available for most platforms. Mozilla Firefox and Google Chrome for any platform, and Safari for Mac OS X are compatible with our Web application. We employ X3DOM as a HTML5/X3D integration model that renders the X3D scene and handles interactive events from the metadata exploration. While the basic structure of the interface is transmitted as XHTML, CSS, and JavaScript files, the actual processed and filtered data for the interactive exploration of metadata is retrieved by the browser as X3D XML encoded objects, which is embedded in HTML DOM, generated in response to the current geospatial query.

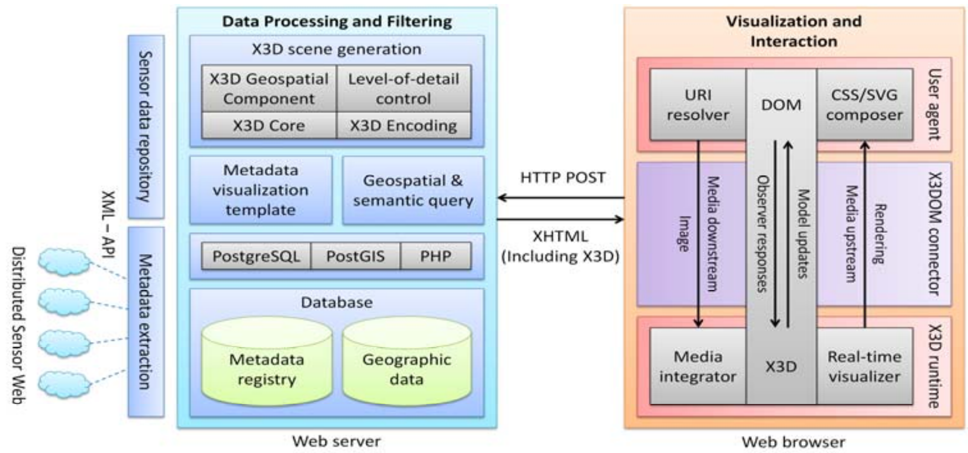


Figure 2. Architecture of the implemented system.

4.2 Metadata Extraction

Our prototype works with online repositories that are constantly updated. The metadata is extracted and stored in an online database, which is updated from distributed Sensor Web resources. In our work, we extract information from publicly available datasets of weather stations on the Web via the personal weather station (PWS) project managed by Weather Underground (Weather Underground 2012). The system assumes information items have a weather station identifier (unique ID), description (text), date and time of last observation (timestamp), geographic location (longitude and latitude), jurisdictional information including city and country names, and physical properties related to weather.

The extraction of metadata is straightforward. In order to create the list of weather stations that are publicly accessible on the Web, we query the web service of Weather Underground and find weather stations, which are registered as contributors to the PWS project. The retrieved information such as unique station identifier (unique ID), text string describing neighborhood, city and country name, station type, and direct access link (URL) are stored in our online database. The actual detailed metadata of each personal weather station is collected by formulating a query with parameters using the list of available stations. The PWS project provides an XML-based API, which gives access to the current status of weather stations. A PHP program extracts the detailed metadata and updates our online database for the information exploration system. Our online database stores description and jurisdictional information as simple attributes in the database. Date information such as timestamp, geographical information including latitude and longitude, and physical properties of weather require unit and format checking and conversion before the information is injected into our database.

4.3 Geospatial Query

A geospatial query is necessary to filter out metadata of sensor resources that are outside of the region of interest during progressive exploration and narrowing of focus. We collect jurisdictional information such as the city and country name when we extract metadata from sensor networks. Therefore, a general query to find metadata of sensor objects that match this city name or region code is straightforward. However, location information such as latitude and longitude is more important because it provides more precise information in a geographic context, and the jurisdictional information is often omitted when we collect metadata from publicly available sensor resources on the Web. In order to make a semantic relation between the jurisdictional name of region and the geographical geometry for the geospatial query, we use the composition of macro geographical (continental) regions, geographical sub-regions, and selected economic and other groupings information (United Nations Statistics Division 2011), which are provided by the statistics division of the United Nations. The correlated region name, code, and geometry are stored into our online database and are used for formulating a casual query based on the jurisdictional region name such as city or country. For example, it is not possible to figure out whether a sensor station is included in South-Eastern Asia, which is a sub-region of the Asia, with only the metadata of the station. Formulation of a geospatial query that refers to the corresponding information from world borders dataset enables such a casual query based on region name. This approach is often used for generating metadata visualization with a statistical summary.

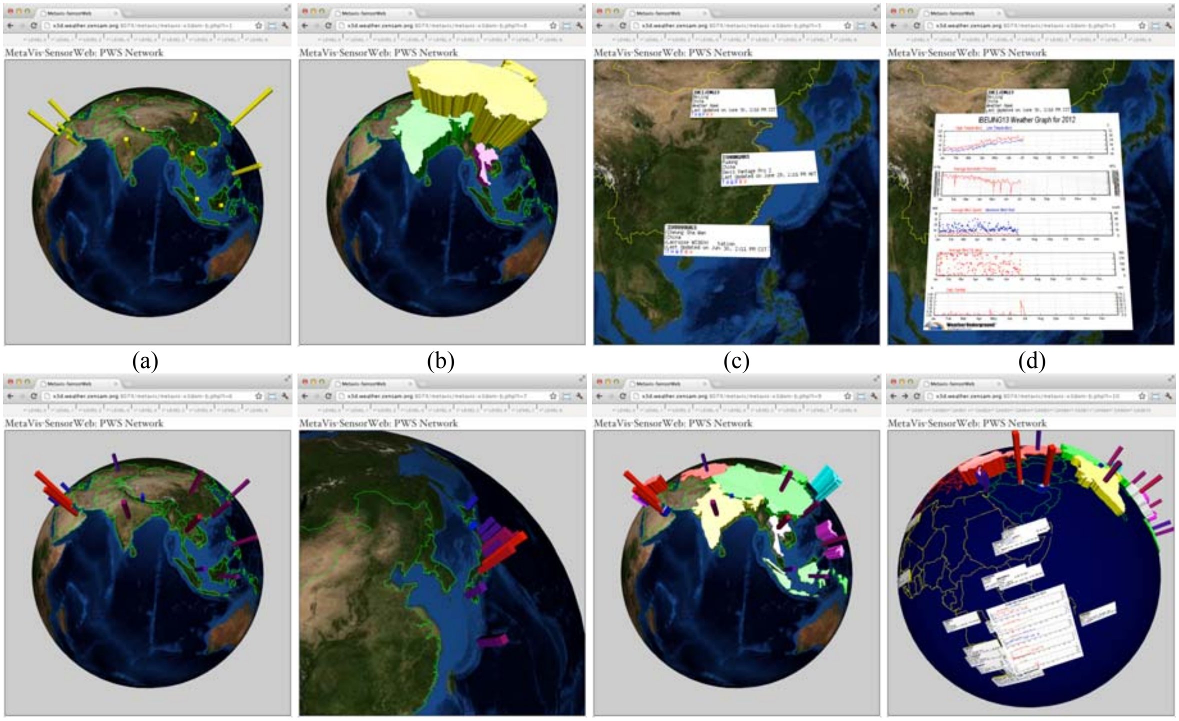
4.4 Metadata Visualization Templates

Metadata of selected sensor systems is visualized as X3D nodes in a scene graph. We implemented X3D scene graph patterns for metadata visualization templates. At first, we implemented a template for the visualization of a statistical summary using geo-referenced 3D bar charts. Objects can be located in arbitrary location using geospatial coordinate system according to the current X3D standard specification. The bar chart can be located at a specific geographic location by specifying the 3D shape node of the bar chart as a child node of a *GeoLocation* node in an X3D scene. However, the current implementation of X3DOM lacks of support for several nodes belong to the geospatial component such as *GeoLocation*, *GeoTransform* and *GeoViewpoint* nodes. Thus we implemented visualization templates using *IndexedFaceset* composed of *GeoCoordinate* node instead of go-referencing standard X3D objects. The rectangular shape of the bar chart can be replaced with an arbitrary 3D object, and it is possible to scale the size of the shape proportionally to attributes of metadata. In addition, the appearance such as color and luminosity can be used to visualize information of metadata attributes implicitly.

Figure 3 shows example visualizations of personal weather stations. Figure 3a shows a 3D bar chart that visualizes the number of stations registered in the database according to country border. Figure 3b shows 3D prism map which is inspired by 3D thematic mapping (Sandvik 2008). Both examples are rendered in a standard X3D player embedded in a Web browser. In these examples, we used Google Chrome, although other browsers including Firefox and Safari should work.

The 2D image sprite is generated dynamically from our server by PHP and the GD graphics library. We employed the GD library to generate dynamic images that directly represent summarized metadata queried from our PostGIS database. The generated sprite can represent practical values of measurement as well as the status of sensor systems and the types of sensors with small icons as well as text strings. Font style, color and size of text string and size, color and shape of icon can express much detailed information in the limited space of the 2-dimentional sprite. The image sprite can be mapped on any 3D geometry in the X3D scene graph since it is used as a regular image texture.

Figure 3c shows the visualization of summarized metadata using the pseudo code. In this example, we focused our interest on the weather stations located in China. The image sprite represents identifier, city and country name, type of the weather station, last observation date and time, composition and status of sensors, which compose the weather station. Font style and color is used to represent status of the sensors in this example. It is possible to combine multiple visualization templates and formulate more dynamic events using the X3D scene graph. For example, the image sprit can be combined with graph drawing template. In order to add event control to the 3D scene, an *element.appendChild* event is attached to the image sprite. The event triggered when the mouse is over the image sprite (*element.onmouseover* attribute) is routed to add X3D nodes that render a 2D graph. Thus the 2D graph showing the recent history of sensor data is displayed when the mouse cursor is over the image sprite as shown in Figure 3d. A 2D image of a graph of recent weather is generated from the API of PWS project of the Weather Underground. The image is mapped as an *ImageTexture* node of a 3D surface by *element.setAttribute* method. It is the most detailed information that our exploration system can display regarding the selected weather station. The final step of seamless focusing in toward the specific sensor system is that we provide a direct link to the Web page of the sensor system by *Anchor* node attached to the 2D graph.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 3. Visualization of sensor resources on a Web-based virtual globe: (a) statistical bar chart, (b) 3D prism, (c) dynamic image sprite, (d) graph drawing of selected sensor data, (e) a global view shows summarized temperature of weather stations in each country, (f) a local view shows separate temperature of weather stations, and (g) combination of 3D prism presenting the number of registered weather stations and bar chart presenting the summarized temperature in each country, and (h) a dynamic 3D scene composed of various visualization templates.

5. USE CASE

In order to investigate how the visualization of metadata on a 3D Web-based globe organized by level-of-detail can enhance the search and exploration of information, we applied our development to a prototype metadata exploration system featuring levels-of-detail for a multi-scaled Sensor Web and used it to visually explore weather stations. The 34,700 personal weather stations are collected from the PWS project and registered in our online database.

The existing data access interface of the PWS project is based on text queries that produce and result lists expressed in HTML table with hyperlinks. This interface provides no mechanism for the user to summarize data or metadata from multiple weather stations. The user's only option is to laboriously follow the link to each individual weather station. We have transitioned the information exploration process from the traditional text-based user interface to a three-dimensional space with a seamless exploration interface based on a virtual globe. Even when the information seeker does not have domain specific knowledge of the weather stations, our system provides an easy and intuitive approach to exploring the available sensor information. When the user first engages with the information exploration interface, our system shows only brief information about how many stations are distributed in jurisdictional area borders (Figure 3a). At this point, the information seeker can decide which areas he or she will explore further to retrieve more detailed information. Once a specific location such as a region border is selected then a geospatial query implicitly formulated within our system filters out unnecessary information and displays only a summarized result of the metadata within the selected region boundary using detailed metadata sprites visualized on top of the 3D scene (Figure 3c). When the user has more interest in a specific station, then he or she can trigger a mouse event to enable the overlay of detailed properties and the recent history of measurement shown in a 2D graph on top of the 3D scene (Figure 3d). If the information seeker still has specific needs for downloading sensor data from the station, our system provides direct access to the sensor system as a hyperlink.

The summarization approaches that reduce level-of-detail at broader views are not limited to summarizing the sensor metadata, but are also applicable to summarizing sensor data themselves in order to expose a broad view of the scientific properties of sensors such as temperature to the users. For example, when the user selects sensor data (e.g. temperature) instead of sensor metadata as the visualization mode, our prototype system displays average values of temperature recorded by sensors in weather stations within each country border (Figure 3e). A geospatial query, which computes average values of temperature by country from registered weather stations, is implicitly formulated within our system, and a dynamic 3D scene is generated using a statistical bar chart. The color and the height scale of the bar chart vary proportionally according to the value of the temperature. The 3D bar chart shows real values scaled to fit on a digital globe, and the user can easily assess differences in average temperature between stations. When the user has more interest in a specific region, e.g. Japan as shown in Figure 3f, the level-of-detail of the dynamic 3D scene is automatically updated by a geospatial query, which is again implicitly formulated within the system.

6. CONCLUSION

We have introduced a visual exploration interface using 3D space for visualizing metadata of the Sensor Web. This approach transitions human processing of information during data discovery from two-dimensional space with text based search to three-dimensional space with visual media navigation. The amount of information transmitted to the user during the exploration is increased dramatically compared to the former text-based approach. Furthermore, the seamless focusing enabled by the new interface provides a less frustrating and more intuitive experience.

The main contribution of this work is the application of dynamic geospatial query and the use of mashups with the X3D-based earth globe to Web-based information exploration of sensor resources. The Web application based on HTML5/X3D integration model eliminated the need for third party plug-ins to enable interactive representation of 3D geospatial information. Therefore the information exploration of the Sensor Web based on an X3D Earth globe with only a standard Web browser implementation without any third party plug-in has been realized. We have designed level-of-detail for proper metadata visualization at multiple levels of exploration and implemented X3D templates for several styles of visualization methods. We have developed a PHP program that enables formulation of a dynamic geospatial query and the generation of an X3D scene for the visualization of the query result.

In the current realization, our prototype system is limited to fairly simple visual representations and query variations. This is partly due to the constrained capabilities of current Web browsers, the current implementation of X3DOM that support X3D Geospatial Component. For example, the current X3DOM still does not conform to the full specification of X3D standard version 3.2. We expect to extend the functionality of our prototype to facilitate the dynamic exploration of the Sensor Web and to allow the user to seamlessly focus in on a particular sensor system in more intuitive ways.

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