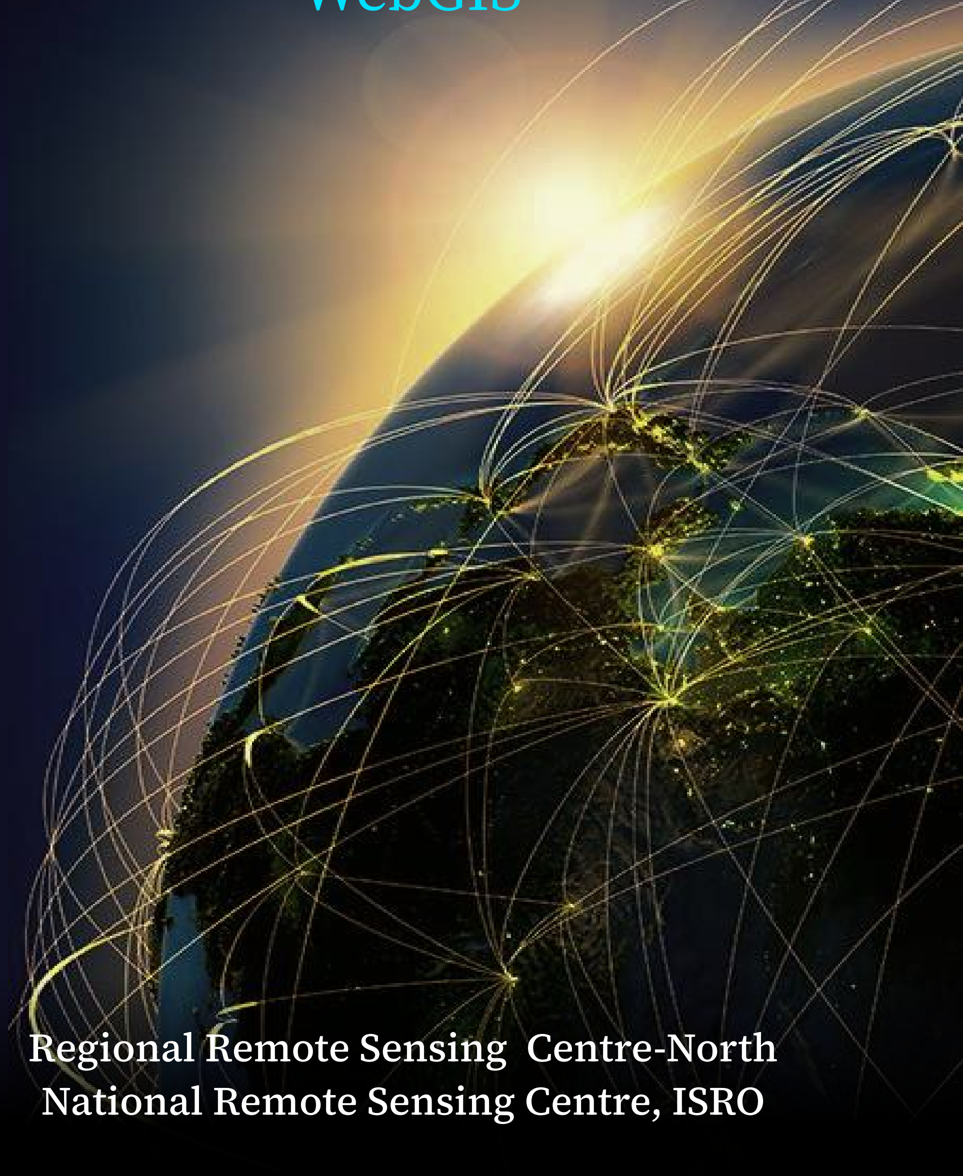
QUICK REFERENCE GUIDE on WebGIS



Regional Remote Sensing Centre-North

National Remote Sensing Centre, ISRO

Quick Reference Guide

On

Web GIS

Regional Remote Sensing Centre-North

National Remote Sensing Centre

Indian Space Research Organisation

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Foreword

National Remote Sensing Centre (NRSC) is one of the primary centres of Indian Space Research Organisation (ISRO), Department of Space (DOS) for developing remote sensing applications, establishing ground stations for receiving satellite data and generating high-quality satellite data and aerial data products. Regional Remote Sensing Centres (RRSC) are part of NRSC supporting various remote sensing tasks specific to their regions at the national level.

At NRSC, our commitment to advancing geospatial technologies is unwavering. NRSC has consistently been at the forefront of innovation, contributing to national development and supporting global initiatives. By enhancing collaboration, data sharing, and decision-making, Web GIS opens new possibilities for addressing complex challenges. The integration of Geographic Information Systems (GIS) with web technologies has fundamentally transformed how we access, analyze, and utilize geospatial data.

This Quick Reference Guide on Web GIS prepared by RRSC-North, is designed to equip users with the essential knowledge and tools needed to effectively leverage Web GIS applications. The guide provides a comprehensive overview of Web GIS, including practical insights and relevant information to help users navigate this dynamic field.

As we continue to explore new frontiers in geospatial science and technology, I encourage you to explore the opportunities that Web GIS offers. I hope that this quick reference guide will be useful for all the students, researchers and scientists who are venturing into the Web GIS domain.

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September 17, 2024 **(Prakash Chauhan)**

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From The Chief General Manager's Desk

National Remote Sensing Centre (NRSC) has five Regional Remote Sensing Centres (RRSCs) spread across the country. These centres are involved in addressing the local and regional issues using space and geospatial technology and also actively participate in capacity building as well as outreach activities in their respective regions. RRSC-North, located at New Delhi, caters to the needs of users in the Northern states of India viz. Delhi, Himachal Pradesh, Jammu & Kashmir, Uttar Pradesh and Uttarakhand. RRSC-North also organises training programmes and workshops on topics related to remote sensing, geographic information systems, digital image processing and their applications for government officials, academia and students.

I am extremely happy that RRSC-North has prepared a "Quick Reference Guide on Web GIS" Basic concepts of Web GIS are covered in a crisp and lucid manner in this compilation. I am sure that this reference guide will be quite helpful for the beginners to get familiar with the concepts of Web GIS in a short time.

एस. के. श्रीवास्तव

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About the Book

It gives me immense pleasure to present this Quick Reference Guide on Web GIS, a comprehensive resource meticulously crafted to assist professionals and enthusiasts in navigating the evolving landscape of web-based Geographic Information Systems (GIS). The Remote Sensing and GIS community has witnessed remarkable advancements in recent years, and this guide stands as a testament to our commitment to fostering knowledge and expertise in this critical field.

At RRSC-North, NRSC, ISRO, we have always prioritized the dissemination of cutting-edge technologies and methodologies to support decision-making processes, research, and development. Web GIS, with its ability to integrate, visualize, and analyze geospatial data through the internet, represents a significant leap towards more accessible and collaborative geospatial solutions. This guide aims to equip users with the essential tools and insights required to harness the full potential of Web GIS technologies.

The contents of this guide have been thoughtfully curated by experts at RRSC-North, combining theoretical foundations with practical applications. It is designed to serve as a handy reference for both novices and seasoned practitioners, ensuring that users can readily find the information they need to address real-world geospatial challenges.

We look forward to your feedback and suggestions, which will help us continually enhance the quality and relevance of our publications.

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Sameer Saran
Deputy General Manager,
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Chapter 1: Introduction to Web GIS

1.1 Introduction

A Geographic Information System (GIS) is a computer system that gathers, processes, stores, manages, analyzes, and displays geospatial data and its associated attribute information. Since its inception in the 1960s, GIS technology has rapidly advanced, becoming integral to mainstream information technology and a key growth area in the geographic information sector. GIS applications are now vital to national economic and social informatization, impacting various professional fields and daily life.

The advent of the Internet has established **Web GIS** as a dominant GIS application. Web GIS is an advanced form of a geospatial information system. It involves a combination of software and hardware that enables the distribution of maps, spatial data, and geographic processing capabilities over a network and the internet using standard web communication protocols like HTTP. Information exchange takes place between a server and a client, with the server being a Geographic Information System (GIS) server, and the client being a web browser, mobile application, or desktop application.

The server possesses a unique Uniform Resource Locator (URL) that clients use to find it on the web. Web GIS broadens the reach of GIS by making its features available to a larger audience. Web GIS is not intended to outperform or compete with desktop GIS but to extend GIS capabilities to everyone. Web GIS reduces the necessity for users to install complex software since most tasks can be carried out within web browsers or mobile applications. A web service is a piece of code operating on the server that executes actions in response to client requests. With the Internet's help, clients can access geospatial information online, regardless of the distance between the server and client. Geographic data and maps can be shared globally through Web GIS.

1.2 Web GIS and its Characteristics

To comprehend Web GIS, it's essential to differentiate it from related concepts: Network GIS, Internet GIS, and World Wide Web GIS (also known as Web Mapping). Clarifying these concepts aids in the proper understanding and application of Web GIS.

Network GIS encompasses the broadest scope, including Client Server (C/S) models, multi-layer, distributed GIS applications based on various distributed computing frameworks. These applications can operate on local area networks, wide area networks, the Internet, and various wireless networks, using protocols such as TCP/IP, HTTP, WAP, GPRS, and Bluetooth.

Internet GIS is a subset of Network GIS, utilizing the TCP/IP protocol to deploy and operate on the Internet. This subset includes both C/S and Browser Server (B/S) models.

Web GIS is a B/S model application system, utilizing the HTTP protocol within Internet or Intranet environments, created to store, manage, analyze, publish, and share geographic information. Thus, it is both a subset of Network GIS and Internet GIS. It represents a more sophisticated, distributed GIS built on higher-level application protocols, often incorporating other distributed computing models to address tasks like load balancing.

Web GIS facilitates data distribution and distributed processing, where the GIS server offers various services to both local and remote users. These services include geographic data cataloging, data access, spatial analysis, model system services, and spatial visualization. Utilizing interoperability technology, multiple GIS servers can collaborate to complete GIS processing tasks, sharing distributed data objects and operating across different platforms. This approach maximizes the use of network resources and enhances the overall efficiency of GIS operations.

1.3 Web GIS Composition

The key elements of Web GIS include:

1. **Server Accessibility**: The server has a URL that allows clients to locate it on the web.
2. **Client Requests**: Clients send requests to the server according to HTTP specifications.
3. **Server Response**: The server performs the requested GIS operations and responds to the client via HTTP.
4. **Response Formats**: Responses can be provided in various formats, including HTML, binary images, XML (Extensible Markup Language), or JSON (JavaScript Object Notation).

Web GIS uses computer technology to create mathematical models of surface information, storing, processing, and analyzing data through Web technology. Web GIS is characterized by being object-oriented, distributed, and interoperable. It encapsulates GIS data and functions into objects that facilitate distributed computing and can be stored on multiple servers. These objects can be easily exchanged and interact using a consistent communication protocol.

Technically, Web GIS, which operates in a B/S mode on the Internet, should have the following characteristics:

1. **Dynamic Web Applications**: Publishes dynamic web applications through a web server.
2. **Client Interface**: The client is a standard web browser, such as Internet Explorer, Google Chrome or Firefox.
3. **User Interaction**: Users interact with maps via a web browser.
4. **Distributed System**: Web GIS is a distributed GIS based on the HTTP protocol in a B/S mode.

5. **Communication Protocol**: It uses the HTTP protocol for communication between the browser and the web server. Users submit requests via the web browser, and the server typically responds with interactive documents, document fragments, or geographic data in formats such as HTML or XML that contain map information.

1.4 Web GIS Advantages

Compared to traditional desktop or LAN-based GIS, Web GIS offers several advantages:

1. **Wider Access**: Web GIS allows customers to access the latest data from multiple servers located in different places simultaneously. This Internet/Intranet capability greatly facilitates GIS data management and simplifies the synthesis of distributed data sources.
2. **Platform Independence**: Regardless of the server or client machine type or the GIS software used, Web GIS enables users to access data transparently through a standard web browser. This feature supports the dynamic combination of distributed components and the collaborative processing and analysis of spatial data, enabling the sharing of remote heterogeneous data.
3. **Reduced System Costs**: Traditional GIS requires expensive professional software for each client, often leading to underutilization of functions and wasted resources. Web GIS, on the other hand, typically only needs a web browser (sometimes with plugins) on the client side, significantly reducing software costs. Additionally, the simplicity of the client setup lowers maintenance costs.
4. **Simpler Operation**: To make GIS accessible to a broader audience beyond professionally trained users, it is essential to simplify system operation. A general-purpose web browser is ideal for reducing operational complexity, making GIS more user-friendly for ordinary users.

5. **Efficient Load Balancing**: Traditional GIS often relies on file server structures, with processing capacity heavily dependent on the client, resulting in inefficiencies. Advanced Web GIS systems leverage network resources, delegating complex and global processing tasks to the server while handling simple operations with small data volumes on the client side. This approach allows for a flexible and efficient distribution of computing and network traffic loads, optimizing performance.

When developing Web GIS applications, selecting the appropriate development tool involves considering several important factors. For public services, the tool should enable the creation of interactive, functional, and aesthetically pleasing Web GIS sites. Many platforms provide custom templates, tag libraries, style libraries, and JavaScript function libraries to support this. The server-side platform should be cross-platform or platform-independent, compatible with both Windows NT and UNIX, with Java-based or CGI-based tools often fitting these requirements.

Web GIS clients, typically browsers, have limited interactivity with HTML-based maps. To enhance client interactivity, developers can use plug-ins, ActiveX controls, or JavaScript/DOM. While server-side processing operates in vector mode, client displays can be in grid or vector mode. Grid images do not require client plug-ins but offer less interactivity, whereas vector maps provide better interactivity but lower security. Therefore, strategies to reduce map data transmission bandwidth are essential.

Web GIS applications must utilize server resources efficiently and be scalable. They should dynamically adjust service numbers based on traffic and computing demands, ensuring effective load balancing across map application servers.

Summary

Web GIS utilizes web technology to enhance accessibility and functionality within geospatial information systems. Its defining characteristics include platform independence, an object-oriented approach, distributed processing capabilities, and interoperability. Users can seamlessly access and analyze geographic data through standard web browsers, facilitated by a GIS server and client applications. This system supports the sharing of maps, spatial data, and geographic processing tasks over the Internet or Intranet. Compared to traditional desktop or LAN-based GIS, Web GIS provides broader access to real-time data from multiple servers, reduces system costs by minimizing client-side software requirements, simplifies operations for users, and optimizes efficiency by balancing processing tasks between servers and clients. These advantages position Web GIS as a robust and cost-effective solution for managing geospatial data across diverse platforms and user requirements.

Chapter 2: Web GIS Architecture & Components

2.1 Web GIS Architecture

Web GIS, or Web Geographic Information Systems, harnesses web-based platforms to manage, analyze, and share geospatial data. Unlike traditional GIS confined to desktop applications, Web GIS exploits internet capabilities to enable users to access and manipulate geospatial information from any location. This system integrates various technologies, such as web mapping, spatial databases, and cloud computing, delivering real-time geospatial data and services through web browsers and mobile applications. This broad accessibility and convenience have established Web GIS as an indispensable tool across numerous industries and applications.

In modern geospatial analysis, Web GIS is pivotal by offering a versatile and scalable platform for collecting, visualizing, and interpreting spatial data. It enables the integration of diverse data sources, including satellite imagery, sensor data, and user-generated content, forming comprehensive geospatial datasets. This capability is crucial for addressing complex spatial issues and making informed decisions in areas like urban planning, environmental monitoring, disaster management, and transportation logistics.

A key benefit of Web GIS is its ability to facilitate real-time data sharing and collaboration among multiple stakeholders. This collaborative feature improves the accuracy and efficiency of geospatial analyses by allowing users to access up-to-date information and work together on shared projects. Moreover, Web GIS supports the creation of interactive and user-friendly applications, customizable to meet the specific needs of different users and industries.

The architecture of Web GIS is designed to efficiently process, store, and disseminate geospatial data, typically comprising three main tiers: the client tier, the server tier, and the database tier.

Client Tier: This layer includes web browsers, mobile apps, and desktop applications through which users interact with the system. It is responsible for rendering maps, handling user input, and sending requests to the server tier. Modern Web GIS platforms use advanced JavaScript libraries like Leaflet and OpenLayers to create dynamic, interactive user experiences.

Server Tier: Serving as the core of Web GIS architecture, the server tier manages most data processing tasks. It includes web servers that handle HTTP requests, GIS servers that process spatial data, and application servers that manage business logic. Technologies such as ArcGIS Server, GeoServer, and MapServer are widely used in this tier to provide robust spatial data management and analytical capabilities.

Database Tier: This layer consists of spatial databases that store geospatial data and attributes. Examples include PostgreSQL with PostGIS, Oracle Spatial, and Microsoft SQL Server with spatial extensions. The database tier ensures data integrity, security, and efficient retrieval, supporting the high-performance requirements of GIS applications.

The integration of cloud computing and big data technologies has further enhanced Web GIS capabilities. Cloud-based GIS solutions, such as Esri's ArcGIS Online and Google Earth Engine, offer scalable and flexible platforms for managing extensive geospatial datasets. Additionally, adopting open data standards from the Open Geospatial Consortium (OGC) ensures interoperability and data sharing across different GIS platforms.

Figure 1 shows the fundamental components and interactions within a typical Web GIS architecture, demonstrating the data flow from the client to the server and finally to the spatial database.

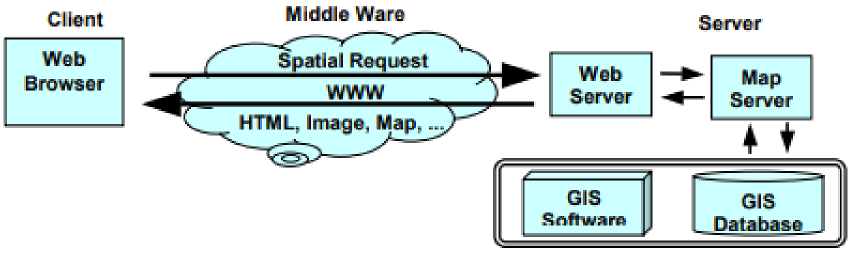


Figure 1 Basic components of Web GIS architecture

2.2 Client Tier

The client tier in Web GIS architecture is the interface layer where users engage with geospatial data and services via web browsers, mobile apps, or desktop GIS software. It functions as the front end, allowing users to visualize, manipulate, and analyze geospatial information. This layer handles map rendering, user inputs, and communication with the server tier. By utilizing advanced JavaScript libraries like Leaflet, OpenLayers, and Mapbox GL JS, the client tier delivers dynamic, interactive mapping experiences for real-time spatial data exploration.

The client tier is essential for several reasons. First, it ensures geospatial data and services are accessible from any internet-connected location, expanding the reach of GIS applications and enabling a broader audience to benefit from spatial analyses. Additionally, by supporting functionalities such as zooming, panning, and querying maps, the client tier enhances user engagement and simplifies the exploration of complex geospatial datasets. Furthermore, this tier allows for the development of tailored applications to meet specific user needs across different industries, such as urban planning, environmental monitoring, and disaster management, ensuring effective data interaction. Modern technologies in the client tier also enable the integration of real-time data, like live traffic updates and weather conditions, providing users with current information for decision-making.

Interaction in the client tier is key for a seamless user experience. Users interact with Web GIS through various input methods, such as mouse clicks, touch gestures, and keyboard commands. The client application processes these inputs and communicates with the server tier to fetch data or perform spatial analyses. A well-designed user interface (UI) ensures easy navigation and access to functionalities. Intuitive design principles, like clear labeling and logical tool grouping, enhance user experience. Immediate visual feedback, such as highlighting selected features or showing loading indicators, helps users understand request statuses and stay engaged. Tools for measuring distances, drawing shapes, and querying data allow users to perform complex analyses directly from the client interface, enabling meaningful insights without advanced technical skills. Allowing users to customize their view by adding layers, changing basemaps, or saving settings increases the application's relevance and usability.

2.3 Server Tier

The server tier is integral to Web GIS architecture, serving as the backbone for data processing, management, and storage. It plays a crucial role in handling client requests, performing complex geospatial computations, and ensuring data integrity and availability. This tier's efficient management ensures users receive accurate geospatial information promptly, making it essential in any Web GIS system.

2.3.1 Overview of the Server Tier

Responsible for processing user requests, conducting spatial analyses, and managing geospatial data storage, the server tier acts as an intermediary between client and database tiers. Its ability to handle large data volumes and complex computations is pivotal for Web GIS application performance and scalability.

The server tier's significance lies in its capacity to efficiently process diverse requests from multiple users simultaneously. It distributes tasks across servers to manage loads effectively, ensuring the responsiveness and reliability of Web GIS applications amid increasing user numbers and data volumes.

2.3.2 Components of Server Tier

Web Servers

Web servers, such as Apache Tomcat, are crucial components that handle HTTP requests from clients, serve static content, and forward dynamic content requests to application servers. Apache Tomcat's robustness, scalability, and compatibility with other server tier components make it widely preferred.

GIS Servers

Specialized GIS servers like GeoServer and MapServer process geospatial data, offering services such as map rendering, spatial querying, and geoprocessing. GeoServer, an open-source platform compliant with Open Geospatial Consortium (OGC) standards, supports diverse data formats for sharing and processing geospatial data. MapServer, renowned for performance and flexibility, efficiently handles large datasets and integrates well with web services.

Application Servers

Application servers execute business logic, manage workflow, and handle tasks like user authentication, session management, and complex spatial analyses. They ensure smooth application operation, meeting user-specific functional requirements.

2.3.3 Data Processing and Management

Handling HTTP Requests

Fundamental to the server tier, web servers receive, process, and route HTTP requests from clients to GIS or application servers. This involves parsing requests, performing security checks, and generating responses for clients.

Geospatial Data Processing

GIS servers process geospatial data retrieved from the database tier, performing tasks such as map rendering, spatial analysis, and data transformation. This processing is critical for tasks like generating map tiles, spatial queries, and geoprocessing operations.

Business Logic Management

Application servers execute defined rules and workflows for Web GIS applications, managing tasks such as user authentication, data validation, and custom spatial analyses. This ensures correct application functionality aligned with user needs.

2.3.4 Key Technologies

ArcGIS Server

A comprehensive platform by Esri, ArcGIS Server offers robust tools for managing, analyzing, and serving geospatial data. It supports various data formats and seamlessly integrates with other Esri products, making it ideal for complex GIS requirements.

GeoServer

An open-source GIS server, GeoServer facilitates sharing, processing, and editing geospatial data in multiple formats. Compliant with OGC standards, GeoServer is versatile and widely used in web-based geospatial applications.

MapServer

Known for high performance and flexibility, MapServer handles large datasets effectively and creates interactive maps over the internet. Supporting diverse data formats and integrating with web services, MapServer is a powerful tool for Web GIS applications.

The server tier is crucial in Web GIS architecture for request processing, data management, and business logic execution. It comprises web servers, GIS servers, and application servers, each fulfilling specific roles to ensure system efficiency and reliability. Key technologies like ArcGIS Server, GeoServer, and MapServer provide robust solutions for meeting the complex demands of modern Web GIS applications.

2.4 Database Tier

The database tier within Web GIS architecture forms the core for storing and retrieving geospatial data, ensuring data integrity, implementing security measures, and optimizing data retrieval efficiency for Web GIS applications.

Essential to Web GIS infrastructure, the database tier is pivotal for managing extensive volumes of geospatial data and facilitating timely data access. It enables seamless integration of spatial data across diverse applications, ensuring users access accurate information when needed.

Importance of Data Storage and Retrieval

Efficient data storage and retrieval are critical functions of the database tier, allowing Web GIS applications to manage large datasets effectively. Structured data organization enhances overall application performance and responsiveness.

2.4.1 Types of Spatial Databases

The database tier supports various spatial databases tailored for managing geospatial data:

PostgreSQL with PostGIS: Renowned for its reliability and open-source nature, PostgreSQL with PostGIS offers robust support for spatial data types and functionalities, making it highly favored among developers.

Oracle Spatial: Oracle Spatial provides extensive capabilities for geospatial data management within Oracle Database, offering scalability and seamless integration with Oracle's comprehensive database management system.

Microsoft SQL Server with Spatial Extensions: Integrating spatial extensions, Microsoft SQL Server enables efficient storage, retrieval, and analysis of geospatial data, tightly integrating with Microsoft's ecosystem.

2.4.2 Data Management

Efficient data management strategies in the database tier include:

Ensuring Data Integrity: Implementing mechanisms to maintain data accuracy and consistency, crucial for reliable analysis and decision-making.

Security Measures: Enforcing rigorous security protocols to safeguard geospatial data against unauthorized access and ensuring compliance with data privacy regulations.

Efficient Data Retrieval: Optimizing query performance and indexing strategies to expedite data retrieval operations, thereby enhancing overall application performance.

2.4.3 Complex Spatial Queries

The database tier supports intricate spatial queries essential for advanced geospatial analysis:

Supporting Complex Queries: Managing complex spatial relationships and operations to derive meaningful insights from geospatial data.

Performance Considerations: Enhancing query performance through strategic indexing, query optimization, and database design to minimize response times and elevate user experience.

The database tier serves as a cornerstone in Web GIS architecture, delivering crucial capabilities for managing, storing, and retrieving geospatial data. With support for diverse spatial databases and efficient data management practices, this tier ensures the reliability, performance, and analytical depth required for modern Web GIS applications.

2.5 Integration of Cloud Computing and Big Data

2.5.1 Cloud-based GIS Solutions

Cloud computing is integral to modern GIS solutions, providing scalable resources and facilitating collaboration and data sharing across diverse locations.

In GIS, cloud-based solutions utilize remote internet servers for storing, managing, and analyzing geospatial data, reducing dependency on local infrastructure and enabling global accessibility. Examples: ArcGIS Online, Google Earth Engine

ArcGIS Online: Developed by Esri, ArcGIS Online offers cloud-based tools for mapping, analysis, and collaborative geospatial applications.

Google Earth Engine: A cloud-based platform specializing in large-scale environmental data analysis, providing extensive geospatial datasets and powerful computational capabilities.

2.5.2 Big Data Technologies

Efficient management of large geospatial datasets is critical for real-time decision-making and insightful analysis.

Managing Large Geospatial Datasets

Big data technologies like Hadoop and Spark enable distributed storage and processing, surpassing traditional database capabilities for handling massive datasets.

Real-time Data Processing

Frameworks supporting real-time processing enable immediate analysis and visualization of geospatial data streams, facilitating rapid responses to dynamic environmental changes.

2.5.3 Benefits of Cloud and Big Data Integration

The integration of cloud computing and big data offers significant advantages for GIS applications:

Scalability: Cloud environments provide scalable resources, allowing GIS systems to manage increasing data volumes and user demands without heavy infrastructure investments.

Flexibility: Cloud-based GIS solutions enhance flexibility by enabling access to geospatial data and tools across various devices and locations, fostering collaboration and informed decision-making.

Cost-effectiveness: By eliminating the need for extensive on-premises infrastructure and maintenance costs, cloud-based GIS solutions and big data technologies reduce operational expenses while optimizing resource utilization.

The integration of cloud computing and big data technologies enhances the scalability, flexibility, and cost-effectiveness of GIS applications. Platforms like ArcGIS Online and Google Earth Engine exemplify this integration, empowering organizations to leverage extensive geospatial datasets and real-time processing capabilities for actionable insights across diverse domains.

2.6 Open Data Standards

2.6.1 Importance of Open Standards

Open data standards play a crucial role in promoting interoperability and facilitating data sharing among various platforms and organizations.

Ensuring Interoperability: These standards enable seamless integration and exchange of geospatial data across different GIS systems and applications.

Promoting Data Sharing: Standardizing data formats and protocols encourages transparency and collaboration in sharing geospatial information.

2.6.2 Key Standards

Open Geospatial Consortium (OGC) Standards

The Open Geospatial Consortium (OGC) develops and promotes open standards specifically for geospatial content and services. These standards significantly enhance interoperability and integration across Web GIS platforms.

Implementation in Web GIS Platforms

Web GIS platforms adopt OGC standards to ensure compatibility and interoperability with diverse geospatial data sources and applications. This implementation supports seamless data exchange, thereby improving the functionality and accessibility of geospatial information.

Open data standards, particularly those set by the Open Geospatial Consortium, are instrumental in fostering interoperability and enhancing data sharing capabilities across global GIS networks. Their implementation in Web GIS platforms ensures efficient data integration and supports collaborative efforts in geospatial data management and analysis.

2.7 Security and Performance Optimization

2.7.1 Security Measures

Ensuring the security of geospatial data is paramount in Web GIS applications, involving robust measures to safeguard sensitive information and maintain user trust.

Protecting Geospatial Data: Implementing encryption and access control mechanisms to protect geospatial datasets from unauthorized access and potential breaches.

User Authentication and Authorization: Enforcing strict authentication protocols and role-based access controls (RBAC) to verify user identities and regulate data access based on predefined permissions.

2.7.2 Performance Optimization

Optimizing performance is crucial for ensuring the responsiveness and efficiency of Web GIS applications, especially when handling large volumes of data and user requests.

Caching Strategies: Utilizing caching mechanisms to store frequently accessed geospatial data temporarily, reducing data retrieval times and enhancing application responsiveness.

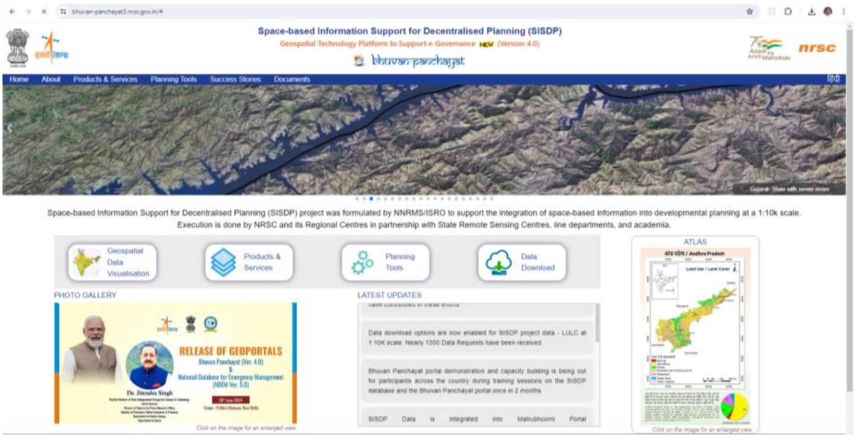
Load Balancing: Distributing incoming traffic across multiple servers to evenly distribute workload and prevent performance bottlenecks, ensuring consistent application performance under varying usage scenarios.

Latency Reduction: Implementing techniques such as content delivery networks (CDNs) and efficient network protocols to minimize latency, improving user experience during data retrieval and interaction.

Integrating robust security measures and implementing effective performance optimization strategies are essential for maintaining the integrity, availability, and responsiveness of Web GIS applications. These efforts ensure that geospatial data remains secure while providing users with reliable access and efficient data interactions across diverse operational environments.

2.8 Case studies

Web GIS applications such as Bhuvan Geoportal, Bhuvan Panchayat Geoportal (Figure. 2), and IBIN showcase the versatility of geospatial technology in delivering accessible and informative data. Bhuvan Geoportal, developed by the Indian Space Research Organisation (ISRO), provides extensive satellite imagery and geospatial data essential for disaster management, agriculture, and urban planning. Users can explore, analyze, and download spatial data pertaining to natural resources and infrastructure across India. Bhuvan Panchayat Geoportal builds upon this foundation by focusing on local governance, offering detailed maps and data tailored for village-level planning and decision-making. IBIN, the Integrated Biodiversity Information Network, utilizes Web GIS to integrate biodiversity data from diverse sources, facilitating comprehensive analysis and conservation initiatives. These platforms highlight the role of Web GIS in enhancing accessibility and decision-making support across various sectors, empowering users with critical spatial insights for informed resource management and strategic planning.


bhuvan-panchayat3.nrsc.gov.in/#
Space-based Information Support for Decentralised Planning (SISDP)
Geospatial Technology Platform to Support e-Governance NEW (Version 4.0)
bhuvan-panchayat
nrsc
Home
About
Products & Services
Planning Tools
Success Stories
Documents
Gujarat- State with seven rivers
Geospatial Data Visualisation
Products & Services
Planning Tools
Data Download
ATLAS
PHOTO GALLERY
LATEST UPDATES
RELEASE OF GEOPORTALS
Bhuvan Panchayat (Ver. 4.0)
&
National Database for Emergency Management (NDEM Ver. 5.0)
Dr. Jitendra Singh
Click on the image for an enlarged view
Click on the image for an enlarged view

Space-based Information Support for Decentralised Planning (SISDP) project was formulated by NNRMS/ISRO to support the integration of space-based information into developmental planning at a 1:10k scale. Execution is done by NRSC and its Regional Centres in partnership with State Remote Sensing Centres, line departments, and academia.

Data download options are now enabled for SISDP project data - LULC at 1:10K scale. Nearly 1350 Data Requests have been received

Bhuvan Panchayat portal demonstration and capacity building is being out for participants across the country during training sessions on the SISDP database and the Bhuvan Panchayat portal once in 2 months

SISDP Data is integrated into Matrubhoomi Portal

Figure 2 Bhuvan-Panchayat geoportal (https://bhuvan-panchayat3.nrsc.gov.in/

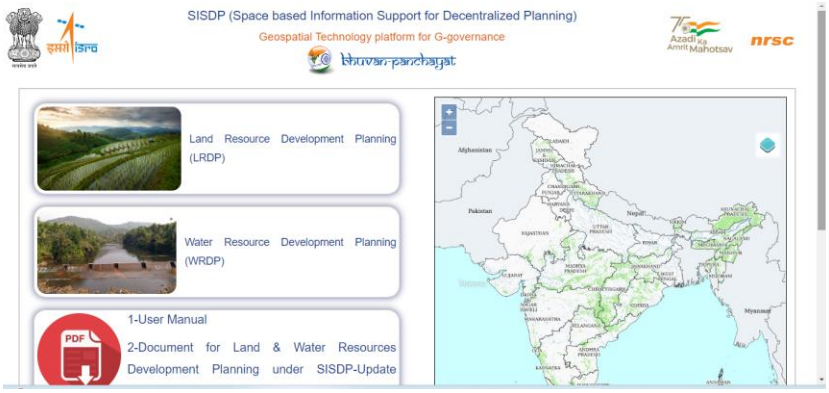

SISDP (Space based Information Support for Decentralized Planning)
Geospatial Technology platform for G-governance
bhuvan-panchayat
Azadi Ka Amrit Mahotsav
nrsc
Land Resource Development Planning (LRDP)
Water Resource Development Planning (WRDP)
1-User Manual
2-Document for Land & Water Resources Development Planning under SISDP-Update
Afghanistan
Pakistan
Nepal
Myanmar

Figure 3 Bhuvan-Panchayat LRD/WRD planning tools on geoportal (https://bhuvan-panchayat3.nrsc.gov.in/)

Summary

In modern geospatial analysis, Web GIS plays a pivotal role by enabling efficient data management and enhancing decision-making processes through its layered architecture. At its core, Web GIS consists of three essential tiers: the client tier, server tier, and database tier. The client tier acts as the user interface, accessible via web browsers, mobile apps, and desktop GIS software, leveraging JavaScript libraries like Leaflet and OpenLayers for interactive map displays. Meanwhile, the server tier, encompassing web servers such as Apache Tomcat and specialized GIS servers like GeoServer and MapServer, handles data processing, HTTP requests, and executes business logic. The database tier stores geospatial data in systems such as PostgreSQL with PostGIS, Oracle Spatial, and Microsoft SQL Server with spatial extensions, ensuring data integrity, security, and supporting complex spatial queries. Integration with cloud computing and big data technologies further enhances Web GIS scalability, flexibility, and cost-effectiveness, showcased by platforms like ArcGIS Online and Google Earth Engine. Open data standards, particularly those from the Open Geospatial Consortium (OGC), are instrumental in ensuring interoperability and promoting data sharing across Web GIS platforms. Robust security measures and performance optimization strategies like caching, load balancing, and latency reduction further bolster the effectiveness of Web GIS in delivering accessible and insightful geospatial information, empowering organizations with informed decision-making capabilities and efficient resource management.

Chapter 3: Webservices

3.1 Open Geospatial Consortium (OGC) Standards

The Open Geospatial Consortium (OGC) is a leading organization in the global geospatial community, established in 1994. It consists of industry leaders, government agencies, research institutions, and universities committed to advancing interoperable solutions for geospatial technologies. OGC's primary mission is to develop and promote open standards for geospatial content and services, aiming to facilitate seamless integration and interoperability across diverse geospatial applications.

Overview of OGC and Its Role in Standardizing Geospatial Web Services

OGC develops and maintains standards that define how geospatial data and services are accessed, exchanged, and utilized. These standards cover data formats, interfaces, protocols, and metadata, providing common frameworks that enable effective communication between different systems and platforms. This ensures that geospatial information can be shared and used without compatibility issues.

Importance of Adhering to OGC Standards for Interoperability

Adherence to OGC standards is essential for achieving interoperability within the geospatial community. It allows geospatial data and services to be seamlessly integrated and utilized across various applications, organizations, and geographic regions. By adhering to these standards, developers and organizations can utilize a shared set of protocols and interfaces to create interoperable geospatial solutions. This fosters collaboration, enhances efficiency, and drives innovation in geospatial data management, analysis, and decision-making.

OGC standards provide a foundation for harmonizing geospatial technologies globally, enabling the exchange of geospatial data and services to support diverse applications and user needs. Adhering to these standards is critical for promoting interoperability, facilitating effective communication and collaboration across the geospatial ecosystem.

3.2 OGC (Open Geospatial Consortium) Web Services

OGC Web Services comprise a set of standards that govern the access and exchange of geospatial data and processing services over the internet. These standards are instrumental in fostering interoperability among various geospatial systems and applications, facilitating seamless integration and sharing of geospatial information. Below, we explore different types of OGC web services that are pivotal in the geospatial domain.

OGC Web Map Service (WMS):

OGC Web Map Service (WMS) stands as one of the earliest and widely adopted standards by OGC. It enables clients to request and receive georeferenced map images generated from server-rendered geospatial data. Key features of WMS include:

Map Rendering: WMS servers dynamically generate map images based on client requests.

Layered Architecture: Supports overlaying multiple thematic layers onto a single map view.

Interactivity: Provides basic interactive capabilities such as zooming and panning.

Example:
A government agency utilizes WMS to offer public access to interactive maps showcasing land use, infrastructure, and environmental data. These maps are accessible via web browsers and can be integrated into third-party applications.

OGC Web Feature Service (WFS):

OGC Web Feature Service (WFS) allows clients to query and retrieve geospatial features (vector data) from remote servers. Unlike WMS, which serves map images, WFS provides actual geospatial data in formats like GML and GeoJSON. Key features of WFS include:

Data Retrieval: Clients can request specific features based on spatial and attribute filters.

Transaction Support: Supports transactions for creating, updating, and deleting geospatial features.

Filtering and Querying: Allows querying of features based on spatial relationships and attribute values.

Example:
A city planning department utilizes WFS to share detailed vector data on building footprints, zoning regulations, and transportation networks. This data aids urban planners and developers in analyzing and proposing new developments.

OGC Web Coverage Service (WCS):

OGC Web Coverage Service (WCS) provides access to multi-dimensional raster data (coverages) over the web, enabling clients to retrieve raw data values (such as satellite images or sensor data) rather than pre-rendered map images. Key features of WCS include:

Access to Raw Data: Allows clients to request raw coverage data in formats like GeoTIFF and NetCDF.

Subsetting and Interpolation: Clients can specify spatial and temporal subsets of data and request interpolated values.

Support for Multi-dimensional Data: Supports coverages with multiple dimensions such as time series and 3D data.

Example:
A climate research institute utilizes WCS to distribute satellite-derived temperature data. Researchers can access specific regions and time periods of interest to study climate patterns and trends.

OGC Web Processing Service (WPS):

OGC Web Processing Service (WPS) defines a standardized interface for executing geospatial processes (geoprocessing) over the web. It allows clients to request complex spatial analysis tasks to be performed by remote servers. Key features of WPS include:

Geoprocessing Tasks: Supports execution of algorithms and models for spatial analysis (e.g., buffering, interpolation, spatial statistics).

Asynchronous Processing: Handles long-running processes asynchronously, providing progress updates and final results.

Integration with Other Services: Integrates seamlessly with other OGC services like WFS and WCS for inputting and outputting geospatial data.

Example:
An environmental consulting firm utilizes WPS to conduct complex hydrological modeling on watershed data. They submit requests for tasks such as flood risk assessment and water quality analysis.

OGC Sensor Web Enablement (SWE) Standards:

OGC Sensor Web Enablement (SWE) standards establish protocols and data models for integrating sensor networks with web-based systems. These standards enable real-time monitoring and management of sensor data over the web. Key components of SWE include:

Sensor Observation Service (SOS): Allows querying and retrieval of sensor observations.

Sensor Planning Service (SPS): Supports tasking and controlling of sensors.

SensorML: Standardized model for describing sensors and sensor systems.

Observations & Measurements (O&M)*:* Data model for encoding sensor observations.

Example:
An environmental monitoring agency deploys a sensor network to monitor urban air quality. SWE standards are employed to collect, process, and disseminate real-time sensor data through a Sensor Observation Service (SOS) to the public and decision-makers.

OGC web services provide a robust framework for accessing, sharing, and processing geospatial data and services over the web. Each service type - WMS, WFS, WCS, WPS, and SWE - offers specific functionalities tailored to different aspects of geospatial applications, from simple map display to complex spatial analysis and sensor integration. Adhering to these standards ensures interoperability, promotes data-driven decision-making, and fosters innovation in the geospatial domain.

3.3 GeoServer: Facilitating Geospatial Data Sharing

GeoServer is a robust open-source server software tailored for distributing geospatial data across web platforms. It plays a crucial role in enabling organizations to deploy geospatial data as OGC-compliant services, thereby enhancing interoperability and accessibility across a wide array of applications.

GeoServer functions as a powerful platform that serves geospatial data using standardized OGC (Open Geospatial Consortium) services. Its flexibility in supporting various geospatial formats and data sources makes it versatile for applications spanning environmental monitoring, urban planning, and disaster management.

Features and Capabilities:

1. Serving OGC-Compliant Services (WMS, WFS, WCS, WPS)

GeoServer supports a suite of OGC standards, which includes:

- **WMS (Web Map Service)**: Allows clients to request and receive map images dynamically over the web.
- **WFS (Web Feature Service)**: Facilitates the retrieval of geospatial features (vector data) from remote servers.
- **WCS (Web Coverage Service)**: Provides access to multi-dimensional raster data (coverages) via the web.
- **WPS (Web Processing Service)**: Executes geospatial processes (geoprocessing tasks) remotely over the web.

These services ensure seamless access, manipulation, and integration of geospatial data across diverse platforms and applications.

2. Data Source Support

GeoServer offers robust support for a variety of data sources, including:

- **PostGIS**: An extension for PostgreSQL enabling storage and management of geospatial data.
- **Oracle Spatial**: Integrates spatial data management capabilities within Oracle Database.
- **Other formats**: GeoServer accommodates a broad spectrum of vector and raster data formats, ensuring compatibility across different data sources and systems.

3. Styling and Visualization Options

- GeoServer provides comprehensive capabilities for styling and visualizing geospatial data, enhancing its presentation:
- **Symbology and Styling**: Allows users to customize how geospatial data appears on maps, including colors, symbols, and labels.
- **Layer Control**: Facilitates effective management and organization of multiple data layers for in-depth analysis and visualization.

- **Integration with Mapping Libraries**: Seamlessly integrates with mapping libraries and frameworks, improving the interactive display of geospatial information in web applications.

GeoServer serves as a cornerstone in the geospatial technology landscape, empowering organizations to effectively share and utilize geospatial data. By leveraging its capabilities in serving OGC-compliant services, supporting diverse data sources, and providing advanced styling options, GeoServer fosters improved decision-making and collaboration across various domains. Its open-source nature and strong community support contribute significantly to its popularity and reliability within the geospatial community.

3.4 MapServer: Enabling Spatially-Enabled Internet Applications

MapServer is a versatile open-source development environment specifically designed for creating spatially-enabled internet applications. It empowers developers to build and deploy dynamic mapping applications that serve geospatial data over the web, addressing a wide array of use cases across various industries.

MapServer serves as a robust tool for developing spatial applications that utilize geospatial data. It facilitates the creation of interactive maps and geospatial services through standardized OGC (Open Geospatial Consortium) services, making it an optimal choice for organizations seeking robust spatial data infrastructure.

Features and Capabilities

1. Serving OGC-Compliant Services (WMS, WFS)

MapServer supports essential OGC standards to provide geospatial data services:

- **WMS (Web Map Service)**: Enables clients to dynamically request and receive map images over the web.

- **WFS (Web Feature Service)**: Facilitates the retrieval of geospatial features (vector data) from remote servers.

These services ensure seamless interoperability and accessibility of geospatial data across diverse platforms and applications.

2. Support for Various Data Formats and Projections

MapServer offers extensive support for a variety of geospatial data formats and projections:

- **Data Formats**: Includes Shapefile, GeoJSON, and GeoTIFF, among others, for both vector and raster data.
- **Projections**: Capable of reprojecting data into different coordinate systems, ensuring compatibility with global mapping standards.

3. Customization and Integration Possibilities

MapServer provides robust opportunities for customization and integration with other technologies:

- **Customization**: Developers can tailor map styles, labels, and interactive elements using MapScript and configuration files.
- **Integration**: Seamlessly integrates with web frameworks and mapping libraries, enhancing the functionality and user experience of spatial applications.

MapServer serves as a fundamental tool for developing and deploying spatially-enabled internet applications. By leveraging its support for OGC-compliant services, diverse data formats, and extensive customization options, organizations can create scalable and interactive mapping solutions tailored to their specific requirements. The open-source nature of MapServer, coupled with its strong community support, ensures reliability and fosters innovation in the realm of geospatial technology.

3.5 Comparison of GeoServer and MapServer

GeoServer and MapServer are two prominent open-source server software options designed for sharing geospatial data over the web. While both serve similar purposes, they exhibit distinct features, performance characteristics, and deployment scenarios tailored to diverse user needs.

Similarities:

1. **OGC-Compliant Services**: Both GeoServer and MapServer support essential OGC standards like WMS (Web Map Service) and WFS (Web Feature Service) for serving geospatial data.
2. **Data Format Support**: They provide extensive support for various geospatial data formats, ensuring compatibility with diverse data sources and systems.
3. **Customization**: Both platforms offer customization capabilities through scripting and configuration, enabling developers to adjust map styles and functionality.

Differences:

1. **User Interface and Administration**: GeoServer typically features a more intuitive administrative interface, while MapServer may require greater technical expertise for setup and configuration.
2. **Performance**: GeoServer is noted for its ease of use and quick setup, whereas MapServer is recognized for its robust performance and stability, particularly under high loads.
3. **Community and Support**: GeoServer boasts a larger user community and comprehensive documentation, appealing to users seeking extensive resources and community support.
4. **Deployment Options:**

5. **GeoServer**: Chosen for its user-friendly interface and straightforward setup, GeoServer suits organizations aiming to deploy geospatial services quickly with minimal technical complexity.
6. **MapServer**: Preferred by users needing high performance and scalability, MapServer excels in environments requiring robust handling of large datasets and heavy web traffic.

Use Cases:

GeoServer:

- **Government Agencies and NGOs**: Ideal for organizations needing rapid deployment of geospatial data for public access and decision-making.
- **Educational Institutions**: Often used in academic settings to teach geospatial concepts due to its accessibility and ease of use.

MapServer:

- **Large Enterprises**: Suitable for organizations requiring scalable solutions to manage substantial datasets and handle high volumes of web traffic.
- **Research Institutions**: Preferred for data-intensive research projects where performance optimization and customization capabilities are crucial.

3.6 Integration and Best Practices

GeoServer and MapServer are integral components of the Web GIS architecture, facilitating the publication and delivery of geospatial data through OGC-compliant web services. Integrating these servers with various components enhances the overall functionality and efficiency of Web GIS implementations.

Integration with Data Sources:

- **Database Integration:** Both GeoServer and MapServer seamlessly integrate with spatial databases like PostgreSQL/PostGIS and Oracle Spatial, enabling efficient management and retrieval of geospatial data.
- **File-Based Data Sources:** They also support diverse file formats (e.g., Shapefile, GeoJSON, GeoTIFF), allowing organizations to utilize existing data sources without extensive conversion efforts.

Integration with Client Applications:

- **Web Mapping Applications:** GeoServer and MapServer integrate with client-side mapping libraries (e.g., Leaflet, OpenLayers) for interactive visualization and interaction with geospatial data via web browsers.
- **Desktop GIS Software:** They serve as data sources or mapping services within desktop GIS applications such as QGIS or ArcGIS, facilitating seamless data exchange and analysis.

Integration with Geospatial Analysis Tools:

- **Geoprocessing Services:** Both platforms support integration with geoprocessing tools (e.g., GDAL, GRASS GIS) for executing complex spatial analysis tasks, enhancing analytical capabilities.
- **Spatial Analysis Models:** Integration with custom spatial analysis models enables automated decision-making processes based on geospatial data.

Best Practices for Configuring and Optimizing OGC Web Services

1. Performance Optimization:
    - Implement caching strategies to improve response times for frequently requested map tiles and data.
    - Distribute incoming requests across multiple server instances for balanced workload and optimal resource utilization.

    - Utilize data compression techniques (e.g., gzip) to reduce data transfer times and enhance overall performance.

2. Security Enhancements:
    - Implement robust access control mechanisms based on user roles and permissions to secure sensitive geospatial data and services.
    - Ensure secure data transmission between clients and server instances using HTTPS encryption to maintain data integrity and confidentiality.
3. Metadata Management:
    - Adhere to standardized metadata formats (e.g., ISO 19115) to enhance data discoverability and interoperability across different systems.
    - Utilize metadata catalogs within GeoServer and MapServer to manage descriptive information about geospatial datasets and services effectively.
4. Scalability and Resilience:
    - Scale horizontally by adding more server instances or leveraging cloud-based solutions to meet increasing user demands and data volumes.
    - Implement backup and recovery procedures to ensure continuous service and data availability in the event of hardware failures or system disruptions.
5. Monitoring and Maintenance:
    - Regularly monitor server performance metrics (e.g., CPU utilization, memory usage) to identify performance bottlenecks and optimize resource allocation.
    - Keep GeoServer and MapServer software up-to-date with the latest patches and updates to mitigate security vulnerabilities and benefit from new features.

By implementing these best practices, organizations can maximize the effectiveness of GeoServer and MapServer deployments within their Web GIS architectures, ensuring efficient data management, secure operations, and optimized performance across geospatial applications.

Summary

GeoServer and MapServer, along with adherence to OGC standards and best practices in integration and optimization, form the cornerstone of robust and interoperable geospatial infrastructure. By leveraging these technologies and principles, organizations can effectively manage, analyze, and share geospatial data, driving informed decision-making and innovation across various domains.

Chapter 4: Spatial Data and Databases for Web GIS

4.1 Introduction

Spatial data plays a pivotal role in a multitude of applications. Spatial data, which includes geographic information about the location and shape of physical features on the earth's surface, is fundamental to the functioning of Geographic Information Systems (GIS). As the internet continues to transform how we access and interact with information, Web GIS has emerged as a powerful tool for disseminating and analyzing spatial data over the web.

Web GIS combines the capabilities of GIS with the accessibility and connectivity of the internet, enabling users to visualize, query, and analyze spatial data through web browsers. Central to the effective functioning of Web GIS are spatial databases, which store and manage the vast amounts of spatial data required for analysis and visualization. Unlike traditional databases that handle only alphanumeric data, spatial databases are designed to efficiently store and process geometric data types, such as points, lines, and polygons. These specialized databases provide the foundation for spatial queries, spatial indexing, and other advanced spatial functions that are essential for Web GIS applications.

PostgreSQL, an advanced open-source relational database system, and its spatial extension, PostGIS, are among the most widely used technologies in the realm of spatial databases. PostgreSQL provides robust support for managing large datasets, while PostGIS adds powerful spatial capabilities, enabling complex spatial queries and operations.

Additionally, GeoNetwork is a key tool for managing and publishing spatial metadata. It allows organizations to catalog and share their spatial data resources efficiently, promoting better data discovery and interoperability. By integrating GeoNetwork with Web GIS platforms, users can easily access and utilize a wide range of spatial data, enhancing the overall effectiveness of spatial data management.

In this chapter, we will explore the fundamentals of spatial data and the crucial role of spatial databases in Web GIS. We will delve into the features and functionalities of PostgreSQL and PostGIS, and examine how GeoNetwork can be leveraged for effective spatial metadata management.

4.2 Spatial Databases

Spatial databases are uniquely designed to store, query, and manage spatial or geospatial data, which encompasses information about the physical location and shape of objects on Earth, including points, lines, and polygons. These databases are crucial in various domains such as geography, urban planning, environmental science, and location-based services.

4.2.1 Need for Spatial Databases

A spatial database is optimized for storing and querying data representing objects in geometric space. Unlike traditional databases that handle alphanumeric data, spatial databases include spatial data types and spatial relationships. The growing importance of spatial data in decision-making, spatial analysis, and geographic information systems (GIS) underscores the need for these specialized databases. Efficient management of spatial data requires advanced storage, indexing, and query capabilities that traditional databases lack.

4.2.2 Comparison with Traditional Databases

Traditional databases are structured to handle data in rows and columns, focusing on alphanumeric values and basic relationships. In contrast, spatial databases are tailored to manage complex data types such as points, lines, and polygons, and to handle spatial relationships and operations. While traditional databases use indexing methods like B-trees, spatial databases employ specialized techniques such as R-trees for optimizing spatial queries. Moreover, spatial databases support a range of spatial functions and operations not available in traditional databases.

4.2.3 Key Features of Spatial Databases

Spatial databases have several distinguishing features:

1. **Spatial Data Types**: Support for geometric data types like points, lines, polygons, and multi-polygons.
2. **Spatial Indexing**: Use of specialized indexing methods like R-trees, Quad-trees, and Grid indexing to enhance spatial query performance.
3. **Spatial Queries and Functions**: Capability to perform spatial queries and operations, including intersection, distance calculation, containment, and proximity analysis.
4. **Coordinate Systems and Projections**: Support for various coordinate systems and map projections to accurately represent spatial data.
5. **Integration with GIS**: Seamless integration with geographic information systems for advanced spatial analysis and visualization.

4.2.4 Spatial Data Types

Spatial databases support various spatial data types designed to represent different kinds of spatial information:

- **Point**: Represents a single location in space.
- **Line String**: Represents a sequence of points forming a continuous line.
- **Polygon**: Represents a closed, two-dimensional area defined by a sequence of points.
- **MultiPoint**: A collection of points.
- **Multi Line String**: A collection of Line Strings.
- **Multi Polygon**: A collection of polygons.

These data types enable the modelling of complex spatial phenomena and support advanced spatial analysis.

4.2.5 Spatial Indexing

Efficient querying of spatial data requires specialized indexing techniques. Spatial databases use various spatial indexing methods to boost query performance:

- **R-tree**: A tree data structure for indexing multi-dimensional information like geographical coordinates.
- **Quad-tree**: A tree structure in which each internal node has exactly four children, used to partition two-dimensional space.
- **Grid Indexing**: Divides the space into a grid and indexes each cell, which can be effective for certain types of spatial queries.

Spatial indexing is essential for managing large datasets and ensuring efficient execution of spatial queries.

4.2.6 Spatial Queries and Functions

Spatial databases offer a comprehensive set of functions and query capabilities for spatial data analysis. Common spatial queries and functions include:

- **Proximity Queries**: Finding objects within a specified distance from a given point.
- **Spatial Joins**: Combining two spatial datasets based on their spatial relationships.
- **Intersection**: Determining whether two spatial objects intersect and identifying the intersecting geometry.
- **Containment**: Checking if one spatial object is contained within another.
- **Distance Calculation**: Measuring the distance between spatial objects.

These queries and functions facilitate complex spatial analysis and are vital for applications in GIS, urban planning, environmental monitoring, and more. Spatial databases are crucial for managing and analyzing spatial data. They offer specialized data types, indexing methods, and query capabilities that traditional databases do not possess. Their ability to efficiently store and process spatial information makes them indispensable in a wide range of applications relying on geographic data.

4.3 PostgreSQL

PostgreSQL is a powerful, open-source relational database management system (RDBMS) known for its robustness, flexibility, and standards compliance. It is widely used in various applications due to its support for complex queries, extensive data types, and advanced features. It can be downloaded freely (**https://www.postgresql.org/download/**). PostgreSQL's architecture is designed to handle large volumes of data and high transaction rates, making it a popular choice for enterprise-level applications.

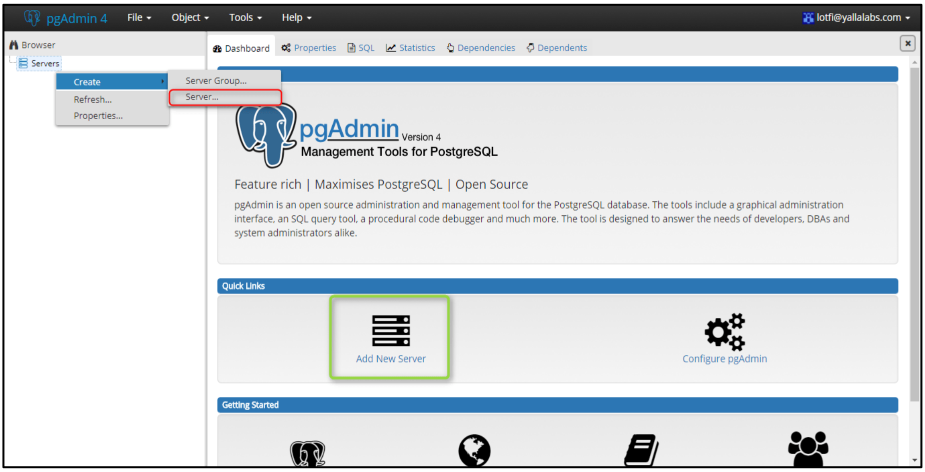
PostgreSQL offers numerous features that contribute to its popularity:

- **ACID Compliance**: Ensures data integrity and reliability through atomicity, consistency, isolation, and durability.
- **Extensibility**: Supports custom data types, functions, operators, and index methods.
- **Advanced Security**: Provides robust authentication, authorization, and data encryption mechanisms.
- **Concurrency Control**: Utilizes multi-version concurrency control (MVCC) to handle multiple transactions simultaneously.
- **Full-Text Search**: Includes powerful full-text search capabilities for indexing and querying large text datasets.
- **Internationalization**: Supports various character encodings, languages, and locale settings.

These features make PostgreSQL a versatile and reliable choice for a wide range of applications.

4.3.1 pgAdmin

pgAdmin is a comprehensive, open-source management tool for PostgreSQL, designed to facilitate database administration and development. It provides a user-friendly graphical interface that allows users to interact with their PostgreSQL databases more efficiently. With pgAdmin, user can create, modify, and delete databases and tables, execute SQL queries, and manage database objects. The tool also offers features for backing up and restoring databases, monitoring server performance, and scheduling tasks. pgAdmin's intuitive design makes it accessible for both beginners and advanced users, enabling practical, hands-on access to PostgreSQL (Figure 4). By providing a visual representation of database structures and operations, pgAdmin simplifies complex database tasks and enhances productivity.



pgAdmin is an open source administration and management tool for the PostgreSQL database. The tools include a graphical administration interface, an SQL query tool, a procedural code debugger and much more. The tool is designed to answer the needs of developers, DBAs and system administrators alike.

Figure 4 pgAdmin4 viewer

4.3.2 PostGIS Extension

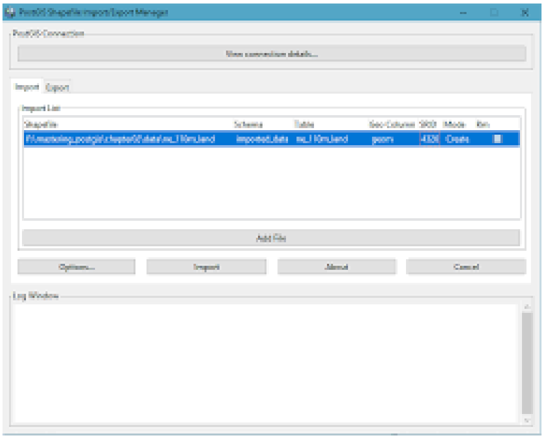
PostGIS is a spatial database extender for PostgreSQL, enabling it to store, query, and manage spatial data. PostGIS adds support for geographic objects, allowing users to perform spatial queries and analysis within the PostgreSQL environment. It is widely used in geographic information systems (GIS), spatial data analysis, and location-based services.

Installing and Configuring PostGIS

To use PostGIS, user need to install and configure it within your PostgreSQL database. The process typically involves:

1. **Installing PostGIS**: Use package managers or build from source to install PostGIS on user PostgreSQL server.
2. **Enabling PostGIS Extension**: Activate the PostGIS extension within user PostgreSQL database by running SQL commands to create the necessary functions, types, and tables.

Once installed, PostGIS integrates seamlessly with PostgreSQL, extending its capabilities to handle spatial data (Figure 5).



Shapefile	Schema	Table	Geo Column	SRID	Mode	Rm
F:\mastering_postgis\chapter02\data\ne_110m_land	imported_data	ne_110m_land	geom	4326	Create	

Figure 5 PostGIS GUI

PostGIS offers a wide range of features and capabilities, including:

- **Spatial Data Types**: Supports geometric and geographic data types such as points, lines, and polygons.

- **Spatial Functions**: Provides numerous functions for spatial analysis, including distance calculations, intersections, and area computations.
- **Spatial Indexing**: Uses spatial indexing methods like R-trees and GIST (Generalized Search Trees) to optimize spatial queries.
- **Coordinate Reference Systems**: Supports various coordinate reference systems and transformations between them.
- **Integration with GIS Software**: Works seamlessly with popular GIS software for advanced spatial analysis and visualization.

These features make PostGIS a powerful tool for managing and analyzing spatial data within PostgreSQL.

Creating Spatial Tables

Creating spatial tables in PostGIS involves defining columns with spatial data types. For example, you can create a table to store point locations with the following SQL command:

```
CREATE TABLE locations (

   id SERIAL PRIMARY KEY,

   name VARCHAR(100),

   geom GEOMETRY(Point, 4326) );
```

This command creates a table with an ID, name, and geometry column to store point data in the WGS 84 coordinate system.

Inserting and Querying Spatial Data

To insert spatial data into a PostGIS table, use the ST_GeomFromText function to convert well-known text (WKT) into a geometry object:

```
INSERT INTO locations (name, geom)
```

```
VALUES ('Central Park', ST_GeomFromText('POINT(-73.9654 40.7829)', 4326));
```

Querying spatial data involves using spatial functions to filter and retrieve data based on spatial relationships. For example, to find all points within a certain distance from a given location:

```
SELECT name

FROM locations

WHERE ST_DWithin(geom, ST_GeomFromText('POINT(-73.9654 40.7829)', 4326),
1000);
```

This query returns all locations within 1000 meters of the specified point.

Spatial Functions and Operations

PostGIS provides a rich set of spatial functions and operations for analyzing spatial data. Some common functions include:

- **ST_Intersection**: Computes the geometric intersection of two geometries.
- **ST_Union**: Merges multiple geometries into a single geometry.
- **ST_Area**: Calculates the area of a polygon.
- **ST_Distance**: Measures the distance between two geometries.

These functions enable complex spatial analysis and are fundamental to spatial data processing.

Indexing Spatial Data for Performance

Efficient querying of spatial data requires indexing. PostGIS supports spatial indexing using GIST indexes. To create a spatial index on a geometry column, use the following SQL command:

```
CREATE INDEX idx_locations_geom ON locations USING GIST (geom);
```

Spatial indexing significantly improves query performance, especially for large datasets, by allowing the database to quickly locate spatial objects based on their geometric properties.

PostgreSQL combined with the PostGIS extension provides a powerful platform for managing and analyzing spatial data. With its advanced features, robust performance, and extensive spatial capabilities, it is an ideal solution for applications requiring spatial data processing and analysis.

Summary

Spatial data, encompassing both vector and raster formats, is crucial for depicting geographic phenomena in fields such as urban planning, environmental monitoring, and navigation. Web GIS enables the online distribution and analysis of spatial data through components like web servers, GIS software, and clients, providing accessibility and real-time sharing, albeit with challenges in security and complexity. Spatial databases are adept at storing and managing spatial data, offering support for various data types (e.g., points, lines, polygons), spatial indexing methods (e.g., R-trees), and complex queries. PostgreSQL, an open-source database management system, when enhanced with PostGIS, effectively handles geographic data through specialized functions and indexing. GeoNetwork, an open-source cataloging application, manages spatial metadata in line with standards such as ISO 19115, and integrates seamlessly with Web GIS.

Chapter 5: Spatial Data Infrastructure

5.1 Overview of SDI

Geospatial data are now-a-days vitally used across many applications and sectors like natural resources management, disaster management, governance, education etc. for informed decision making. Geospatial datasets are primarily captured, stored and managed by various agencies using Geographical Information Systems (GIS) often resulting in duplication of efforts among agencies and users. Further, there is a need for proper mechanism for cataloguing data for future use and also for the ease of accessing datasets. Spatial Data Infrastructure (SDI) serves as the backbone for managing, accessing, and sharing geospatial data efficiently and effectively. Such infrastructures allow for reusability and easy access of geospatial datasets to various stakeholders in a typical organizational setup hence avoiding data duplication and also eases the major issues of data discovery and access. The concept of SDI emerged in response to the ever-growing recognition of the value of geographic information and the vital need to overcome barriers to its access and effective utilization.

Spatial Data Infrastructure (SDI) is defined as the "base collection of technologies, policies and institutional arrangements that facilitate the availability and access to spatial data"(Nebert, 2004). It avoids data duplication, enables data sharing and makes data readily searchable and available to various stakeholders. Government and institutions across the world have identified the usefulness of geospatial dataset access and utilization for planning uses using such infrastructure, hence in the literature one can find different levels of SDIs viz. Global to local including at organisation level called corporate level (Figure 6).

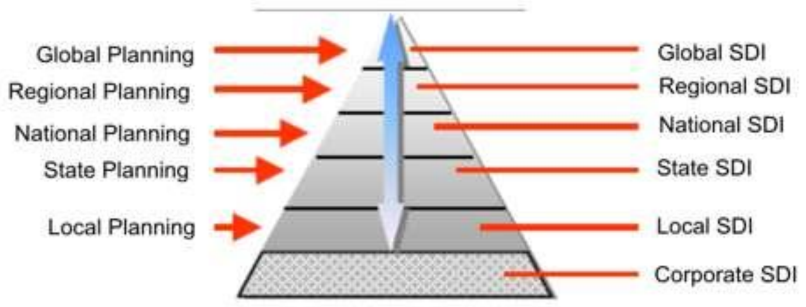


Figure 6 Different Levels of Spatial Data Infrastructure (source: https://sensorsandsystems.com/sdis-and-regional-competitiveness)

SDI encompasses a range of concepts and components, including datasets (framework & thematic), metadata standards, and clearinghouses.

5.2 SDI datasets

There are two broad categories of data available under SDI, namely framework data and thematic data. Table 1 list some examples of both types of datasets available under SDI.

Table 1: SDI Datasets

S. No.	Data	Examples
1	Framework Data	• Boundaries (government units) • Road Network • Hydrology • Satellite data • Digital Elevation Model etc.
2	Thematic data	• Land use/ Land cover • Geology • Vegetation • Biodiversity • Forest • Additional themes like flood, geo-tourism sites, etc.

5.3 Metadata and Standards

Metadata i.e. "data about the data" is very important concept in the context of SDI providing essential information about spatial datasets, including their content, spatial properties of extent, quality, and accessibility. Metadata provides the foundation information to define a searchable catalog of data in the SDI (Simmons, 2018).

Metadata standards, such as ISO 19115, FGDC (Federal Geographic Data Committee), National Spatial Data Infrastructure (NSDI) standard prescribe the structure and format for documenting geospatial data, ensuring consistency and interoperability across different SDI implementations. Further metadata apart from data cataloguing also enables users to discover, evaluate, and utilize spatial data effectively, enhancing data transparency, trustworthiness, and fitness of reuse. Here the Indian NSDI 2.0 metadata standard (which is also used by the NRSC Bhuvan portal) was used for cataloguing the datasets having following metadata fields for each dataset (Table 2). The basic metadata category includes:

- Data Identification Information
- Contact Information
- Geographic Location
- Coverage
- Citation
- Metadata Stamp
- Dataset Topic Category
- Language
- Abstract describing the data and
- Data Quality

Table 2 : Indian NSDI Metadata Items

S.No	Metadata Category	Metadata Items	
1	Data Identification Information	Name of the Dataset	
2		Theme	
3		Keywords	
4		Access Constraints	
5		Use Constraints	
6		Purpose of creating data	
7		Data Type	
8		Edition	
9		Status	
10	Contact Information	Contact Person	
11		Organisation	
12		Mailing Address	
13		City/Locality	
14		Country	
15		Contact Telephone	
16		Contact Fax	
17		Contact Email	
18	Geographic Location	Spheroid / Datum	
19	Coverage	Upper left	
20		Upper right	
21		Lower right	
22		Lower left	
23	Citation	Data Prepared by	
24		Original Source	
25		Source Date	
26		Lineage	State
27			Area of Interest (Sq.Km)
28			Scale
29		Corporate Name (Partner Institution)	
30	Metadata Stamp	Metadata Date Stamp	
31	Dataset Topic Category	Data Identification topic category	
32	Language	Language ISO 0639-2Bsh	
33	Abstract describing the data	Data Identification abstract	
34	Data Quality	Accuracy	

5.4 Clearing house

Clearinghouse serve as centralized repositories within SDI, facilitating the discovery, access, and distribution of spatial data and services. These clearinghouses employ metadata catalogs and search tools to enable users to find relevant datasets based on theme or keywords. Clearinghouses also promote data sharing and collaboration by providing mechanisms for data exchange, interoperability, and collaboration among stakeholders. The typical component of an SDI is shown in figure 7 .

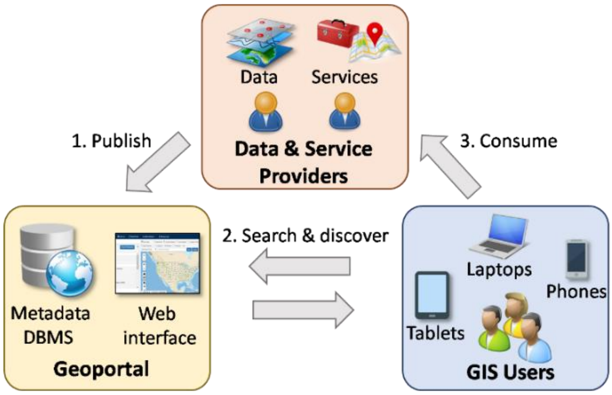


Figure 7 SDI component and architecture

The three main components of SDI are :

Data & Service providers: They primarily publish the GIS resources (data or services) to the centralized geoportal.

Geoportal: It serves as the single window access platform implemented using Internet based GIS technology, enabling users to search and find the desired geospatial data (framework & thematic) and services.

GIS Users- are the end-users who consume and use the data and services provided by the providers

The users can access the SDI either through PCs/Laptops, mobile phone and tablets. The users search for the datasets based on metadata items using keywords attributes of the datasets organised in the backend database using a particular metadata standard. Metadata details are organized and stored as per the Indian NSDI 2.0 metadata standard in the backend database systems.

5.5 GeoNetwork

GeoNetwork is an open-source cataloging application designed to manage spatially referenced resources. It facilitates the discovery, editing, and sharing of geospatial data and metadata, making it an essential tool for organizations that require efficient access to geospatial information. The main purpose of GeoNetwork is to improve the availability and accessibility of geospatial data across different users and systems, fostering collaboration and informed decision-making.

5.5.1 Features and Benefits of GeoNetwork

GeoNetwork offers a range of features that enhance its utility:

- **User-Friendly Interface**: Intuitive web-based interface for easy interaction with spatial metadata.
- **Metadata Management**: Comprehensive tools for creating, editing, and validating metadata.
- **Standards Compliance**: Support for international metadata standards like ISO 19115 and INSPIRE.
- **Search and Discovery**: Advanced search capabilities to find spatial data quickly and efficiently.
- **Interoperability**: Seamless integration with other geospatial tools and services through OGC standards.

These features make GeoNetwork a robust platform for managing and disseminating spatial data, promoting data sharing, and improving spatial data infrastructures.

5.5.2 Installing and Configuring GeoNetwork

Before installing GeoNetwork, user must ensure that the server/system meets the following requirements:

- **Operating System**: Compatible with major OS like Windows, Linux, and macOS.
- **Java Runtime Environment (JRE)**: Required for running GeoNetwork.
- **Web Server**: Apache Tomcat or another supported web server.
- **Database**: PostgreSQL, MySQL, or another supported database system for storing metadata.

Installation Steps

To install GeoNetwork, follow these steps:

1. **Download GeoNetwork**: Obtain the latest version from the GeoNetwork website.
2. **Install Java**: Ensure JRE is installed and configured on your system.
3. **Set Up Web Server**: Install and configure Apache Tomcat or another supported web server.
4. **Deploy GeoNetwork**: Deploy the GeoNetwork WAR file to your web server.
5. **Configure Database**: Set up your database and configure GeoNetwork to connect to it.

These steps will get GeoNetwork up and running, ready for configuration and use.

Configuration Options

GeoNetwork offers various configuration options to tailor the system to your needs:

- **User Management**: Define user roles and permissions to control access to data and metadata.

- **Metadata Templates**: Create templates for different types of metadata to streamline the creation process.
- **Search Settings**: Customize search parameters and indexing options to enhance data retrieval.
- **Interface Customization**: Modify the user interface to match organizational branding and preferences.

These configuration options ensure that GeoNetwork can be adapted to suit specific organizational requirements.

5.5.3 Managing Spatial Metadata with GeoNetwork

GeoNetwork provides tools for creating and editing metadata, allowing users to document spatial data comprehensively. The platform supports various metadata elements, including title, abstract, geographic extent, and data quality. Users can create metadata from scratch or use predefined templates to expedite the process.

Metadata Standards and Formats

GeoNetwork supports multiple metadata standards and formats to ensure compatibility and interoperability. Key standards include:

- **ISO 19115**: International standard for geographic information metadata.
- **INSPIRE**: European directive for spatial data infrastructure.
- **Dublin Core**: Simple metadata standard for resource description.

Supporting these standards ensures that metadata can be shared and understood across different systems and organizations.

Searching and Cataloging Spatial Data

GeoNetwork's advanced search functionality allows users to find and retrieve spatial data quickly. Users can search using keywords, geographic extent, and other metadata attributes. The cataloging feature organizes metadata records, making it easy to maintain and update spatial data inventories.

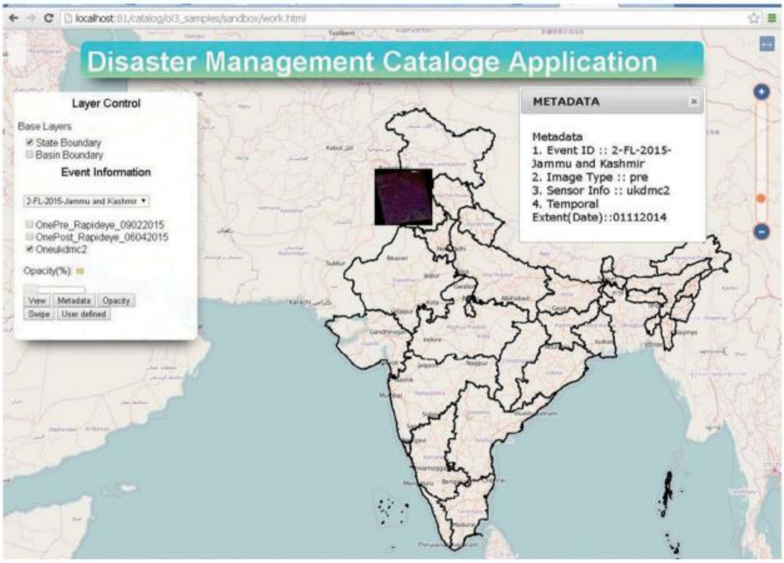
5.5.4 Integrating GeoNetwork with Web GIS

Connecting GeoNetwork with Spatial Databases

GeoNetwork can be integrated with spatial databases such as PostgreSQL/PostGIS to manage and query spatial data effectively. This integration allows users to store spatial data in a robust database system and leverage GeoNetwork's metadata management capabilities for better data organization and retrieval.

Publishing Spatial Data and Services

GeoNetwork enables the publication of spatial data and services, making them accessible to a broader audience. Users can publish Web Map Services (WMS), Web Feature Services (WFS), and other OGC-compliant services directly from GeoNetwork. This functionality supports the creation of dynamic, interactive maps and geospatial applications that can be accessed over the web. Figure 8 shows web application developed over GeoNetwork for organising, cataloguing, searching and retrieval of satellite data for Disaster Management Support.


localhost:81/catalog/ol3_samples/sandbox/work.html
Disaster Management Cataloge Application
Layer Control
Event Information
Opacity(%): 10
View
Metadata
Opacity
Swipe
User defined
METADATA

Base Layers
☑ State Boundary
☐ Basin Boundary

2-FL-2015-Jammu and Kashmir

☐ OnePre_Rapideye_09022015
☐ OnePost_Rapideye_06042015
☑ Oneukdmc2

Metadata
1. Event ID :: 2-FL-2015-Jammu and Kashmir
2. Image Type :: pre
3. Sensor Info :: ukdmc2
4. Temporal Extent(Date)::01112014

Figure 8 DMS application for cataloguing and searching satellite dataset (Source: Sharma, Vinod Kumar, et al. "Assessing the potential of open-source libraries for managing satellite data products–A case study on disaster management." Annals of GIS 23.1 (2017)

GeoNetwork is a powerful tool for managing spatial metadata and facilitating the discovery and sharing of geospatial data. Its robust features and flexibility make it an essential component of any geospatial data infrastructure.

Chapter 6: Web GIS Tools and Platform

Web GIS (Geographic Information Systems) tools and platforms provide a means to visualize, analyse, and manage spatial data on the web. These tools are used across various sectors, including urban planning, environmental management, transportation, and more. Here are some popular Web GIS tools and platforms:

6.1 Open-Source Web GIS Tools:

6.1.1 OpenLayers

OpenLayers is an open-source JavaScript library for displaying dynamic maps in web browsers. It provides a powerful and versatile framework for building interactive map applications, supporting a variety of geographic data formats and services. OpenLayers is widely used in web mapping due to its flexibility, extensibility, and the robust set of features it offers.

Key Features

Multiple Map Projections: OpenLayers supports various map projections, allowing developers to display maps in different coordinate systems. This is crucial for accurately representing geographical data.

Layer Support: The library supports different types of layers, including vector layers, raster layers, and tiled map layers. This enables the integration of diverse data sources, such as WMS (Web Map Service), WMTS (Web Map Tile Service), and XYZ tile sources.

Rich Interaction Capabilities: OpenLayers provides extensive tools for user interaction, including zooming, panning, and feature selection. It also supports advanced interactions like drawing and modifying geometries directly on the map.

Styling and Customization: With OpenLayers, developers can customize the appearance of their maps through various styling options. This includes customizing the look of map layers, vector features, and controls.

Integration with External Data Sources: OpenLayers can integrate with numerous external data sources, including GeoJSON, KML, and GML. This allows for the easy incorporation of geographical data from different formats into a single map application.

Performance Optimization: The library includes features for optimizing map performance, such as tile caching, clustering for point data, and the use of WebGL for rendering complex geometries.

Creating a Map using Openlayers

To start using OpenLayers, you need to include the OpenLayers library in your HTML file. It can be done by adding the following lines to HTML `<head>` section:

```
<link rel="stylesheet" href="https://cdn.jsdelivr.net/npm/ol/ol.css" type="text/css">
<script src="https://cdn.jsdelivr.net/npm/ol/ol.js"></script>
```

Here's a basic example of creating a simple map with OpenLayers:

```
<!DOCTYPE html>
<html lang="en">
<head>
   <meta charset="UTF-8">
   <title>OpenLayers Basic Map</title>
   <link rel="stylesheet" href="https://cdn.jsdelivr.net/npm/ol/ol.css" type="text/css">
   <style>
      #map {
         width: 100%;
         height: 500px;
      }
   </style>
</head>
<body>
   <div id="map"></div>
   <script src="https://cdn.jsdelivr.net/npm/ol/ol.js"></script>
   <script>
      var map = new ol.Map({
         target: 'map',
      layers: [
        new ol.layer.Tile({
          source: new ol.source.OSM()
        })
      ],
      view: new ol.View({
        center: ol.proj.fromLonLat([0, 0]),
        zoom: 2
      })
    });
  </script>
</body>
</html>
```

This code sets up a basic OpenLayers map centered on the coordinates [0, 0] with a zoom level of 2, using OpenStreetMap as the tile source.

OpenLayers offers a range of built-in interactions and controls to enhance user interaction with the map. These include default interactions like pinch zoom, double-click zoom, drag pan, and more specialized controls like drawing tools.

Here’s an example of adding a drawing interaction to the map:

```
<script>
  var draw = new ol.interaction.Draw({
    source: vectorSource,
    type: 'Polygon'
  });
  map.addInteraction(draw);
</script>
```

OpenLayers is a robust and flexible library for building web-based map applications. Its extensive feature set, support for multiple data formats, and rich interaction capabilities make it an ideal choice for developers looking to create sophisticated mapping solutions. Whether you need to display simple maps or build complex geographic information systems (GIS), OpenLayers provides the tools necessary to achieve your goals.

6.1.2 Leaflet

Leaflet is a modern, open source JavaScript library developed to build interactive maps for mobile devices. It works efficiently on all major desktop and mobile platforms, taking advantage of HTML5 and CSS3 in modern browsers, while also supporting access to older browsers. Support for plug-in extensions, with a friendly, easy-to-use API documentation and a simple, readable source code. Leaflet's powerful open-source library plug-in involves all aspects of map applications, including map services. There are more than 140 plug-ins for data provision, data format, geocoding, route and route search, map controls and interactions. These controls enrich the functions of leaflet, at the same time, it is very convenient to implement custom controls with good expansibility.

Key Features of Leaflet

Lightweight and Performance-Optimized: Leaflet is designed to be fast and responsive, with a small file size (~38 KB). It offers smooth interaction and high performance on both desktop and mobile devices.

Ease of Use: Leaflet's API is simple and well-documented, making it easy for developers to get started. It has a straightforward setup process with minimal boilerplate code.

Customizable: Leaflet supports various map tile providers, including OpenStreetMap, Mapbox, and more. Developers can customize maps extensively using a wide range of plugins and extensions.

Rich Functionality: Supports various features like markers, popups, vectors (polylines, polygons), image overlays, and tile layers. Offers built-in controls for zooming, panning, scale display, and more.

Responsive Design: Leaflet is optimized for mobile devices, offering touch interaction and responsiveness out-of-the-box.

Extensible with Plugins: A vibrant ecosystem of plugins extends Leaflet's capabilities, adding functionalities like heat maps, clustering, geocoding, and more. Examples include Leaflet Draw (for drawing shapes), Leaflet Heat (for heat maps), and Leaflet Marker Cluster (for clustering markers).

Creating a Map using Leaflet

We can create a map in the 'map' div (Figure 9), add tiles of our choice, and then add a marker with some text in a popup:

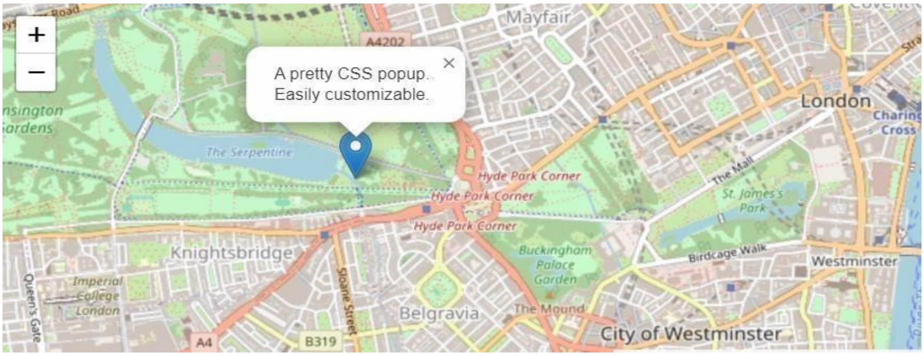


Figure 9 Map created using Leaflet

Below are the steps for creating the map:

1. Including Leaflet in a project

 Include the Leaflet CSS and JavaScript files in your HTML Page:

```
<link rel="stylesheet" href="https://unpkg.com/leaflet/dist/leaflet.css" /><script
src="https://unpkg.com/leaflet/dist/leaflet.js"></script>
```

2. Creating a Map

 Initialize a map by specifying a DOM element and setting the view to a particular geographical location and zoom level:

```
var map = L.map('map').setView([51.505, -0.09], 13);
```

3. Adding Tile Layers

 Add a tile layer to the map, typically from a tile provider like OpenStreetMap:

```
L.tileLayer('https://tile.openstreetmap.org/{z}/{x}/{y}.png', {
   maxZoom: 19,
   attribution: '&copy; <a
href="http://www.openstreetmap.org/copyright">OpenStreetMap</a>'
}).addTo(map);
```

4. Adding Markers and Popups

 Add markers and popups to the map:

```
var marker = L.marker([51.5, -0.09]).addTo(map); marker.bindPopup("<b>A CSS
popup. </b> <br>Easily  customizable.").openPopup();
```

5. Using Plugins

 Extend functionality by including plugins. For example, to add a marker clustering feature, you might include the Leaflet.markercluster plugin:

```
<link rel=”stylesheet”
href="https://unpkg.com/leaflet.markercluster/dist/MarkerCluster.css" />
<script
src=”https://unpkg.com/leaflet.markercluster/dist/leaflet.markercluster.js"></script>
```

Advantages

- **Open Source:** Free to use and modify.
- **Community Support**: Extensive community contributions and support forums.
- **Documentation**: Comprehensive and clear documentation with numerous examples.
- **Integration**: Easy integration with other libraries and frameworks like Angular, React, and Vue.js.

Limitations

- **Simplicity**: While its simplicity is an advantage, it might lack some advanced features available in other GIS tools.
- **Performance with Large Datasets**: May struggle with performance when handling very large datasets compared to more robust GIS platforms.

6.2 Servers for Web GIS

6.2.1 Geo Server

GeoServer is a robust and popular open-source server that enables users to share, process, and edit geospatial data. It is designed to publish spatial information using open standards, allowing for the creation of interoperable spatial data services and applications.

Overview

- **Website:** GeoServer
- **License:** GNU General Public License (GPL)
- **Language:** Java
- **Supported Data Formats:** Vector (Shapefile, PostGIS, GeoJSON, GML, etc.), Raster (GeoTIFF, ArcGrid, etc.)

Key Features

1. Standards Compliance

GeoServer supports a wide range of Open Geospatial Consortium (OGC) standards such as Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS), and Web Processing Service (WPS).

2. Data Interoperability

It allows integration with numerous data sources, including relational databases (e.g., PostgreSQL/PostGIS, Oracle, MySQL), flat file formats (e.g., Shapefile, GeoTIFF), and web services (e.g., WMS, WFS).

3. Styling and Visualization

Uses the Styled Layer Descriptor (SLD) standard to define how data should be visualized, enabling advanced cartographic rendering and theming. Supports CSS-like styling with GeoServer CSS and the more advanced GeoCSS.

4. Spatial Processing

Provides tools for spatial processing and analysis through WPS, enabling complex geospatial operations such as buffering, clipping, and reprojection.

5. Scalability and Performance

Designed to handle large datasets and high-demand environments with performance optimizations like spatial indexing and caching (GeoWebCache integration).

6. Extensibility

GeoServer's modular architecture allows for extensions and plugins, enabling additional functionalities like advanced data formats, security enhancements, and specialized processing capabilities.

7. User-Friendly Interface

Includes a web-based administration interface for easy configuration and management of data stores, layers, services, and settings.

Basic Usage

Installation and Setup

GeoServer can be installed on various operating systems (Windows, Linux, MacOS). It requires Java and can be run as a standalone application or deployed in a servlet container like Apache Tomcat.

1. Download and install GeoServer
2. Publishing Data
   - **Data Stores:** Add a data store to connect to a source of spatial data.
     - Go to the GeoServer web admin interface.
     - Navigate to Stores > Add new Store.
     - Select the type of data source (e.g., Shapefile, PostGIS).
     - Configure the connection parameters (file path, database connection details).
   - **Layers:** Create layers from the data stores to publish your spatial data.
     - Navigate to Layers > Add a new Layer.
     - Select the data store and the data source (e.g., specific table or file)
     - Configure layer settings, including default styles and bounding boxes.
3. Configuring Services
   - **WMS (Web Map Service):** Provides map images based on spatial data.
     - Enable WMS in the Services section.
     - Configure basic settings, such as the title, abstract, and contact information.
   - **WFS (Web Feature Service):** Allows querying and editing of features.
     - Enable WFS and configure settings similar to WMS.
   - **WCS (Web Coverage Service):** For raster data access and processing.
     - Enable WCS if dealing with raster data.
4. Styling Data
   - Use the integrated style editor to create and manage SLD or CSSbased styles for layers.
     - Navigate to Styles > Add a new Style.

- Use the graphical style editor or upload an SLD file - Apply the style to the desired layer.
- Accessing Published Data

5. Access your published layers via standard URLs, e.g., for WMS:
   - WMS GetCapabilities:

   http://geoserver-url/geoserver/ows?service=WMS&request=GetCapabilities`

   - WFS GetCapabilities:

   'http://geoserver-url/geoserver/ows?service=WFS&request=GetCapabilities`

Advantages

- **Interoperability:** Complies with OGC standards, ensuring compatibility with various GIS clients and applications.
- **Flexibility:** Supports a wide range of data formats and services, making it versatile for different geospatial tasks.
- **Community and Support:** Strong open-source community with extensive documentation, tutorials, and user forums.
- **Integration:** Works well with other GIS software and platforms like QGIS, OpenLayers, Leaflet, and more.

Limitations

- **Complexity:** Can be complex to set up and configure for new users, particularly those without a background in GIS.
- **Performance:** May require tuning and optimization for very large datasets or high-load environments.

GeoServer is a powerful and flexible tool for managing and serving geospatial data on the web. Its support for open standards and wide range of functionalities make it an excellent choice for building robust Web GIS applications. Whether you need to publish maps, provide data services, or perform spatial analysis, GeoServer offers a comprehensive solution to meet your needs.

6.2.2 Map Server

MapServer is another robust open-source platform for publishing spatial data and interactive mapping applications to the web. Originally developed by the University of Minnesota, MapServer has evolved to become a widely used tool for serving geospatial data over the web.

Overview

- **Website:** MapServer
- **License:** MIT License
- **Language:** C
- **Supported Data Formats:** Vector (Shapefile, PostGIS, GeoJSON, GML, etc.), Raster (GeoTIFF, ArcGrid, etc.)

Key Features

1. Standards Compliance

Supports a range of Open Geospatial Consortium (OGC) standards including Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS), and Web Map Tile Service (WMTS).

2. High Performance

Known for its speed and efficiency, capable of handling large datasets and highdemand environments. Optimized for both raster and vector data rendering.

3. Flexibility

Can be used for both simple and complex mapping applications. Highly configurable, allowing detailed customization of map rendering and data processing.

4. Data Interoperability

Integrates with various data sources, including relational databases (e.g., PostgreSQL/PostGIS, Oracle, MySQL), flat file formats (e.g., Shapefile, GeoTIFF), and web services (e.g., WMS, WFS).

5. Advanced Cartography

Supports complex styling and rendering capabilities using Mapfile syntax. Allows for detailed control over the appearance and behavior of maps.

6. Extensibility

Modular architecture with support for numerous extensions and plugins to add additional functionality. Extensible through scripting languages like Python and PHP.

Advantages

- **Performance**: High-speed rendering and efficient handling of large datasets.
- **Flexibility**: Highly configurable and capable of supporting a wide range of mapping applications.
- **Standards Compliance:** Supports numerous OGC standards, ensuring interoperability with various GIS clients and applications.
- **Open Source:** Free to use and modify, with a strong community and extensive documentation.

6.3 Commercial Web GIS Platforms

- ArcGIS Online (Esri)
- Google Maps Platform
- Mapbox
- Carto

6.3.1 ArcGIS Online (Esri)

ArcGIS Online, developed by Esri, is a cloud-based mapping and analysis platform that provides comprehensive tools for creating, sharing, and analysing geospatial data. It is widely used for its robust features and integration with other ArcGIS products.

ArcGIS Online operates under a proprietary license that offers various subscription-based tiers to accommodate different user needs. The platform supports a wide range of data formats, including Shapefiles, GeoJSON, CSV, KML, and many others, making it a versatile tool for handling diverse geospatial data.

6.3.2 Google Map Platform

The Google Maps API, a JavaScript based programming interface provides multiple functions which may be used to support queries, manipulate maps and edit geodata. A server based spatial database with GIS-functions can be used to analyse geodata and to store them permanently in an appropriate geodata format. With the combination of the Google Maps API and open source software it becomes possible to develop the web-based system GMGIS which uses the geodata infrastructure of Google Maps and calls all GIS-functions within a browser which are then performed on a server. This new system has more functionality than only presenting and browsing geodata especially tools that generate new geographic datasets from existing datasets. Figure 10 summarizes the system components.

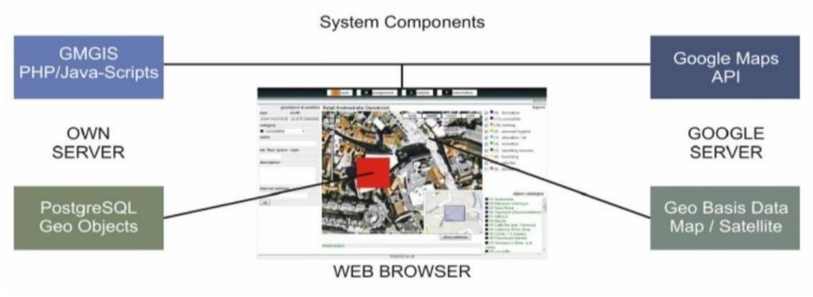


Figure 10 System Component for Web GIS with Google map platform

6.3.3 Mapbox

Mapbox is a widely used web mapping platform that provides developers and businesses with powerful tools to create, customize, and publish interactive maps. It offers a range of APIs, SDKs, and developer tools that empower users to integrate maps and geospatial data into their applications or websites. Mapbox offers SDKs for popular programming languages such as JavaScript, Android, iOS, Unity, and more. These SDKs provide pre-built components and functions that simplify the integration of maps into applications across different platforms.

Mapbox is built on a highly scalable infrastructure that can handle large volumes of map requests and user traffic.

6.3.4 CARTO (CartoDB) – The Geospatial Platform in the Cloud

CARTO is the leading cloud-native location intelligence platform for GIS scientists and professionals. One of the big issues today is that we don't know how to use the growing demand for data to visualize and analyze. CARTO is where data meets maps on the web. Instead of using desktop GIS software, CARTO provides it all in the cloud. As long as you have an internet connection, you can access it with just a web browser. The biggest benefit of a cloud-native approach is the ability to leverage cloud computing resources and technologies that are highly scalable, flexible, and efficient.

Behind the scenes, CARTO leverages PostgreSQL + PostGIS as a web service. User can have complete control of a fully managed database. Figure 11 shows a simple architecture diagram for how CARTO works.

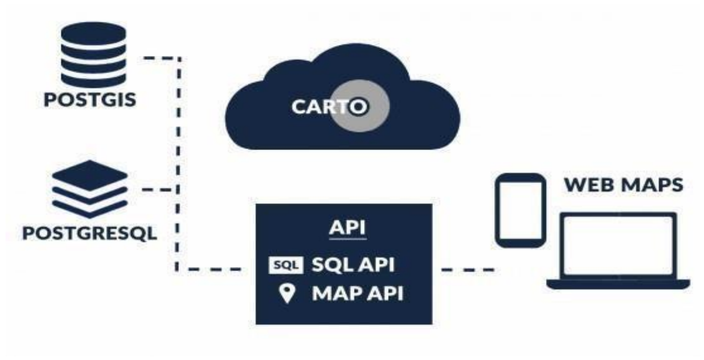


Figure 11 :simple architecture diagram for how CARTO works

Chapter 7: Developing Web GIS Applications

To create & display interactive map on the web we use a programming language. One of the most common and versatile technologies for web mapping is JavaScript, a programming language that runs in the browser and can manipulate the web page elements.

JavaScript is a scripting language that can be embedded in HTML and executed by the browser. It can access and modify the web page elements, such as text, images, forms, and maps, using the Document Object Model (DOM). JavaScript can also use various libraries and frameworks that provide ready-made map components, such as Leaflet, OpenLayers, Mapbox GL JS, Google Maps API, and D3.js.

For displaying interactive map, we will be using ReactJS and Openlayers.

ReactJS: ReactJS is an open-source JavaScript library, crafted with precision by Facebook, that aims to simplify the intricate process of building interactive user interfaces and ReactJS is most widely used Technology for Web GIS.

Openlayers: OpenLayers is a powerful, open-source JavaScript library designed for displaying map data in web browsers. It allows developers to create dynamic and interactive maps by integrating various mapping services and data sources.

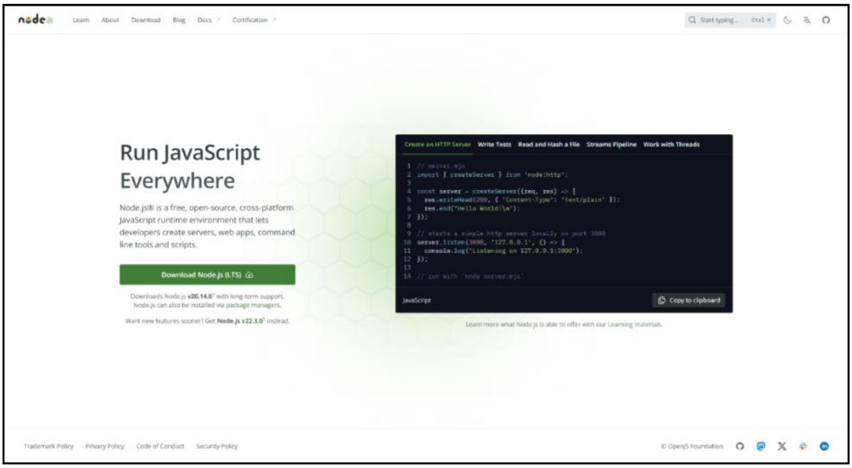
7.1 Getting Started with Web GIS applications

Step 1: Setting Up Your React Project

First, we need to install Node.js and npm for managing Javascript & React libraries in our system.

To Install Node.js go to https://nodejs.org/en (Figure 12) and click on Download Node.js button (as shown in figure below) to download the Node.js. After downloading the

Node.js installer, install it in your system. This Node.js includes npm so no need to download & install npm separately.



Run JavaScript Everywhere

Node.js® is a free, open-source, cross-platform JavaScript runtime environment that lets developers create servers, web apps, command line tools and scripts.

Downloads Node.js v20.14.0 with long-term support. Node.js can also be installed via package managers.

Want new features sooner? Get Node.js v22.3.0 instead.

```javascript
// server.mjs
import { createServer } from 'node:http';

const server = createServer((req, res) => {
  res.writeHead(200, { 'Content-Type': 'text/plain' });
  res.end('Hello World!\n');
});

// starts a simple http server locally on port 3000
server.listen(3000, '127.0.0.1', () => {
  console.log('Listening on 127.0.0.1:3000');
});

// run with `node server.mjs`
```

Learn more what Node.js is able to offer with our Learning materials.

Figure 12 Node JS download page https://nodejs.org/en

After installing the Node.js & npm, we need to create a ReactJS project. To create a new React project, go to a directory in which you want to create the project, and then open command prompt in this directory. To open command prompt in the directory just type cmd in the address bar (figure 13) and press enter.

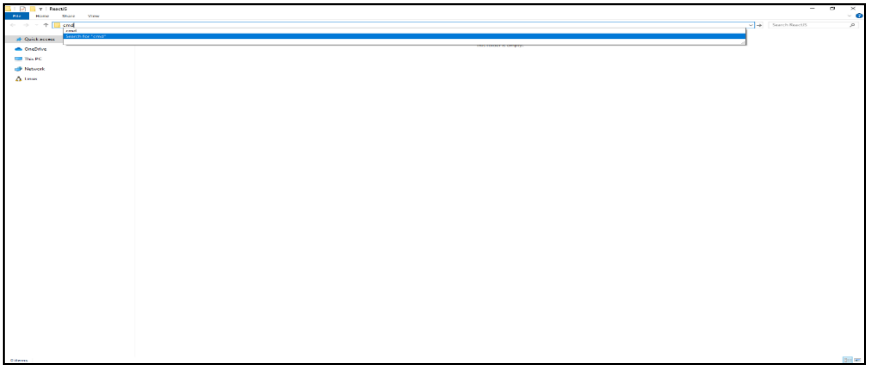


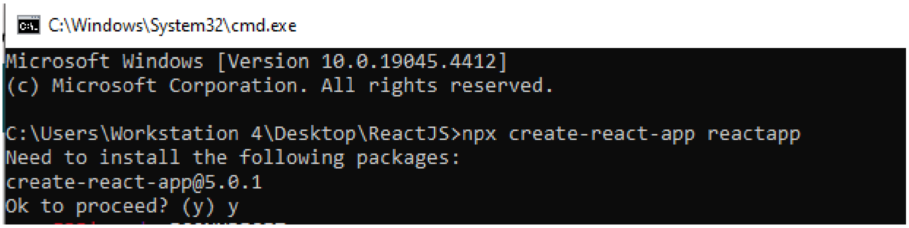
Figure 13 open cmd prompt from folder

In command prompt run “npx create-react-app project-name” (figure 14) this will setup a new ReactJS project in a new directory named as “project-name”. You can give any name to “project-name” but in small letters only. If this command fails then run “npm install -g create-react-app” first and then run “npx create-react-app project-name”.

Note :- If you're behind a proxy server, you might need to configure npm to use the proxy. You can set the proxy settings using npm config, in command prompt type:

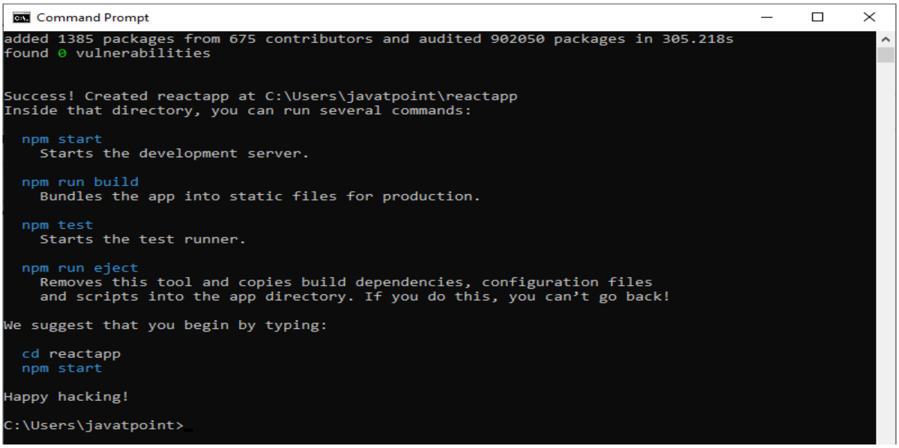
npm config set proxy ***http://username:password@proxy_address:port***

npm config set https-proxy ***http://username:password@proxy_address:port***



```
Microsoft Windows [Version 10.0.19045.4412]
(c) Microsoft Corporation. All rights reserved.

C:\Users\Workstation 4\Desktop\ReactJS>npx create-react-app reactapp
Need to install the following packages:
create-react-app@5.0.1
Ok to proceed? (y) y
```



```
added 1385 packages from 675 contributors and audited 902050 packages in 305.218s
found 0 vulnerabilities


Success! Created reactapp at C:\Users\javatpoint\reactapp
Inside that directory, you can run several commands:

  npm start
    Starts the development server.

  npm run build
    Bundles the app into static files for production.

  npm test
    Starts the test runner.

  npm run eject
    Removes this tool and copies build dependencies, configuration files
    and scripts into the app directory. If you do this, you can’t go back!

We suggest that you begin by typing:

  cd reactapp
  npm start

Happy hacking!

C:\Users\javatpoint>_
```

Figure 14 creating react app

The above command will take some time to install the necessary files to run the project and then creates a project named “reactapp”.

Step 2: Install OpenLayers

Now to install Openlayers in ReactJS project, go to the project directory ("reactapp") and open command prompt in this directory and type:

"npm install ol" this will install openlayers in the project

Step 3: Create a Map Component

Create a new file MapComponent.js in the src directory of your project. This component will render the map using OpenLayers.

In MapComponent.js add the below code:

```
import React, { useEffect } from 'react';
import 'ol/ol.css';
import Map from 'ol/Map';
import View from 'ol/View';
import TileLayer from 'ol/layer/Tile';
import OSM from 'ol/source/OSM';
const MapComponent = () => {
  useEffect(() => {
    const map = new Map({
      target: 'map',
      layers: [
        new TileLayer({
          source: new OSM()
        })
      ],
      view: new View({
        center: [0, 0],
        zoom: 2
      })
    });
 return () => {
 map.setTarget(null);
    };
  }, []);

  return <div id="map" style={{ width: '100%', height: '400px' }}></div>;
};
export default MapComponent;
```

Step 4: Use the Map Component

In your App.js file, import and use the MapComponent:

In App.js file, which will be in src directory add below code:

```
import React from 'react';
import './App.css';
import MapComponent from './MapComponent';
function App() {
  return (
    <div className="App">
      <h1>React OpenLayers Map</h1>
      <MapComponent />
    </div>
  );}
export default App;
```

The above code will add the MapComponent in the App.js file.

Step 5: Run Your Application

Now you can run your React application by going to the directory of your project and run command prompt and type:

“npm start”

This will start the development server at port 3000, and you should see a basic map rendered on the browser page if the browser page does not open then manually open a browser and type http://localhost:3000 to open the map (Figure 15)

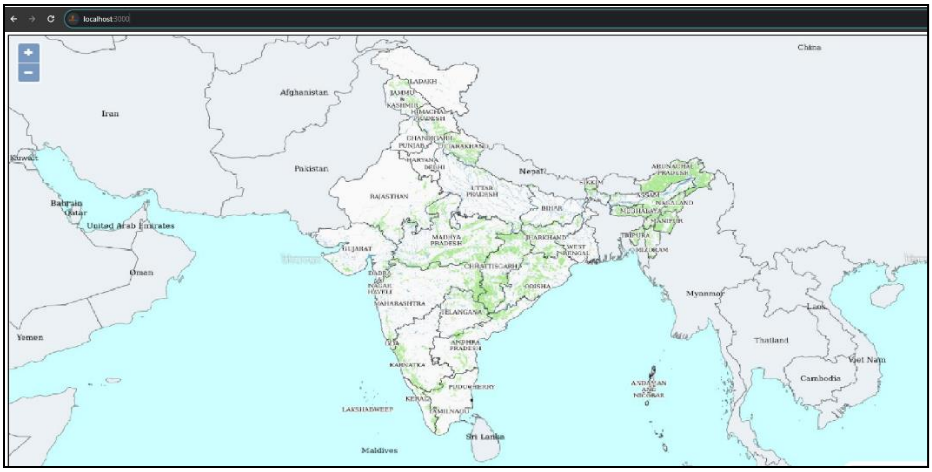


Figure 15 Map created using openlayers and react

By following the above steps we displayed a static map on the web browser. Now if we want to show a marker on a map whose location (latitude & longitude) is saved in a Database. Follow the tutorial on next page to achieve the functionality.

7.2 Connect to database and show a marker on map

To show a marker on the map fetched from database we need a backend server & database. To develop backend and to manage database we need a programming language and database server. One of the most common and versatile technologies for backend development nowadays is Node.js & for storing Geospatial data we use PostgreSQL.

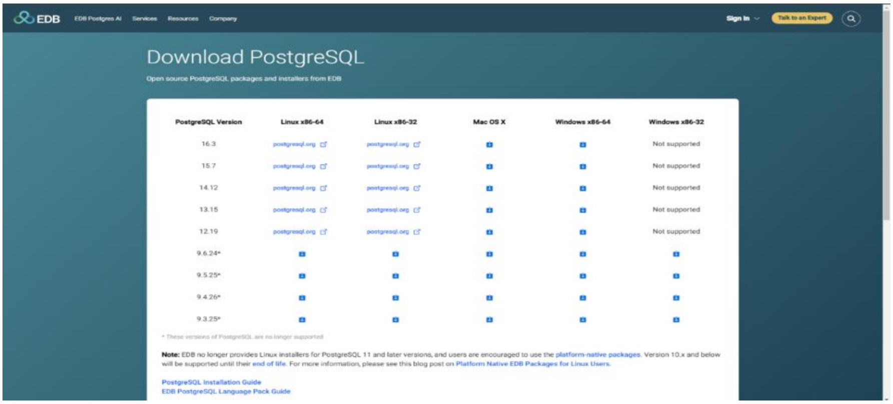
Node.js: Node.js is a cross-platform, open-source JavaScript runtime environment that can run on Windows, Linux, Unix, macOS, and more. Node.js runs on the V8 JavaScript engine, and executes JavaScript code outside a web browser. Node.js lets developers use JavaScript to write command line tools and for server-side scripting

PostgreSQL: PostgreSQL is a powerful, open-source relational database system known for its robustness, scalability, and support for advanced data types and features. When combined with GIS (Geographic Information Systems) capabilities, PostgreSQL becomes a potent tool for managing spatial data. This is primarily achieved through the PostGIS extension.

Getting Started

Step 1: Set Up PostgreSQL

1. First, we need to install node.js and postgresql.
2. For installing PostgreSQL go to https://www.enterprisedb.com/downloads/postgres-postgresql-downloads (Figure 16) a list of different PostgreSQL version will be shown (as shown in figure below) click on the download icon under Windows x86-64. After downloading, install the PostgreSQL on the system.



Download PostgreSQL

Open source PostgreSQL packages and installers from EDB

PostgreSQL Version	Linux x86-64	Linux x86-32	Mac OS X	Windows x86-64	Windows x86-32
16.3	postgresql.org	postgresql.org	⬇	⬇	Not supported
15.7	postgresql.org	postgresql.org	⬇	⬇	Not supported
14.12	postgresql.org	postgresql.org	⬇	⬇	Not supported
13.15	postgresql.org	postgresql.org	⬇	⬇	Not supported
12.19	postgresql.org	postgresql.org	⬇	⬇	Not supported
9.6.24*	⬇	⬇	⬇	⬇	⬇
9.5.25*	⬇	⬇	⬇	⬇	⬇
9.4.26*	⬇	⬇	⬇	⬇	⬇
9.3.25*	⬇	⬇	⬇	⬇	⬇

* These versions of PostgreSQL are no longer supported

Note: EDB no longer provides Linux installers for PostgreSQL 11 and later versions, and users are encouraged to use the platform-native packages. Version 10.x and below will be supported until their end of life. For more information, please see this blog post on Platform Native EDB Packages for Linux Users.

PostgreSQL Installation Guide
EDB PostgreSQL Language Pack Guide

Figure 16 Download Postgresql

3. Once installed, create a new database and user. You can do this using the psql command-line tool or a GUI tool like pgAdmin.

Step 2: Create a Database Connection in Node.js

Create a file named db.js to handle the PostgreSQL database connection in the project directory and write the below code:

```
const { Pool } = require('pg');
const pool = new Pool({
  user: 'myuser',
  host: 'localhost',
  database: 'mydatabase',
  password: 'mypassword',
  port: 5432,
});
module.exports = pool;
```

Step 3: Create Your Express Server

Create a file named server.js to set up your Express server and write the below code:

```
const express = require('express');
const pool = require('./db');
const app = express();
app.use(express.json());
app.get('/data', async (req, res) => {
  try {
    const result = await pool.query(‘SELECT ST_X(location) AS longitude,
ST_Y(location) AS latitude FROM markers;’);
    res.json(result.rows);
  } catch (err) {
    console.error(err.message);
    res.status(500).send('Server Error');
  }
});
const PORT = process.env.PORT || 5000;
app.listen(PORT, () => console.log(`Server running on port ${PORT}`));
```

We are assuming that a table named markers containing a location of a marker already exists in the database.

Step 4: Run Your Application

In the project root directory open cmd and type:

“node server.js” this will start the backend server at port 5000.

Step 5: Access backend data from frontend

To access the backend data from frontend we make a request from frontend to backend using a fetch() function in ReactJS. The Fetch API provides a JavaScript interface for accessing and manipulating parts of the protocol, such as requests and responses. It also provides a global fetch() method that provides an easy, logical way to fetch resources asynchronously across the network.

Now in the MapComponent.js file we have created earlier in the frontend tutorial replace the code in the file with below code:

```
import React, { useEffect, useRef, useState } from 'react';
import 'ol/ol.css';
import { Map, View } from 'ol';
import TileLayer from 'ol/layer/Tile';
import OSM from 'ol/source/OSM';
import { fromLonLat } from 'ol/proj';
import { Feature } from 'ol';
import { Point } from 'ol/geom';
import { Vector as VectorLayer } from 'ol/layer';
import { Vector as VectorSource } from 'ol/source';
import { Icon, Style } from 'ol/style';
export default function App(){
  const mapRef = useRef();
  const [markers, setMarkers] = useState([]);
  useEffect(() => {
    // Initialize the map
    const map = new Map({
      target: mapRef.current,
      layers: [
        new TileLayer({
          source: new OSM(),
        }),
      ],
      view: new View({
        center: fromLonLat([77.5946, 12.9716]),
        zoom: 5,
      }),
    });
    // Fetch marker data from the backend
    fetch('http://localhost:5000/data)
```

```
      .then((response) => response.json())
      .then((data) => {
        setMarkers(data);

 const vectorSource = new VectorSource({
          features: data.map((marker) => {
            const feature = new Feature({
              geometry: new Point(fromLonLat([marker.lng, marker.lat])),
              name: marker.title,
            });
            feature.setStyle(
              new Style({
                image: new Icon({
                  src: 'https://openlayers.org/en/v6.5.0/examples/data/icon.png',
                }),
              })
            );
            return feature;
          }),
        });
        const vectorLayer = new VectorLayer({
          source: vectorSource,
        });
        map.addLayer(vectorLayer);
      })
      .catch((error) => console.error('Error fetching marker data:', error));
  }, []);
  return <div ref={mapRef} style={{ width: '100%', height: '400px' }}></div>;
};
```

This will show a marker fetched from the postgres database using node.js server (Figure 17)

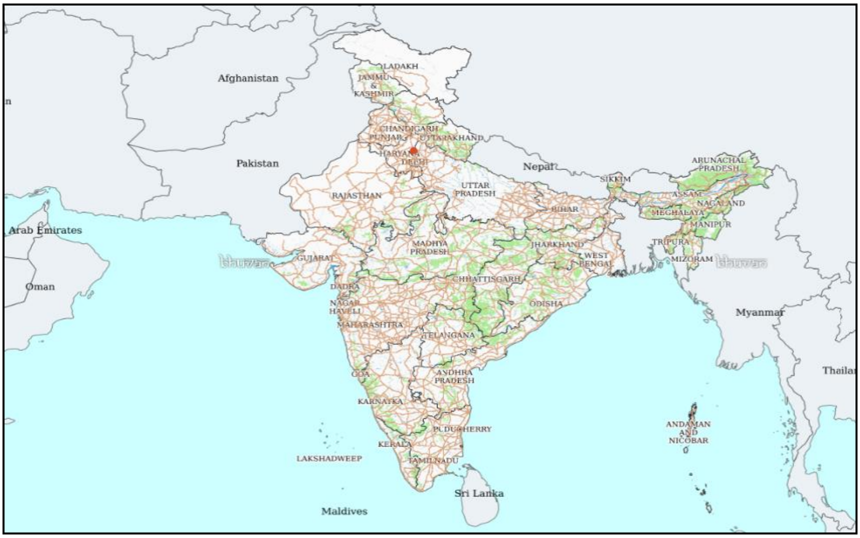


Figure 17 showing marker from database on to map

Chapter 8: Security and Vulnerability in Web GIS Applications

Web GIS (Geographic Information Systems) involves the use of web technologies to present and analyse spatial data. Given the sensitivity and value of geographic data, securing Web GIS applications is critical. Here are key aspects and best practices for securing Web GIS systems:

1. **Network Security**
   - Firewalls: Deploy firewalls to protect against unauthorized access and monitor incoming and outgoing network traffic.
   - VPN: Use Virtual Private Networks (VPN) for secure remote access.
   - Intrusion Detection/Prevention Systems (IDS/IPS): Implement IDS/IPS to detect and prevent malicious activities.
2. **Secure APIs**
   - API Security: Secure APIs by using API gateways, authentication tokens, and enforcing strict access control policies.
   - Rate Limiting: Implement rate limiting to prevent abuse and denial-of-service attacks.
   - Logging and Monitoring: Monitor API usage and log access details for auditing and anomaly detection.
3. **User Education and Training**
   - Educate users about security best practices and the importance of protecting sensitive geographic data.
   - Conduct regular training sessions and awareness programs on cybersecurity threats and safe practices.
4. **Compliance and Audits**
   - Ensure compliance with relevant regulations and standards such as GDPR, HIPAA, and ISO/IEC 27001.

- Conduct regular security audits and vulnerability assessments to identify and remediate security weaknesses.

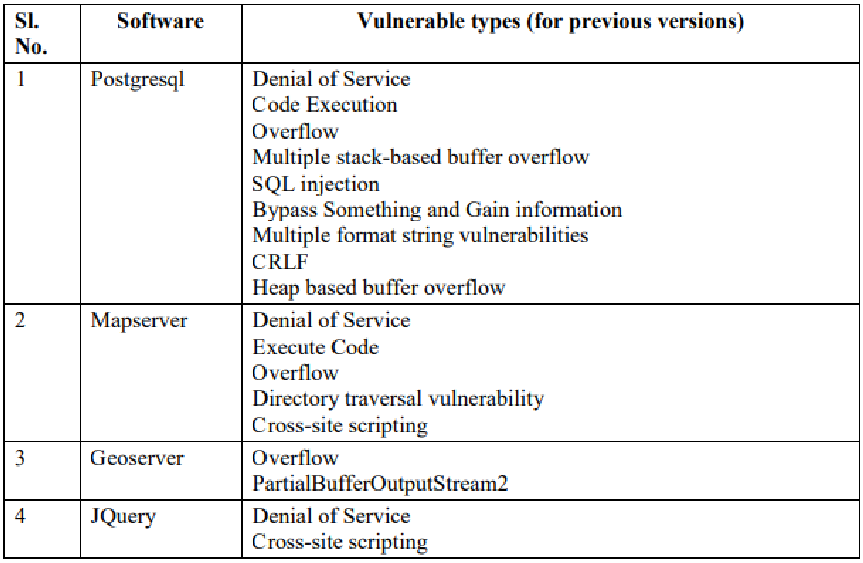
5. **Incident Response Plan**
   - Develop and maintain an incident response plan to quickly address and mitigate security breaches.
   - Conduct regular drills and update the plan based on lessons learned from past incidents.
6. **Data Integrity and Backup**
   - Data Integrity: Ensure data integrity by using checksums and hash functions to verify data consistency.
   - Regular Backups: Perform regular backups of all critical data and store them securely. Test backup restoration procedures periodically.
7. **Regular Software Updates and Patch Management**
   - Keep all software components, including GIS servers, databases, and libraries, up to date with the latest security patches.
   - Use automated tools to manage and apply patches regularly.
8. **Data Encryption**
   - In Transit: Use HTTPS (SSL/TLS) to encrypt data transmitted between clients and servers. This prevents eavesdropping and man-in-the-middle attacks.
   - At Rest: Encrypt data stored on servers using encryption standards like AES. This protects data in case of unauthorized access to storage.
9. **Input Validation and Sanitization**
   - Validate and sanitize all user inputs to prevent common web vulnerabilities such as SQL injection, cross-site scripting (XSS), and cross-site request forgery (CSRF).
   - Use parameterized queries and prepared statements for database interactions.
10. **Authentication and Authorization**
    - Authentication: Ensure that users are who they claim to be. Implement robust authentication mechanisms.

- Authorization: Control what authenticated users can do and what data they can access. Implement role-based access control (RBAC) to ensure users have appropriate permissions based on their roles.

11. Vulnerability Check During Development

During the phases of development and deployment of the web applications, it is advisable to check latest vulnerabilities with respect to the version of the software in the stack. Table 3 shows the excerpts from the CVE statistics from cvedetails.com and cve.mitre.org for the software in open Geostack .

Table 3 Vulnerability in Software in Open Geo stack



Sl. No.	**Software**	**Vulnerable types (for previous versions)**
1	Postgresql	Denial of Service Code Execution Overflow Multiple stack-based buffer overflow SQL injection Bypass Something and Gain information Multiple format string vulnerabilities CRLF Heap based buffer overflow
2	Mapserver	Denial of Service Execute Code Overflow Directory traversal vulnerability Cross-site scripting
3	Geoserver	Overflow PartialBufferOutputStream2
4	JQuery	Denial of Service Cross-site scripting

12. Security of Client-Side Scripting

Traditional Web GIS are not vulnerable to Client-Side Scripting because they do not use Scripts as a data transport mechanism. With the widespread use of tile caches technique, vulnerable Web GIS have already been found in the wild today. In tile caches service with Ajax, the JavaScript source code without any encryption is very vulnerable. They usually record the calling methods of map tiles with plaintext, which makes the algorithm open and may leak the structure of the map tiles stored in server side. Therefore, the JavaScript source code need be encrypted and confused to improve its own security. The main encryption methods include JScript. Encode encryption, decimal html encoding, hex html encoding, hex escaped character and other escaped characters, etc.

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