ADVANCED HEALTH INFORMATION SHARING WITH WEB-BASED GIS

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ADVANCED HEALTH INFORMATION SHARING WITH WEB-BASED GIS

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PREFACE

This technical report is a reproduction of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Geodesy and Geomatics Engineering, March 2010. The research was supervised by Dr. David Coleman and Dr. Harold Boley, and funding was provided by the GeoConnections Secretariat of Natural Resources Canada.

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ABSTRACT

Web-based GIS is increasingly utilized in health organizations to share and visualize georeferenced health data through the Web. In the development of a public information and disease surveillance network, issues of data publishing and user access are important concerns. The handling of data heterogeneity, lack of available data and tools, and methods of health information representation constitute continuing challenges. The purpose of this research is to address these three problems and provide new solutions for health information sharing.

Regarding data heterogeneity, a geospatial-enabled RuleML method has been designed for semantic disease information queries. Geospatial and non-spatial components of health data are represented through an ontology-based approach. The support for spatial representation in the proposed method enables the discovery of spatial relations in a semantic system. This research proposed an improved system, based on ontologies and rules, addressing both non-spatial and geospatial semantics for the querying of respiratory disease information.

Furthermore, a new architecture based on open standards and Web Services was designed to provide better solutions in health information sharing with Web-based GIS. This architecture overcomes the weakness of a closely coupled design, allows interoperable data access, and enables dynamic data integration from different providers for decision making. This architecture has demonstrated its effectiveness in an infectious disease information mapping application across international borders. In addition to demonstrating health information sharing, this research provided an initial approach to designing and implementing Web Processing Services that allow online sharing of health data processing functionalities.

For the dissemination of health information, a health information representation model has been designed to facilitate users' understanding in using health information. This model covers health information representation in the semantic, geometric, and graphic dimensions with the purpose of minimizing user misunderstanding. The platform-independent XML format was utilized in the implementation of this model, and maps can be generated from this XML format for visualization and analysis.

ACKNOWLEDGEMENTS

I would like to thank my original co-supervisor, Dr. Darka Mioc, for her constant encouragement and support through most of my PhD studies. I sincerely appreciate my current co-supervisor, Dr. David Coleman, for his guidance in my research and thesis writing. Without his illuminating instructions and comments, this dissertation could hardly reach its present quality. I would also like to express my gratitude to my co-supervisor, Dr. Harold Boley, for providing me with advice on my research and writing. I thank Dr. Yun Zhang, Dr. Peter Dare, Dr. Edmund Biden, and Dr. Songnian Li for reviewing my thesis and providing me valuable comments and suggestions.

I am truly grateful to Mr. Xiaolun Yi, our project partner and colleague from the GGE department. His inspiration and assistance have walked through my research and preparation of the papers for publication.

Many thanks also go to the professors and staff at the GGE department, especially David Fraser, who has instructed and helped me greatly in the past few years. I want to thank all my friends and colleagues who gave me help both in studies and life.

Last but not least, I deeply appreciate my family for their great love and spiritual support throughout all my studies.

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List of Symbols, Nomenclature or Abbreviations

9IM	Nine Intersection Model
AAMR	Age-Adjusted Morbidity Ratio
ASMR	Age-Specific Morbidity Ratio
CGDI	Canadian Geospatial Data Infrastructure
CMR	Crude Morbidity Rate
DE-9IM	Dimensionally Extended Nine Intersection Model
DL	Description Logic
GML	Geography Markup Language
HERXML	HEalth Representation Extensible Markup Language
HL7	Health Level 7
ICD-9	International Classification of Diseases 9
ISMR	Indirect Standardized Morbidity Ratio
ISO/TC 211	International Standards Organization Technical Committee 211
KVP	Key Value Pairs
NMR	Normalized Morbidity Ratio
OGC	Open Geospatial Consortium
OWL	Web Ontology Language
RDF	Resource Description Framework
RuleML	Rule Markup Language
SDI	Spatial Data Infrastructure

SLD	Styled Layer Descriptor
SMR	Standardized Morbidity Ratio
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SVG	Scalable Vector Graphics
WCS	Web Coverage Service
WFS	Web Feature Service
WMC	Web Map Context
WMS	Web Map Service
WPS	Web Processing Service
XML	Extensible Markup Language

Chapter 1. Introduction

Presented is the development on health information sharing with the use of Web-based GIS. This research incorporates Geospatial Web Services, Spatial Data Infrastructure (SDI), XML, and Semantic Web in health studies. Detailed research objectives are presented in Section 1.5. The main goal of this work is to provide solutions on heterogeneous health data sharing architecture and health information representation model through Web-based GIS. Providing wide access to health information and minimizing user misunderstanding in its dissemination are essential for public health safety. To achieve this goal, this dissertation is presented through the following research papers:

Paper 1 (peer reviewed)

Gao, S., D. Mioc, F. Anton, X. Yi, and D. J. Coleman (2008). "Online GIS services for mapping and sharing disease information." *International Journal of Health Geographics*, 8:3. Available at: http://www.ij-healthgeographics.com/content/8/1/3, DOI: 10.1186/1476-072X-8-3.

Paper 2 (peer reviewed)

Gao, S., D. Mioc, X. Yi, F. Anton, E. Oldfield, and D. J. Coleman (2008). "The Canadian Geospatial Data Infrastructure and health mapping." *European Journal of Geography (CyberGeo)*. Available at: http://www.cybergeo.eu/index21123.html, article 434.

Paper 3 (peer reviewed)

Gao, S., D. Mioc, X. Yi, F. Anton, E. Oldfield, and D. J. Coleman (2009). "Towards Web-based representation and processing of health information." *International Journal of Health Geographics*, 7:8. Available at: http://www.ij-healthgeographics.com/content/7/1/8, DOI: 10.1186/1476-072X-7-8.

Paper 4 (peer reviewed)

Gao, S., H. Boley, D. Mioc, F. Anton, and X. Yi (2009). "Geospatial-Enabled RuleML in a Study on Querying Respiratory Disease Information." *Lecture Notes in Computer Science*, 5858, Springer, pp. 272-281.

Paper 5

Gao, S., D. Mioc, and X. Yi (2009). "The measurement of Geospatial Web Service quality in SDIs." *The 17th International Conference on Geoinformatics, Geoinformatics 2009*, Fairfax, VA, USA, August 12-14.

The seven subsections of this chapter will bridge together these five papers by:

a. briefly describing the dissertation structure;

b. introducing the background of health GIS and new emerging technologies;

c. stating the key problems associated with health GIS applications;

d. reviewing recent development related to health GIS applications;

e. presenting the objectives of this research;

f. exploring the methodologies used in this study; and

g. presenting an overview of subsequent chapters in this dissertation.

1.1 Dissertation Structure

This dissertation includes an introduction, five papers as five body chapters, and a conclusion. In the five papers, the first author conducted the major research, with input and assistance from the co-authors. The organization of this dissertation is shown in Figure 1.1.

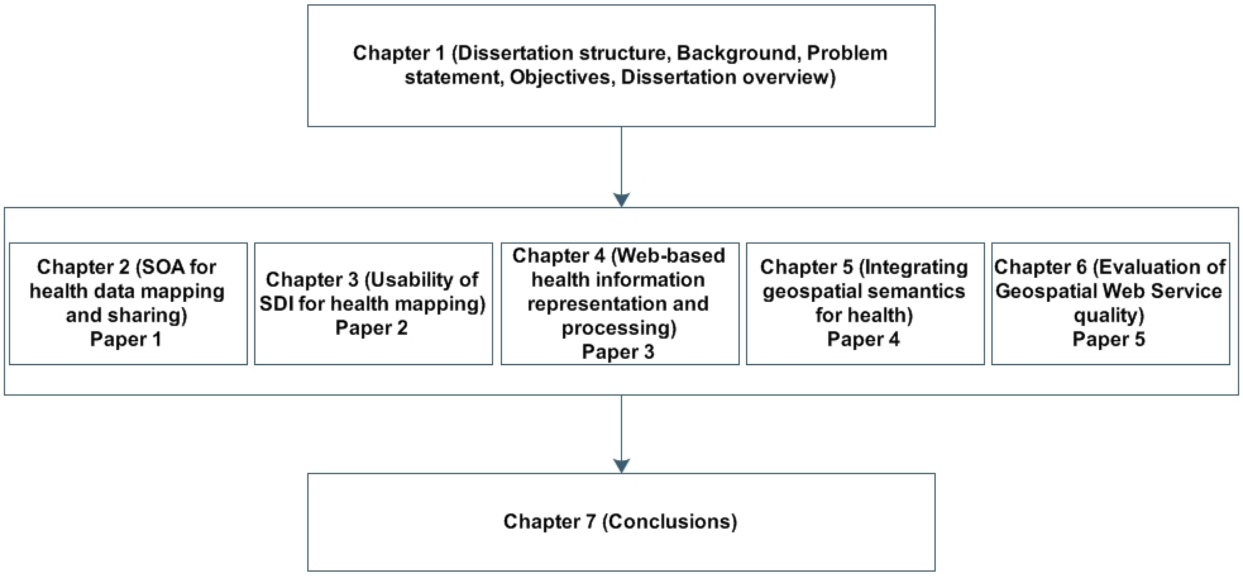

Figure 1.1: Dissertation structure

1.2 Background

Health data are concerned with people's health experiences. Health care providers such as emergency departments, hospitals, clinics, and care facilities are responsible for the health security of people. Health data cover a wide range of areas, including inpatient, outpatient, survey, laboratory, facility, demographic, socio-economic, and environmental information. Their collections can be done through surveillance (e.g., disease registries, population health surveys), the administration of health care systems (e.g., records of emergency department visits, hospital discharge, medical and pharmaceutical services, sales for over-the-counter medications), clinical care delivery (e.g., laboratory and pathology reports, medical records, diagnostic images), administration of public and private sector services (e.g., census statistics, employment records, motor vehicle license and accident records, school enrollment lists, work or school absenteeism records), primary care networks (e.g., patient rosters), environmental monitoring (air pollution observations, air temperature, water quality), cohort research findings, and questionnaire surveys.

Since ancient times, people began to realize that diseases in humans and animals are associated with location. For example, Marco Polo became aware of hoof diseases in animals that had consumed selenium-accumulating plants and suffered physical abnormalities, and he believed the cause was the local water supply in given areas [National Research Council (U.S.), 2007]. In the 19th century, Dr. John Snow discovered that deaths associated with the major cholera outbreak in London were located around specific water pumps (subsequently found to be contaminated) by introducing the locations of disease outbreaks into his analysis. At different locations on the Earth, variabilities in natural earth processes, environmental quality, ecological issues, and human activities are likely to affect human health. Throughout history, many geographical studies on health activities have been explored [Cromley, 2003].

Boulos et al. [2001] divided geographical studies on health activities into geography of diseases and geography of health care systems based on the two intertwined concepts: health (individual and community health matters) and health care (clinical issues, service planning and management issues). The geography of diseases relates to disease outbreaks, such as detection, modeling, and exploration of disease outbreaks, disease risk factor analysis, and etiology hypothesis. The geography of health care systems records details and abilities about health care providers, and supports health facility planning, management, and delivery for balancing needs in health care access.

Geospatial information such as zip codes / postcodes or addresses of patients and health care facilities is usually recorded in the health data collection. Based on the georeferenced health data, geographical studies of health can improve the understanding of disease etiology, control and prevention, and the evaluation of patterns in environmental health pathogenesis [Hasson et al., 1999; Hakim and Bitto, 2004; Jin et al., 2005]. The use of spatial location in health studies can also help health care professionals to focus more on health promotion and illness prevention, with good management, early identification, and public awareness.

1.2.1 GIS Mapping and Analysis

GIS mapping technologies can generate maps for health in desktop or Web applications. The mapping technologies can produce interactive interfaces for users, with the support of GIS basic functions such as zoom in, zoom out, pan, and hyperlink. This thesis differentiates two types of mapping technology: static mapping and dynamic mapping, based on whether maps are generated on demand or not.

Static mapping is a passive mapping process. The cartographic representation and mapping variables are pre-defined. The maps already exist or are rendered. Many Web mapping applications use the static mapping strategy, as it allows quick interaction between the GIS server and clients. As an example of this static mapping technique, the World Health Organization's Global Health Atlas platform maintains an electronic library which provides mapping on public health in the form of publications, statistics, and static maps categorized by geographical area and topics [World Health Organization, 2010a].

Dynamic mapping is an active mapping process, in which the cartographic representation and map variables can be set by users interactively. It is often used in both desktop and Web applications. As an example of a desktop dynamic mapping technique, *SIGEpi* is a statistical, analytical, and geographical information system software package developed by the Pan American Health Organization, a regional office of the World Health Organization [Pan American Health Organization, 2003]. The SIGEpi software program is a cooperative project that includes technical support in the development of GIS applications, analytical methods, and training materials in medical epidemiology and public health. Scalable Vector Graphics (SVG)-based Web applications can be also deemed examples of dynamic mapping, since users can do customization on the SVG maps, such as changing color schemes and mapping attributes.

Besides mapping abilities that provide various map representations, GIS also offers a lot of spatial analysis functions to be used for health studies, including geocoding functions, overlay functions, generalization functions, proximity analysis functions, network analysis functions, geostatistics analysis functions, spatial statistics functions, raster analysis functions, and so on. In health studies, one or a combination of several analysis functions may be applied to specific applications. Rushton [1998] mentioned two kinds of analysis that can not be done without GIS: one is to find areas where disease incidence is statistically significant to perform further investigation; the other is to examine spatial relations between disease incidence and various georeferenced health data. In addition, incorporating time information in the analysis can reveal trends over time in order to reach more robust conclusions.

1.2.2 Benefits of (Web-based) GIS

The dramatic increase in new diseases such as Severe Acute Respiratory Syndrome (SARS) and the threat of other diseases such as drug-resistant tuberculosis, combined with increased cross-jurisdiction trade and travel provide opportunities for diseases to spread across borders at alarming speed. GIS is emerging as a powerful technology for early disease detection and for appropriate and timely responses to disease outbreaks. GIS enables the integration of interdependent data from different sources, and supports mapping and spatial analysis for decision making. GIS, remote sensing, and global positioning system technologies have all been increasingly applied to health applications.

The use of GIS technology can inform health officials and the public about emerging health threats, and assist their decision making at all levels. Health information related to demographics, meteorological conditions, administrative boundaries, distance from patient to hospitals/clinics, and disease vectors (farm animals, migratory birds, and water wells) all may be visualized. GIS is highly suitable for analyzing epidemiological data, revealing trends and interrelationships which would be difficult to discover in tabular formats [World Health Organization, 2010b]. Thus, dependencies and relationships between variables that may not have been previously considered can be revealed.

GIS has been applied widely in health research, such as chronic respiratory symptoms, air pollution morbidity/mortality trends, drinking water quality, road transportation planning, hospital accessibility patterns, disease clusters, health care planning, and climate change impacts. A large number of health research projects applied GIS to: commuter safety [Hall and Kaltenecker, 1999], environmental health decisions [Bédard et al., 2003], health data maps [Buckeridge et al., 2002], maps of health service providers [Fulcher and Kaukinen, 2005], population growth [Hathout, 2002], disease cluster identification [Koch and Denike, 2001], geographical access to health care [Scott et al., 1998], and geographical epidemiology [Yiannakoulias et al., 2003]. These cases illustrated the advantages of GIS technology for a community-of-practice in response to the growing demand of geospatial information in the health decision making process for medical, social, economic, and environmental benefits.

The recent SARS outbreak of 2002-03 demonstrated the need for geographical applications in health [Boulos, 2004]. During the outbreak, the World Health Organization, Centers for Disease Control, and Health Canada were proactively engaged in mapping the viral pandemic, and applying GIS models to global and national health policy. GIS technology has proven invaluable toward its epidemiological modeling and eventual control.

The key benefits of GIS are identified below [Richards et al., 1999; New Brunswick Lung Association, 2006].

a. GIS mapping can show disease prevalence across geographical areas, enabling lobbyists to seek funds and resources for improved health care and manage surge in demand.
b. GIS benefits health practitioners and the public by increasing awareness of the spread of communicable diseases (e.g., avian influenza, treatment resistant tuberculosis), and possible risk factor stratification.
c. Disease surveillance with GIS can help health officials to monitor diseases over time and plan immunization strategies.
d. GIS can be used to assess health facility and resource distribution, provide optimal solution for health access, and balance the needs and costs.
e. GIS can illustrate health data at multiple scales, from a very local scale to provincial, national, and international scales.
f. Implementing GIS in health institutions is cost-effective from both disease prevention and health promotion points of view.

The emergence of Web-based GIS further pushes GIS functionalities to the Internet. Web-based GIS combines the power of the World Wide Web with basic desktop GIS functions (e.g., generating maps, viewing maps, interacting with maps). More advanced Web-based GIS provides the abilities to perform spatial query and analysis. Via Web-based GIS, information can be reached by users more easily. With all the Web data access and the necessary functions provided through one browser window, the expensive process of acquiring proprietary GIS software can be avoided. While GIS technologies require considerable skills to learn, Web-based GIS can provide information to a wider audience even with limited GIS knowledge [Kamadjeu and Tolentino, 2006a]. Web-based GIS in health can increase the number of users and be achieved with minimal costs [Maclachlan et al., 2007].

Disease detection at early states is important for health officials to take effective counter-measures to control the spread of disease. Web-based GIS technology can support this by providing quick access to distributed data for analysis, visualization, planning, and modeling. Since the response of Web-based GIS is in near real-time, it is effective for understanding disease phenomena to support decision making. Opportunities for leveraging health monitoring/surveillance are now being offered via Web-based GIS applications [Conte et al., 2005; Kamadjeu and Tolentino, 2006b; Wang et al., 2008].

1.2.3 Health Applications Using (Web-based) GIS

GIS can be used to analyze public health care parameters, provide critical information in a timely manner, support health care policy development, monitor climatic events, coordinate medical response measures, and educate decision makers and the general public. The data used in these applications cover the health, environmental, and socio-economic sources. Common data include hospital and emergency room admissions, ambulance databases, patients' location at the time of incidents, cumulative ambient concentrations obtained from air-monitoring and weather stations, questionnaire survey and interview data, hospital staff data, remote sensing images (used to extract land cover), groundwater-surface water hydrologic fluxes and water quality data, demographic statistics, and economic vectors. The main categories of health GIS applications are discussed in the following subsections.

1.2.3.1 Disease Pattern Detection

Disease patterns are important to health practitioners in the investigation of disease outbreaks over space and time. Mapping the populations at risk is widely used to show the geographical distribution and variation of illness [Chaput et al., 2002; Richardson et al., 2004; Beale et al., 2008]. GIS can illustrate health events at multiple scales, from a community level to regional, provincial, national, and international levels. As disease phenomena have no boundaries, disease pattern detection should not be constrained to administrative boundaries. Time information can also be incorporated in GIS to study the spatial and temporal trends in disease prevalence [AvRuskin et al., 2004]. Using spatial statistics methods with GIS to detect spatial clusters and spatio-temporal clusters helps the identification of excess or unusual disease occurrences [Hjalmars et al., 1996; Perez et al., 2002].

1.2.3.2 Disease Monitoring and Surveillance

Health scientists who perform disease monitoring and surveillance need to understand the effect of disease agents in the cause of diseases. To help describe the presence and distribution of disease agents (physical, chemical, or biological), GIS has been used to identify sources of these agents, and subsequently monitor the environment in order to detect the presence of these agents [Cromley, 2003]. Spatial analysis, together with univariate analysis, multivariate analysis, logistic regression, and probability models is commonly used in modeling hazard exposure, risk assessment, disease spread, and health outcome. GIS can also integrate various georeferenced sources to determine the association between disease symptoms and air pollution, meteorological variables (temperature, relative humidity, etc.), water quality, or socio-economic factors. For example, several studies investigated the relationship between chronic respiratory symptoms and long-term ambient concentrations of fine particulates, total suspended particulates, ozone, and sulfur dioxide among residents who are close to major roads or industrial complexes [Abbey et al., 1995; Garshick et al., 2003].

1.2.3.3 Health Facility Distribution

GIS provides the abilities to describe the spatial organization of health care (numbers, types, and locations), examine the changing spatial distribution of health care systems, and explore improvements of health care delivery [Fortney et al., 1999; McLafferty, 2003]. The population (age, gender, income, race), health facility capacities, access cost (time, distance) have been taken into consideration in health facility planning and distribution evaluation [Haynes et al., 1999; Messina et al., 2006]. GIS can be used to identify population segments vulnerable to varied geographical access to critical medical treatment, provide optimal routes for emergency responses, assess resource allocations, monitor health facility utilization patterns, and plan intervention strategies. For example, Lwasa [2006] carried out a study to demonstrate the value of GIS technologies in the provision of information required for the planning of health infrastructure in Uganda, with the ability to enhance access to the public as well as the understanding of spatial distribution of facilities. The adoption of GIS in health care applications can assist stakeholders and policy makers in effectively distributing health care resources to overcome geographical inequalities in accessing health care among different population groups.

1.2.3.4 Health Care and Education

GIS and the development of the Internet have brought a new way for the general public to visualize and analyze health data. They facilitate public access, awareness, and participation in health decision making. Maps can be disseminated to the general public for alerting them to the distribution of disease agents. With the utilization of maps, it is easy to explain the geographical variation of health exposure. People can be informed about the environmental hazards around themselves and prepare themselves for disease outbreaks. GIS also supports the public in efficiently locating the nearest health facilities. In addition, GIS programs or courses are offered in many health-related schools and health associations.

1.2.4 Emerging Technologies for Health GIS Applications

The development of Web-based GIS provides new opportunities for health information delivery and sharing via the Internet. The following subsections briefly describe key technologies that can be utilized for health GIS applications.

1.2.4.1 XML, SOA, and OGC Standards

The Internet provides an efficient way for electronic information exchange. Accommodation of health information exchange is no exception, although privacy and confidentiality issues need to be taken into consideration. The Extensible Markup Language (XML) is an open standard for data exchange across multiple media and platforms over the Internet, which is optimized for machine processing but can be easily transformed to human-readable presentation syntaxes. For example, the *Health Level 7 (HL7)* standards, accredited by the non-profit American National Standards Institute, allow clinical and administrative data exchange across health care information systems [HL7, 2010]. The HL7 standards suite incorporates a new approach to clinical information exchange, constructed around the HL7 Reference Information Model, which utilizes methodology to integrate health care information (messages, data types, datasets, and terminologies) via XML syntax. The *Geography Markup Language (GML)* is designed as a standard for geospatial data sharing. It is an XML standard which is able to model, transport, and store geospatial information as well as non-spatial information [Lake, 1999; OGC, 2004].

To overcome the disadvantages of tightly coupled systems and improve their reusability, the concept of *Service Oriented Architecture (SOA)* has become widespread. Commonly there are three types of actors in this architecture: service providers, service requestors, and service brokers. Service providers are responsible for providing functions as services to requestors and for registering function descriptions with service brokers. For the discovery of services, the service broker serves as the bridge in linking the service providers and requestors. The development of SOA provides a new solution for application development and integration. Web Services -- a common implementation of service oriented architectures -- are based on SOA to support machine-to-machine functionality sharing over the Internet. To support inter-communication, Web Services provide functionalities through clearly defined interfaces, independent of hardware and system platforms, network protocols, and development languages. They provide a loosely coupled architecture for building Web applications.

To facilitate geospatial information sharing, the *Open Geospatial Consortium (OGC)* concentrates on the development of interoperable geospatial standards that are independent of industrial vendors. It initiated the *Open Web Service (OWS)* program based on SOA and Web Services, and has proposed several geospatial specifications to support geospatial data sharing and interoperability. The framework of OWS contains five main categories of services: client services, registry services, processing-workflow services, portrayal services, and data services [OGC, 2003]. Dozens of Geospatial Web Service specifications have been proposed or adopted by OGC, such as *Web Map Service (WMS), Styled Layer Descriptor (SLD), Web Map Context (WMC), Geography Markup*

Language (GML), Web Feature Service (WFS), Web Coverage Service (WCS), Keyhole Markup Language (KML), and Web Processing Service (WPS).

1.2.4.2 Development of Spatial Data Infrastructure

A Spatial Data Infrastructure (SDI) consists of relevant base collections of technologies, policies, and institutional arrangements which can facilitate discovery, evaluation, and access to spatial data [Nebert, 2004]. It aims to serve all levels of government, industries, non-profit organizations, academia, and the general public for their social and economic activities. The principle in guiding the SDI development is that once it is built, many applications can get benefits out of this. Groot [1997] pointed out two essential purposes in building SDIs. One purpose is to save time, effort, and money in geospatial data access, and facilitate users in determining how fit the geospatial data are for their applications. The other purpose is to promote data sharing through harmonization and standardization to avoid unnecessary geospatial data duplication. SDIs mainly deal with the interaction between people and geospatial data. The main components of an SDI include data providers, databases and metadata, data network, technologies, institutional arrangements, policies and standards, and end-users [Coleman and Nebert, 1998]. According to the stakeholders and organization structure of SDIs, hierarchies in global SDIs, regional SDIs, national SDIs, provincial SDIs, and local SDIs can be observed.

The development of SDIs began in the early 1990s, and their developments are influenced by the needs of stakeholders and new information technologies. Three kinds of changes can be seen in system architectures, information exchange, and application development solutions. The system architecture in geospatial data sharing went through client-server architecture and multi-tier architecture (with a client, Web server, application server, and database), and SOA has gained popularity recently. At the early stage of the geospatial information exchange, data are usually obtained through storage devices (e.g., CDs) or file downloading from HTTP/FTP servers. The data downloaded still need post processing before they can be used for applications. Nowadays, geospatial data exchange tends toward the provision of value-added information, which can be served for user applications directly instead of raw data downloading. Current Web 2.0 technologies revolutionize the Web to further facilitate data sharing and collaboration between users. In particular, Web 2.0 mashups allow the combination of multiple data sources and services over the Web. The mashup technology changes the standalone application development pattern, supports fast application development, and lowers the programming skills in the development for the general public.

The initial SDI movement was carried out through national funding and efforts, and significant developments have taken place with the U.S. National Spatial Data Infrastructure (NSDI)[1], the Canadian Geospatial Data Infrastructure (CGDI)[2], and the

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[1] http://www.fgdc.gov/nsdi/nsdi.html

[2] http://www.geoconnections.org/en/aboutcgdi.html

Australian Spatial Data Infrastructure (ASDI)[1]. With the development of national SDIs, provincial SDIs also emerged such as GeoNova: Nova Scotia's SDI[2], GeoBC: British Columbia's SDI[3], and GeoNB: New Brunswick's SDI[4] in Canada. Local governments are playing a key role in SDI development nowadays, as they provide fundamental data sources for higher level SDIs. Local governments and the private sector will play an increasingly important role in future SDI development [Rajabifard et al., 2006; Harvey and Tulloch, 2006].

SDIs provide a framework for collecting, accessing, and disseminating of geospatial data, and can enhance decision making for current problems relying on spatial data. SDIs have been served for GIS applications in different fields, such as public health, agriculture, transportation, forestry, and environment. Providing public health information in SDI is very useful and public health data will be an essential component of SDI. Croner [2003] pointed out the dynamic system of public health readiness requires the development of geospatial infrastructure via the Internet. In Canada, one of four priority areas in the CGDI is public health, and the CGDI endeavors to share geospatial information for tracking and monitoring population health [CGDI, 2010]. Since 2005, more than 20

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[1] http://www.ga.gov.au/nmd/asdi/

[2] http://www.gov.ns.ca/geonova/home/default.asp

[3] http://www.geobc.gov.bc.ca/

[4] http://www.snb.ca/gdam-igec/e/2900e_1.asp

projects have been funded by CGDI for public health at the federal, provincial, local, and enterprise levels[1].

1.2.4.3 Semantic Data Integration

"The Semantic Web is an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation" [Berners-Lee et al., 2001]. There are three sources of heterogeneity -- syntactic, schematic, and semantic -- that need to be considered during geospatial data integration [Bishr, 1998]. *Syntactic* heterogeneity deals with different data structures and formats. *Schematic* heterogeneity is due to database schemas organized with different properties and structures. *Semantic* heterogeneity is caused by different interpretations of data and metadata, hampering the unambiguous distributed access to information sources. Two types of semantic heterogeneity are distinguished [Lutz et al., 2003]: one is *cognitive heterogeneity* that arises when two disciplines have different conceptualizations of real world facts; the other is *naming heterogeneity* which refers to different names for identical concepts of real world facts. Resolving semantic heterogeneity would greatly enhance the handling of syntactic heterogeneity and schematic heterogeneity [Bishr et al., 1999]. Formal ontologies constitute an important notion of the Semantic Web, and have been characterized as formal specifications of conceptualizations [Gruber, 1993]. With

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[1] http://www.geoconnexions.org/en/communities/publichealth/projects

well-designed ontologies, the semantics of distributed data can be unambiguously defined, semantic heterogeneity can be resolved, and therefore data sharing and integration can be enabled.

Considerable research has been done on conceptual frameworks for the semantic comparison between different geospatial concepts. To compare the meaning of concepts underlying given data, background knowledge can be utilized to perform similarity analysis. The similarity of concepts can be evaluated based on their name, description, properties, and attributes [Kokla and Kavouras, 2001; Mostafavi, 2006]. Uitermark et al. [1999] located semantic similarity at the object instance level (e.g., *related, relevant, incompatible*) based on their class-level relationships and computational geometry (spatial overlay). Raubal [2004] defined conceptual vector spaces (sets of quality dimensions) to measure the semantic distance between instances of concepts. Rodriguez and Egenhofer [2004] determined the semantic similarity of spatial entity classes by taking their characteristics (parts, functions, and attributes) and semantic interrelations into account. Zhou [2005] pointed out a strong connection with reality, ontology, meaning, and representation in geospatial data semantics, and implemented a semantic integration method by employing implicit spatial neighborhood information in evaluating semantic similarities. Brodeur et al. [2005] introduced a conceptual framework for geospatial data interoperability through geosemantic proximity comparison between geospatial concepts, with the use of intrinsic properties (identification, attributes, attribute values, geometries, temporalities, and domains) and extrinsic properties (semantic, spatial, and temporal relations). In this framework, geospatial concepts are defined using XML

Schema, and the interoperability among different geospatial data is handled through geosemantic proximity comparison.

The above methodologies provide frameworks to compare semantic similarity among heterogeneous data, but the question of *how* to represent these geospatial concepts through Semantic Web techniques (such as ontologies and rules) in a manner that allows automatic machine reasoning and deduction is still open. Ontology-based approaches have been used to query geospatial information; for example, different application ontologies have been connected through shared domain ontologies [Klien et al., 2006; Lutz and Klien, 2006]. The relationship between different concepts can be deduced through shared concepts. Ontologies are usually expressed through the standard Web Ontology Language (OWL). Description Logic (DL) [Baader and ebrary, 2003], which strives for decidability and usually for tractability, constitutes the formal underpinning for OWL deductive reasoning. DL represents knowledge through a TBox (terminology of concepts and properties) and an ABox (assertion of instances using the terminology).

Rules, with Horn Logic as their formal underpinning, complement DL to express other kinds of knowledge in the Semantic Web [Grosof et al., 2003]. Rules represent 'if then' knowledge which allows machine deduction avoiding explicitly enumerating all possible instance facts as used by (extensional) databases. Lutz and Kolas [2007] presented a methodology that applies a set of domain rules and schema mapping rules for available data to support the discovery process in SDIs.

With the proper data representation in the Semantic Web, the query of heterogeneous data sources can both respect the meaning of data and deduce new knowledge from existing ontologies and rules. The Semantic Web approach has great potential for health GIS applications. For example, Boulos [2005a] proposed to construct a foundation evidence base and ontology-based framework of modular reusable models for more informed health planning and better outcome using GIS.

1.3 Problem Statement

Applying (Web-based) GIS in health information sharing requires the consideration of data sources, analysis functionalities, and dissemination approaches. Although considerable research has already been done for health GIS applications, three challenges still need to be addressed.

Data Heterogeneity

Public health data tend to be divided into silos: hospitals, physicians, financial management, etc. This data fragmentation is partially due to federal budgets that allocate separate funding blocks for different providers and services. Although many provinces now utilize an integrated health care delivery model, the organization of public health data remains fragmented [New Brunswick Lung Association, 2006]. The data collection process varies amongst different health organizations with different tools and methods. The integration of health data across service systems is a challenge [McLafferty, 2003]. The heterogeneity problems of health data come from different input formats, different spatial levels (e.g, point, postcode, county), different ways in describing a concept, different naming conventions, different terminologies, different information models, and different data transmission standards. For example, no central repository of health data exists in the United States and there is considerable variation in the formats and location requirements of the data that are reported [National Research Council (U.S.), 2007]. The variability in the implementation of health standards (e.g., Health Level 7 standards) also makes it difficult to combine data from multiple health care delivery systems [Lober et al., 2002]. The sharing of health data across states or regions is uncommon, as inconsistencies across states regarding their use of geocoding references, statistical and mapping software limit the possibilities to integrate data for multi-state studies [Gregorio et al., 2006].

Resource Deficiency

Health data are primarily collected from hospitalization services such as documentation on current patient and client health records. These data, even anonymized statistical data, are absent from many other areas of public health, such as preventive services, intervention strategies and patient outcomes, private health care providers, impact of health care policies or services, and policy development and health program evaluation [New Brunswick Lung Association, 2006]. This kind of data deficiency causes the inability to access multiple georeferenced data for decision making related to public health. The data deficiency is also of concern since many cases are never reported, and the responsibility of government entities to protect patient confidentiality makes the location of incident cases difficult to obtain [National Research Council (U.S.), 2007].

Ultimately, this results in a lack of available data for decision making in health GIS applications.

Although increasing numbers of Web-based GIS systems are being developed for health information dissemination, Zeng et al. [2005] pointed out disease information systems are not fully interoperable because they are often developed in isolation from one another. As barriers still exist in the current systems, non-automated approaches such as email attachments and manual data reentry are usually needed when disease control agencies need to share information across systems [Zeng et al., 2005]. Furthermore, many health applications using Web-based GIS allow the dynamic generation of maps, but the user-demand analysis functions in these applications are still very limited.

Health Information Representation

Privacy and confidentiality issues have been given a lot of attention in health studies. Privacy is to protect personal information not to be disclosed and distributed. The privacy rules consider the rights of privacy in doctor-patient relationships and personal health information from the perspective of public access; confidentiality is the responsibility of health practitioners to hold confidential the patient's information [Ölvingson et al., 2002]. Therefore, the representation of health information needs to capture health information distribution while minimizing individual identification potential.

As health activities are social events that are related to spatial locations, GIS mapping is usually applied in representing these data. But considerable information is missing from such maps, such as methods used and data source metadata. As the representation of information is essential for appropriate interpretation, consideration needs to be given on the use of GIS in interpreting health data. A good health information representation model could facilitate information delivery and overcome confusion.

1.4 Research and Development on Health GIS

1.4.1 Data Heterogeneity

To support health decision making, health GIS systems need to integrate a wide range of georeferenced data from various organizations and sources. The successfully implemented health GIS applications require standardized methodology, appropriate tools for data collection, and accurate data integration over time [Wiafe and Davenhall, 2005]. There are many advantages of data integration from multiple health systems, such as monitoring and understanding health status on a regional or national level, comparing contemporaneous data from similar regions, and validating detection algorithms [Lober et al., 2002].

Two kinds of approaches are commonly applied in data integration: schema-based and semantics-based (usually, ontology-based). The *schema-based* approach matches data sources from different database schemas into uniform database storage. A common schema needs to be designed before data integration. Buckeridge et al. [2002] pointed out that the development of a data model which explicitly defines how concepts within data sources relate to each other in health systems could allow the integration of a wide range of georeferenced data for health decision making.

The *ontology-based* approach requires the definition of ontologies (e.g., domain ontologies designed by experts) and the semantic description of concepts. The description of data semantics can be represented in Resource Definition Framework (Schema), RDF(S), or OWL. Thus, ambiguities in data are removed with the explicit description. Many health standards, such as HL7 and Health Insurance Portability and Accountability Act (HIPAA) can serve as ontologies in the exchange and integration of health data. Schuurman and Leszczynski [2008] defined ontology-based metadata through interviews with health professionals, and utilized description logic to map near-identical concepts between the perinatal databases of two jurisdictions. Considerable research has been conducted concerning the mapping and integration between different health ontologies [Lee et al., 2006; Rey et al., 2006; Ryan, 2006].

However, previous research handled spatial locations as text-based information (e.g., the name of a city) and defined their relations using ontologies (e.g., a city is inside a province) in health data integration. To relieve the efforts to explicitly define all spatial relationships between spatial objects in health data integration, the consideration of geospatial semantics still needs to be explored.

1.4.2 Resource Deficiency

The control of health resource access needs to prevent the unauthorized disclosure of patient privacy information, protect the integrity of health care data, and ensure the availability of health data for authorized persons [Barrows and Clayton, 1996]. Several kinds of technologies can be used for access control such as multi-level and role-based access model, and public key encryption.

Web-based interfaces are popular for data management and access [Scotch et al., 2006]. The use of Web technologies can facilitate the distribution of health resources. The development of Web-based GIS enables the generation of user-requested maps online. Depending on the requirements of applications, Web-based GIS thin-client or thick-client solutions have been used for sharing health information through maps [Inoue et al., 2003; Qian et al., 2004; Blanton et al., 2006; Kamadjeu and Tolentino, 2006a].

Web-based GIS allows health agencies to export their data and maps to accessible Web portals. Toubiana et al. [2005] coupled a data warehouse with Web-based GIS to support communicable disease monitoring. Tsui et al. [2003] described a real-time public health surveillance system, in which clinical data collected by health care providers are transferred to a database in the real-time outbreak and disease surveillance system through HL7 messages. In this system, detection systems and GIS are used to analyze the database and publish results through the Web. Zeng et al. [2004] showed a case study of a bioportal system, which gathers data from different departments through HL7 messages, and then integrates them into the bioportal data store for Web-based GIS.

Along with the rapid development proprietary software (e.g., ESRI ArcGIS server, MapInfo and MapXtreme), widely-used free software (e.g., Google maps, Yahoo maps) and open source software (e.g, GeoServer, MapServer) for Web-based GIS, different Web-based GIS solutions for health applications emerged. Boulos and Honda [2006] proposed to publish health maps through open source Web-based GIS software. Currently, most proprietary and open source Web-based GIS solutions provide support for OGC standards.

While many health systems are implemented using Web-based GIS for the distribution of health information through Web maps, differences in operating systems, network protocols, and data models still cause problems in health information access and exchange. Meanwhile, these health systems using Web-based GIS usually only offer mapping abilities, and the provision of spatial processing functionalities is limited. The methods in distributing health resources still need to be explored to solve the resource deficiency problem. The development of SDIs can benefit health GIS applications, while current health GIS applications have limited SDI-like arrangement [Boulos, 2004]. The building of global and jurisdictional data sharing infrastructures will be one future trend in health GIS [Yan et al., 2006].

1.4.3 Health Information Representation

Access to databases (or data warehouses) is deemed the greatest obstacle to health GIS studies. At the heart of the problem is the associated issues related to individual privacy rights, national security, data confidentiality, and copyright management [Boulos, 2005b]. As geospatial technologies progress and become more readily available, interrelated issues of confidentiality, privacy rights, and security have been recognized in health GIS applications. To protect individual spatial information, Kwan et al. [2004] mentioned three statistical methods: aggregation, affine transformation, and random perturbation. *Aggregation* is the most common method to group data, and the spatial resolution reduces in this process. *Affine transformation* translates, rotates, and scales the point pattern. *Random perturbation* introduces errors in the original data during the randomization process. These statistical methods serve as geographical masks for representing confidential data on maps.

It is generally agreed that there is consistent trade-off between spatial analysis accuracy and privacy rules [Kwan et al., 2004; Sherman and Fetters, 2007]. For example, the frequently used aggregation methods may hide some details within the data. With the data aggregation in different spatial levels and different divisions of areas, it is likely to get different spatial patterns and correlation coefficients. This is referred to the literature as the "Modifiable Areal Unit Problem (MAUP)" [Openshaw and Taylor, 1981; Openshaw and Alvandies, 1999]. The ideal solution to overcome this problem is to use more detailed data. Some studies showed the results in some aggregate level analysis (e.g., census tract and block group) are comparable, and seeking data finer than census tract may not be compelling [Krieger et al., 2002; Gregorio et al., 2005]. Various studies were carried out with the use of statistical methods for geospatial privacy issues. Leitner and Curtis [2004] did an empirical study on the use of different geographical masks (global and local) for representing confidential point data. Cassa et al. [2006] applied a population density based Gaussian spatial skew to generate random noise to anonymize spatial surveillance data.

The privacy and confidentiality issues require the consideration of data representation in health applications using Web-based GIS. Cromley [2003] discussed the need of implementing disease surveillance systems which can be utilized for distributing information of meaningful spatial aggregates to meet the needs of large research communities and the general public. Web maps are usually provided to users in health applications using Web-based GIS. However, maps can easily mislead [Hanchette, 1998], and poorly designed maps can inadvertently mis-communicate information [Monmonier, 1991]. The complex nature of the data, and the heterogeneity in user skill and knowledge both demand consideration when a data depiction is to be designed for facilitating appropriate interpretation [Buckeridge et al., 2002].

1.5 Objectives

The main objective of this research is to develop a health GIS information sharing architecture and representation model to allow the wide access and limit the misunderstanding of health information. This research focuses on solving the identified three problems to advance health information sharing. To achieve this objective, the following sub-objectives are identified:

a. Design an architecture by using SOA and SDI for health data mapping and sharing.
b. Develop performance evaluation metrics to measure SDI effectiveness and build trust of SDIs for health applications.
c. Build a health information representation model to share and exchange essential health statistical information.
d. Build a health GIS ontology framework enabling both geospatial and non-spatial reasoning in health data integration and query.

This research will create a loosely coupled and interoperable health information sharing architecture, analyze the effectiveness of SDI related to health studies, generate a health information representation model, and incorporate the geospatial semantics in rule reasoning in the Semantic Web.

1.6 Methodology

This research concentrates on the design and implementation of new methods and architectures for advancing health GIS information sharing. It is carried out through a literature review followed by model design, prototyping, and result validation stages. The proposed methodology for achieving the objectives is described in the following subsections.

1.6.1 Architecture Design for Health Information Sharing

A common way to share health information is through Web maps in health GIS applications. Heterogeneous health data can be integrated by location and represented in a homogeneous form with maps. The goal of this methodology is to support the following requirements in health information sharing:

a. Allow heterogeneous health data integration and sharing.
b. Achieve interoperability in health data access without the need to consider platforms and languages in the application development.
c. Support scalability, allowing various health organizations to publish their data through the Web.
d. Consider privacy issues of health data while providing important information to users.
e. Support the use of geospatial processing functionalities for health information analysis via the Web.

This methodology considers the tiers in the architecture design, approaches, and interoperable standards for health information sharing. The SOA and SDI based architecture is used to publish health information through Geospatial Web Services. The appeal of SOA is that it facilitates health information sharing and integration with loosely coupled design. Four common tiers -- the data storage tier, ontology engine tier, standard health service tier, and map and animation tier -- are explored in the architecture design. Four interoperable OGC Geospatial Web Service standards (WMS, SLD, WMC, WPS,) are adopted for health information processing, mapping and sharing. WMS (with the support of the time tag) is used to assist health organizations publish their data through Web maps. Access control makes sure that users with different privileges can access different levels of detailed health information generated from spatial aggregation. The SLD-enabled WMS strategy allows the maps achieved from different WMS services to have the same cartographic style for visualization purposes. The WMC supports health organization collaboration with the sharing of current view of users (e.g., Web-based maps from several WMS services) in an XML format in which WMS service connection parameters are stored. WPS empowers health departments to access geospatial tools and functionalities through the Web. Successfully designed, this methodology will help build geospatially enabled infrastructure for health.

1.6.2 Usability Analysis and Performance Evaluation of SDIs

Current SDI developments enable users to access data through Geospatial Web Services. The attractiveness of SDIs is that they can enable horizontal integration of data across sectors (e.g., health, environment, safety, communities) and vertical data integration (e.g., local, provincial, national) to provide value-added services for decision making. Studies on SDI usability were mainly concentrated on geospatial data usability, and the usability of SDI for health is still a challenge.

The proposed methodology provides a systematic approach on how to evaluate the usability of SDIs for health mapping. It combines determined usability metrics to evaluate the effectiveness of SDI (such as CGDI) components for health mapping. To evaluate SDIs in health mapping, this methodology designs health applications that cover the basic geographical functionalities for health within an SDI. The study of usability is based on developed health applications with two kinds of users: developers and end-users. Additionally, this methodology provides basics for further investigation of SDI for health applications. From the usability study, the limitations of the CGDI for health mapping are also identified, such as health information representation, semantic interoperability issues, and trust of services.

The rapid development of the SDI would lead to a large number of Geospatial Web Services. To improve their effectiveness and efficiency for health GIS applications, this methodology further designs a technical framework to evaluate the Geospatial Web Service quality in SDIs through the activities happening during their consumption. Objective and subjective evaluation of Geospatial Web Service quality are proposed. The objective evaluation score considers the response (e.g., content, speed) of the interaction between the applications and those Geospatial Web Services. The subjective evaluation score considers the attitudes of users towards the Geospatial Web Services through questionnaire surveys.

1.6.3 Model Development for Health Information Representation

To facilitate health information exchange between various users via the Web, the following issues need to be considered in the health information representation model design:

a. the content of health information representation;
b. the metadata of health information sources;
c. the privacy issues of health information; and
d. the consistency in health information representation, independent of environment and platforms.

The proposed methodology develops an XML schema to share the statistical results of various health activities, such as public health surveillance, outbreak investigation, direct health services, and public health research. The design of this XML schema follows a cyclic model: requirement analysis, conceptual design, implementation, and application validation. The content of the XML file includes semantic, geometric, and cartographic representation of health information. The metadata of health sources in the XML file ensures the understandability and quality of health information. The privacy issues are considered by using statistical results, and detailed health information can be required with the support from the metadata. The use of XML in health information representation allows cross platform information exchange, and the development of a parser allows the interpretation of these XML-based files into maps.

1.6.4 Geospatial Semantics Exploration for Health Information Sharing

Geospatial semantics describes the underlying meaning of geospatial objects and their spatial relationships corresponding to the real world. This methodology works on the semantic heterogeneity for health using both non-spatial semantics and geospatial semantics. In order to incorporate geospatial semantics into the current Semantic Web, the following issues are still challenges:

a. geospatial data representation in the Semantic Web languages;
b. geospatial relation discovery and deduction with the utilization of spatial operations and topological functionalities in the Semantic Web; and
c. cartographic considerations to represent health information.

The incorporation of geospatial semantics into the Semantic Web would allow the integration of ontologies and rules for heterogeneous information reasoning and deduction, which are helpful for health studies. Successfully implemented, this methodology would be able to represent health concept hierarchies, spatial operations, topological operators, cartographic representation styles, and people’s knowledge with ontologies and rules, and thus allow automated health information query, reasoning, and mapping.

1.6.5 Evaluation of the Research

This research addresses the three identified problems: data heterogeneity, resource deficiency, and health information representation in georeferenced health information sharing environments. The following criteria are proposed to quantify the extent to which this research actually meets the objective and "improves" the use of Web-based GIS in selected health-related applications. If all the criteria are met, then in that sense the objective is achieved.

For heterogeneous health data integration, the data sources can be retrieved from the data level through files or databases. With the popularity of Web Services, the data could also be accessed from the service level through (Geospatial) Web Services. Meanwhile, as georeferenced health data include a spatial component, the integration and query of health data should not only be able to support non-spatial semantic matching (e.g., using taxonomies, concept relations), but also need to handle geospatial semantic matching with spatial relations and operations. The requirements of heterogeneous health data integration call for a framework to support the handling of both non-spatial semantics and geospatial semantics from the data level and service level, as shown in Table 1.1.

Table 1.1: Requirements for heterogeneous health data integration

	Non-spatial semantics	Geospatial semantics
Data level	●	●
Service level	●	●

For the resource deficiency problem, georeferenced health maps and functionalities need to be accessed by users. The use of these resources requires the consideration of accessibility, interoperability, trust, and privacy issues. In the context of this research, *Accessibility* refers to that the resources are able to be readily accessed by users. *Interoperability* allows the exchange of the resources through standard interfaces. *Trust* refers to the resources' dependability and the quality in the interaction with those resources. *Privacy* provides solutions for access control and privacy management in health information dissemination. To overcome the deficiency in health information sharing, consideration needs to be taken on the accessibility, interoperability, trust, and privacy issues of resources as shown in Table 1.2.

Table 1.2: Requirements in solving resource deficiency

	Accessibility	Interoperability	Trust	Privacy
Georeferenced health data/maps	●	●	●	●
Geospatial processing functionalities	●	●	●	●

For the online representation of health information, the representation model needs to be exchangeable and cover essential health information. In order to define more completely the content requirements of online health information representation, many factors must be considered, including mapping variables, representation dimensions, and privacy issues, as shown in Table 1.3. The mapping variables should provide the vital information for user visualization purposes. The representation dimensions need to include information related to the interpretation of health data including semantic, geometric, and graphic representation. Privacy issues also need consideration in the distribution of health information representation.

Table 1.3: Requirements for health information representation

	Exchangea-bility	Mapping variables	Representation dimensions			Privacy
			Semantic	Geometric	Graphic	
Online representation	●	●	●	●	●	●

1.7 Overview

Each of the following five chapters addresses different aspects of the data heterogeneity, resource deficiency, and health information representation problems discussed in this chapter. Chapter 2 works on the health architecture design to share data from different health organizations with the consideration of the sensitive issues. Chapter 3 explores the use of CGDI for health, and points out the weakness of CGDI in health information representation. Chapter 4 enriches the health data sharing architecture to support the sharing of health processing functionalities, and designs a health information representation model to facilitate the dissemination and understanding of health information. Chapter 5 uses ontologies and rules to enable the query of heterogeneous data from files or Web Services, considering non-spatial and geospatial semantics. Chapter 6 details the methods on how to evaluate Geospatial Web Services for building trust of SDI for health applications.

The paper that forms Chapter 2 presents a solution to the first objective of this research: designing an architecture by using SOA and SDI for health data mapping and sharing. An architecture was designed and a case study of infectious diseases was carried out across the New Brunswick and Maine border based on this architecture. Through data matching, the heterogeneity problem was handled by integrating data from both sides to a common data schema, and representing them as maps in the user interfaces. The reusability and interoperability were handled by the use of open-standard Geospatial Web Services, such as WMS, SLD, and WMC. As people usually prefer to use the spatial boundaries with which they are familiar to convey health information (such as administrative boundaries), online health information representation was addressed by statistical calculation, thematic mapping, and access control with levels of detail.

The paper constituting Chapter 3 presents a response to the second objective of this research: developing performance evaluation metrics to measure the SDI effectiveness and build trust of SDIs for health applications. Metrics in evaluating the usability of CGDI components in health mapping were selected, including: cost, accessibility, response time, data quality, reliability, exchangeability, interoperability, cartographic representation, and security. CGDI enabled health applications that support basic geospatial functions, such as thematic mapping, spatio-temporal processing, spatio-temporal trend representation, and health facility distribution, were developed for the evaluation study. Based on the opinions of developers and users about the developed applications, a matrix that links the usability metrics and CGDI components was determined. Meanwhile, the limitations found in CGDI for health include the handling of semantic heterogeneity, cartographic representation of Web-based GIS applications, trust of Geospatial Web Services, and security issues.

The paper in Chapter 4 responds to the third objective: building a health information representation model to share and exchange essential health statistical information. A HEalth Representation XML (HERXML) was designed to share the semantic, geometric, and graphic representation of health information regardless of platform or system via the Web. Its design regards several issues such as metadata, statistical methods, comprehensiveness, platform-independent representation, and semantic interpretation. Meanwhile, this chapter enriches the first objective with the use of OGC WPS to support online processing of health data. WPS allows users to input their raw data and get the processing results which can be represented in maps or HERXML. This extension can enhance the development of geospatial public health infrastructure that makes data and functionalities to be more available to users while keeping affordable cost for health organizations.

The paper that forms Chapter 5 addresses the fourth objective: building a health GIS ontology framework enabling both geospatial and non-spatial reasoning in health data integration and query. The geospatial information representation was incorporated in RuleML, a standard rule language in the Semantic Web. The ontology and rule framework designed in this research facilitates heterogeneous health information query and reasoning. Ontologies define the relationships between different concepts in semantics, geometries and graphics, such as the respiratory disease ontologies in this study. The rules, including reasoning rules and cartographic rules, were used to integrate various data sources into a homogenous representation. With the implementation of geospatial and non-spatial semantics in the proposed system, four case scenarios were used to demonstrate respiratory disease information query and reasoning with semantic, geometric, and graphic requirements.

The paper in Chapter 6 further explores the second objective: developing performance evaluation metrics to measure the SDI effectiveness and build trust of SDIs for health applications. A quality evaluation framework on how to evaluate the Geospatial Web Services in SDIs is presented. The framework was developed based on service activities and service usage. Service activities include the details on service commitment, service description, service process, and service outcome following the process of service consumption. With the criteria that need to be fulfilled in this Geospatial Web Service evaluation framework, objective and subjective evaluation were explored. Objective measurement quantifies the test results to scores based on the fulfillment of the evaluation framework. Subjective measurement can be implemented through questionnaires related to service activities and service usage, based on the level of satisfaction (e.g., strongly disagree, neutral) of developers and end-users.

Finally, Chapter 7 summarizes the overall work of this research, and gives recommendations about further research on Web-based GIS for health information sharing.

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Chapter 2. Online GIS Services for Mapping and Sharing of Disease Information[♣]

Abstract

Disease data sharing is important for the collaborative preparation, response, and recovery stages of disease control. Disease phenomena are strongly associated with spatial and temporal factors. Web-based Geographical Information Systems provide a real-time and dynamic way to represent disease information on maps. However, data heterogeneity, integration, interoperability, and cartographic representation are still major challenges in the health geographical fields. These challenges cause barriers in extensively sharing health data and restrain the effectiveness in understanding and responding to disease outbreaks. To overcome these challenges in disease data mapping and sharing, the senior authors have designed an interoperable service oriented architecture based on Open Geospatial Consortium specifications to share spatio-temporal disease information.

A case study of infectious disease mapping across New Brunswick (Canada) and Maine (USA) was carried out to evaluate the proposed architecture, which uses standard Web Map Service, Styled Layer Descriptor, and Web Map Context specifications. The case

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study shows the effectiveness of an infectious disease surveillance system and enables cross-border visualization, analysis, and sharing of infectious disease information through interactive maps and/or animation in collaboration with multiple partners via a distributed network. It enables data sharing and users' collaboration in an open and interactive manner.

In this project, the senior authors developed a service oriented architecture for online disease mapping that is distributed, loosely coupled, and interoperable. An implementation of this architecture has been applied to the New Brunswick and Maine infectious disease studies. This study has shown that the development of standard health services and spatial data infrastructure could enhance the efficiency and effectiveness of public health surveillance.

2.1 Background

Currently, such factors as booming population, environmental pollution, rapid urbanization, and global warming all influence the conditions for disease outbreaks. Disease studies have revealed strong spatial aspects, including disease case location and disease diffusion. Thus, mapping spatial aspects of diseases could help people understand some puzzles of disease outbreak. The development of disease mapping was traced by Tom Koch from a map of plague outbreaks at Bari, Italy in 1694 to a map of Acquired Immunodeficiency Syndrome (AIDS) for the entire earth in the present-day [Koch, 2005]. Unlike the raw disease data, disease maps offer a visual means of identifying cause and effect relationships existing between humans and their environment. Disease maps can enable health practitioners and the general public to visually communicate about disease distribution.

Geographical Information System (GIS) provides an effective way of managing, storing, analyzing, and mapping disease information. GIS has strong capabilities in mapping and analyzing not only spatial data, but also non-spatial data, and can integrate many kinds of data to greatly enhance disease surveillance. It can render disease data along with other kinds of data like demographic and environmental data, representing the differences with various cartographic styles. Gupta and Shriram [2004] identified many useful functions of GIS such as network analysis, buffer analysis, and statistical analysis in the area of disease surveillance. When a disease appears, GIS could represent disease information rapidly and analyze the disease's spread dynamically. [Boulos, 2004] emphasized that the GIS technologies and services that are able to function proactively in real-time are extremely and critically important to creating a "spatial health information infrastructure".

Meanwhile, the rapid development of the Internet influences the popularity of Web-based GIS, which itself shows great potential for the sharing of disease information through distributed networks. Distributing and sharing disease maps via the Web could help decision makers across health jurisdictions and authorities collaborate in preventing, controlling, and responding to a specific disease outbreak.

Documented applications are already making health information accessible through the Web [Benneyan et al., 2000; Edberg, 2005]. Custom online interactive health maps could be implemented using Google Maps API, Google Earth KML, or MSN Virtual Earth Map Control [Boulos, 2005]. The maturity of Web-based GIS enables the generation of thematic maps dynamically and efficiently, with a thin/thick client or hybrid architectures. For example, Inoue et al. [2003] developed a thin client, Web-based GIS application to dynamically generate and display infectious disease surveillance data through maps and charts. Blanton et al. [2006] integrated federal, state and local data and developed map tools for rabies surveillance with a Web-based GIS thin client architecture.

Other applications have employed thick client, Web-based GIS approaches to visualize health information through Java Applets and Scalable Vector Graphics (SVG). Qian et al. [2004] provided a thick client, Web-based GIS approach to visualize global SARS information using a Java Applet. Kamadjeu and Tolentino [2006] implemented a Web-based public health information system to generate district-level country immunization coverage maps and graphs with SVG. As the response performance of Web-based GIS is in near real-time, it is effective for understanding the disease phenomena to support decision making.

Time is an important factor in analyzing disease outbreak. Foody [2006] highlighted the spatio-temporal characteristic as an important feature in recent health studies. By comparing thematic maps at different time intervals, the spatial-temporal change of the disease could be projected, including temporal cluster shift, vector transmission rates, and mobility of susceptible populations. Greene et al. [2005] analyzed the spatial, temporal, and spatio-temporal patterns of viral meningitis to aid the identification of risk factors. Greiling et al. [2005] developed a desktop application with a time bar for exploring spatio-temporal patterns of colon cancer mortality rates.

2.1.1 Challenges in Disease Mapping

The experience of disease outbreak has demonstrated the importance of applying statistical models and mapping tools in making health policies. Despite the continual development of disease mapping technologies, four major challenges still exist.

1. **Disease data heterogeneity**. Disease data are collected by different health organizations in various ways, which creates a barrier to data sharing. These data may be stored and distributed in different places through files or databases. Commonly, there are three sources of heterogeneity: semantic, schematic, and syntactic heterogeneities that need to be considered during data integration [Bishr, 1998]. Techniques that can facilitate the sharing and integration of disease data are highly valuable. *Semantic heterogeneity* arises from the cognitive differences and naming convention variations among various disciplines. *Schematic heterogeneity* deals with the different methods of describing the facts of the world, including hierarchies, properties, and relationships. *Syntactic heterogeneity* refers to diversity in representations or storage models. The schema integration approach and ontology-based approach could be used to overcome these heterogeneities and thus facilitate data sharing.

2. **Difficulties in integration and reusability**. Integrating and reusing the current health applications is constrained to a large extent. Zeng et al. [2004] pointed out that the isolation of existing stand-alone disease management systems leads to a data sharing problem. Most health information systems have a closed architecture – even the ones that use Web-based technology are difficult to integrate. Typically, users can only access maps from such a health application, and it is difficult to integrate datasets from these applications. A service oriented architecture with loosely coupled services could link distributed health data and support reuse of services.

3. **Lack of interoperability between different disease services**. Interoperability makes it easy to communicate, execute programs, or transfer data among various systems in a unified manner. For disease studies, it is important to utilize distributed disease information and share the data through standard interfaces. In analyzing disease information and the health decision making process, it is helpful to integrate many kinds of spatial and non-spatial data, including roads, hospitals, available medical resources, etc. To address spatial data sharing and interoperability, many international organizations such as Open Geospatial Consortium (OGC), and the International Standards Organization Technical Committee 211 (ISO/TC211) are attempting to address standards and application specifications. Since spatial representation makes disease phenomena more understandable, integrating these open geospatial standards for the development of Web-based disease tracking and analysis systems represents a great opportunity to improve health data sharing, interoperability, and visualization. Boulos and Honda [2006]

proposed to publish health maps through Open Source Web GIS software that usually supports OGC specifications.

4. **Concerns over appropriate cartographic representation and sensitive dissemination of disease data**. Cartographic representation deals the data representation using graphics. It greatly influences the understanding of disease phenomena. Many health practitioners are eager to map disease data to certain district boundaries, which could show the patterns of disease distribution and support their decision making. Disease data contain private information, and sharing of such data may cause considerable concern. For example, if the disease information shows one area with high disease rates, people would possibly avoid both the area and its inhabitants. Bell et al. [2006] listed four kinds of methods to protect the confidentiality of disease data: (a) the aggregation of data in spatial and temporal dimensions; (b) removal of the geographical identifiers from the original data; (c) relocation of individual records randomly on a small scale; and (d) limitation of access to the data through a user- and/or function-restricted computer environment. When compared with original data, the aggregated results would have some differences. Leitner and Curtis [2006] identified geographical masking methods used to preserve individual confidentiality and measured the similarity of the aggregated data through different cell sizes with the original point pattern. Meanwhile, such factors as population density, racial tendency, environmental pollution, and cultural difference all affect disease studies. Considering those factors in the mapping process will improve the cartographic representation of disease information.

2.2 Methods

2.2.1 Disease Mapping Architecture

To overcome in particular the heterogeneous data integration and service interoperability challenges to disease mapping, the senior authors proposed a disease mapping architecture illustrated in Figure 2.1. The architecture contains four tiers: a *data storage* tier, an *ontology engine* tier, a *standard health services* tier, and a *maps and animation* tier.

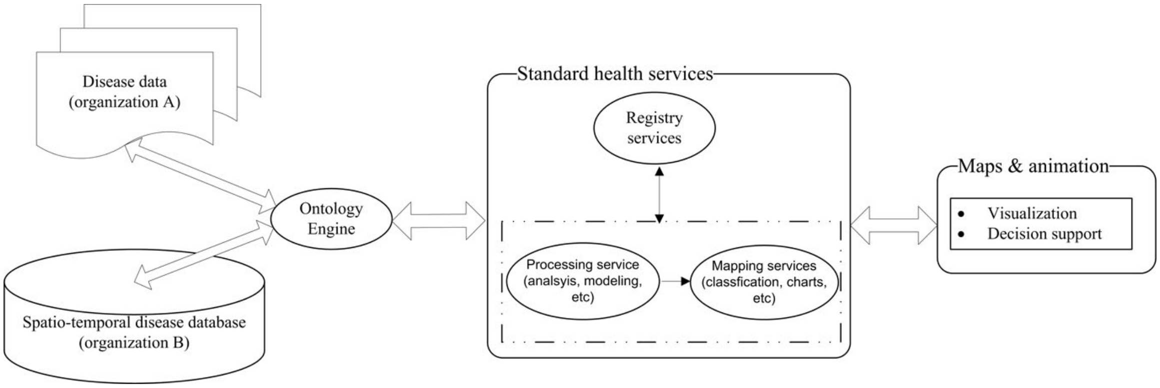


Figure 2.1: Disease mapping architecture

(This architecture includes a data storage tier, an ontology engine tier, a standard health services tier, and a maps and animation tier.)

- ***Data storage tier.*** Health data could be collected by different health organizations and stored in files or databases. They can be accessed through the Internet or Intranet for data sharing.

- ***Ontology engine tier***. The ontology engine is designed to overcome the heterogeneity existing in the distributed health data. It provides a uniform way for the standard health services to retrieve data. Health data matching and transformation tasks are processed by the ontology engine.

- ***Standard health services tier***. Explicit standards are proposed to be used in this tier for the interoperability of the disease mapping systems. OGC provides many specifications in sharing spatial related data, which is possible to support disease data sharing. Generally, there would be three kinds of services:

  - *Health data processing services* are responsible for analyzing the disease from spatial and temporal aspects. Many statistical methods are used in the analysis of the disease. Most common ones are crude morbidity ratio, and standardized morbidity ratio. Other methods use spatial autocorrelation indicators like Moran's I and Local G^* in detecting disease clusters [Greiling et al., 2005].

  - *Health mapping services* could serve the cartographic representation of health data to the clients. Providing disease information through dynamically generated maps could control privacy issues more effectively than the SVG or Java Applet technologies which transfer the disease data to the client side.

  - *Health registry services* act as the service brokers in the service oriented architecture. With the health registry services, all description information about health processing services, and health mapping services could be published and discovered conveniently through uniform interfaces.

- **Maps and animation tier.** It provides the spatio-temporal maps for the health practitioners and public in their decision making process. Ogao [2006] categorized three types of animation methods from "low" to "high" according to the respective levels of interactivity and complementary domain knowledge that each of them offers to the user: passive, interactive, and inference-based animations. Through visualization tools like maps and animation, people could generate hypotheses in disease studies and seek the explanatory factors, which is important in decision making. The ability to share maps or animations in a distributed environment could also provide a collaborative mechanism in preparation, response, and recovery stages of disease control.

2.2.2 Study Area and Data Description

The province of New Brunswick, Canada and the state of Maine, U.S.A. are the study areas. They share a common, highly travelled territorial border. There are significant volumes of goods and people travelling across this international border and infectious agents are easily carried across both sides. To assure the privacy of the health data, different health organizations or users have different rights in accessing detailed levels of health data. There will be different levels of privilege in dealing with visualizing and tracking the levels of health data.

In this study, six levels of administrative/census areas that cover the entire territory of both sides were chosen. New Brunswick is organized into "Province", "Health Region", "Census Division", "Census Subdivision", "Forward Sortation Area", and "Dissemination Area" geo-layers. In Maine, the corresponding levels are "State", "Health Service Area", "County", "County Subdivision", "Zip Code", and "Census Block Group" respectively.

The data for infectious disease mapping used in this study includes disease data, population data, and six levels of geometric boundary data. The infectious disease data for New Brunswick are represented by the hospital discharge data recorded for the New Brunswick Department of Health between 1997 and 2002. The corresponding Maine data were collected through the research partners at the University of Southern Maine. The six levels of geometric boundary data for New Brunswick were obtained from Service New Brunswick, Statistics Canada, and Canadian Geospatial Data Infrastructure (CGDI) portal. The six levels of geometric boundary data for Maine were obtained from the American National Spatial Data Infrastructure (NSDI) portal. The population data of New Brunswick and Maine were acquired from Statistics Canada and the U.S. Census Bureau respectively.

2.2.3 Spatio-temporal Data Model and Data Matching

The spatio-temporal object-oriented data model can provide a uniform way to manage spatio-temporal data and support better data management and analysis. The spatio-temporal object-oriented data model used in this study is shown in Figure 2.2. The

Disease class, which describes the disease characteristics, could be extended to its subcategories of disease such as *Infectious disease* and *Respiratory disease*. By comparison, a *Disease event* is a spatio-temporal object that relates to a certain kind of disease. It is the activity that associates with a certain kind of disease, such as a hospital observation, training and education service to patients. It includes the patient and the time information. *Time* could be an instant or interval. *Patient* is related to the disease case location. *Location* could be an administrative area or geo-coding point. *Administrative area* could be national level, provincial level, county level, etc.

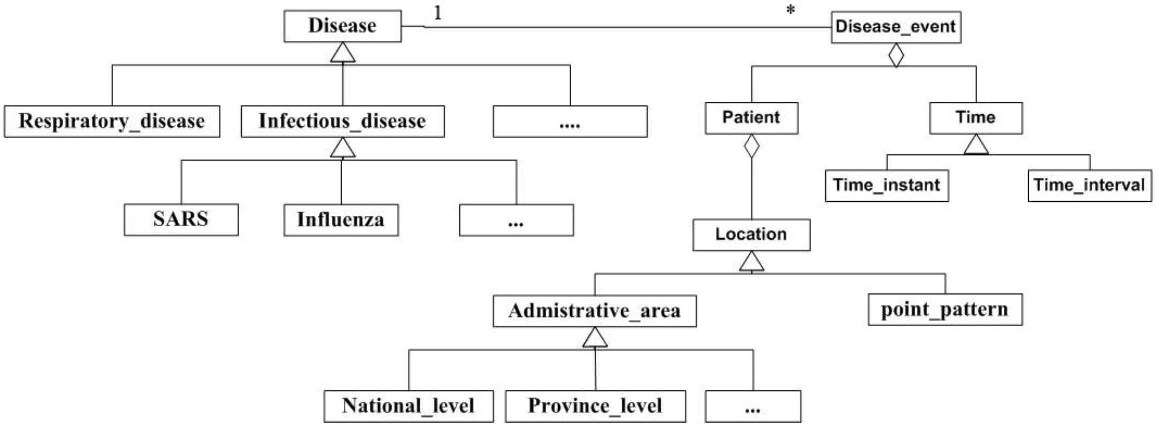


Figure 2.2: Spatio-temporal data model for disease data

(This data model is an object-oriented model and used for the data integration.)

We integrated the data from New Brunswick and Maine mainly through a common schema integration approach. All the attributes in describing disease, disease event, patient, time, and the six administrative geographical levels of both sides were specified. For instance, in constructing the jurisdiction of Health Region, common attributes such as name, spatial boundary, state/province code, and vaccine stock are described. Moreover, a data dictionary was built to match the similar world facts with different definitions to the common schema. For example, the postal code attribute used in New Brunswick and zip code attribute used in Maine were matched to the postcode attribute in the common schema. Through the data matching, the Maine data and New Brunswick data would then be handled in the same way.

2.2.4 Statistical Methods for Data Processing

This study concentrated on the spatial, temporal, and demographic factors and their influence on the infectious disease outbreak, which could show the disease distribution with spatial, temporal, age, and gender differences. The statistical methods used are basic statistical calculations of disease rates, as more complex methods would delay the response time in the online mapping process. These statistical methods are the following: Crude Morbidity Rate (CMR), Normalized Morbidity Ratio (NMR), Age-Specific Morbidity Ratio (ASMR), Age-Adjusted Morbidity Ratio (AAMR), and Standardized Morbidity Ratio (SMR) (See Section 3.4.3.2 for details on these).

The purpose of these statistical methods is to provide a standardized legend (pattern /color) for data representation across temporal, spatial, and jurisdictional layers. The disease data used are in point patterns, which were generated through geo-coding process with the postal code and/or geo-coded civic addresses. Since the name of the postal code may change over time, considerations the spatial location of postal code and/or geo-coded civic addresses were taken to ensure the geo-coding quality. With the "point-in-polygon" spatial operation, it is easy to roll up data and calculate disease cases in relation to certain administrative boundaries. The above five statistical methods were used to calculate the statistical values of disease rates. These statistical values could be expressed through disease mapping variables related to time (e.g., annual, seasonal, monthly, weekly, daily), gender (e.g., male, female, both), age group (e.g., 0-4, …, 85+, total), geographical level (e.g., Dissemination Areas / Census Block Group, Census Divisions / County, etc.), and/or disease type (e.g., influenza). In the classification maps or charts, the generated thematic maps were based on the above multiple disease mapping variables.

Processing time is also an important factor for online infectious disease mapping, as it takes time to calculate the statistical values. Taking this into account, two flexible interfaces have been developed for obtaining the statistical results. For pre-computed cases, the system could respond in real-time. In such a case, the statistical values of the pre-defined conditions (spatial level, age group, etc) have already been calculated. The other situation is more flexible and is processed in real-time. Users can define the parameters (certain time interval, specific age group, etc) according to their requirements. In addition, a cache mechanism was developed to maintain calculated statistical values. Data warehousing can be used as an alternative approach to improve the processing performance.

2.2.5 OGC Services for Disease Mapping

The OGC Web Map Service (WMS), Styled Layer Descriptor (SLD), and Web Map Context (WMC) were implemented for the disease mapping and sharing in this study. WMS publishes its ability to produce maps rather than its ability to access specific data holdings, and generates spatially referenced maps dynamically [OGC, 2001]. SLD allows user-defined symbolization in producing maps [OGC, 2005a], which makes it possible to integrate maps from different WMS in the same style. WMC uses Extensible Markup Language (XML) based context documents including information about the servers providing layers in the overall map, the bounding box, and map projection shared by all the maps, and these provide sufficient operational metadata for clients to reproduce the maps [OGC, 2005b].

2.3 Results

This study dealt with the visualization of infectious disease spatio-temporal outbreaks and propagation across New Brunswick and Maine in different resolutions, through the implementation of a service oriented online infectious disease mapping and sharing system. The implemented framework is shown in Figure 2.3. All the WMS services could be registered in the health portal for user access. Through the health portal, users could obtain disease maps from the desired WMS that distributes over the Internet, and share the acquired WMS maps with others through WMC.

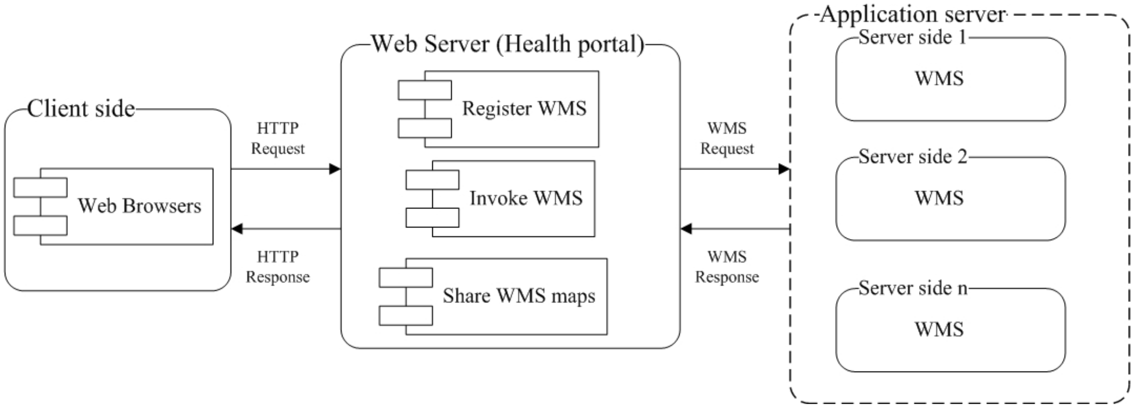


Figure 2.3: Implemented mapping and collaboration framework

(The framework contains client side, health portal and application server.)

2.3.1 Web Map Service Support

The most important operation in the Web Map Service is GetMap. It supports the parameters for getting images in certain spatial extent, time, coordinate reference system, style, image height, image width, and image format. To maintain the flexibility of showing the maps in different styles, SLD supports user-defined symbolization in representing the data in maps. For instance, multiple disease maps accessed from different WMS Services can be represented using the same cartographic style.

In the infectious disease mapping process, several mapping variables, including age group, statistical method, and gender need to be considered. However, the standard Web Map Service could not support parameters such as disease type, gender, and statistical method, among others. For the integration of Web Map Services in the disease mapping, a convention was developed to name map layers. As to different combinations of gender, age, geographical level, disease type and statistical method variables, a distinct WMS layer name is assigned to each of them through customized encoding rules. The Web Map Service parses the infectious disease mapping parameters from the layer name. As the service is compatible with WMS, thematic disease maps could be accessed by a health portal or any OGC compatible clients. Figure 2.4 shows the classification map retrieved from a Web Map Service which describes Crude Morbidity Ratio distribution of all the cells with the parameters (Dissemination Area / Census Block Group level, year 2000, Crude Morbidity Ratio, all age group, influenza). Figure 2.5 shows the Crude Morbidity Ratio distribution of year 2001 with the same parameters. By comparing different mapping variables at different times and geographical levels, users can visualize the pattern and movement of the infectious disease.

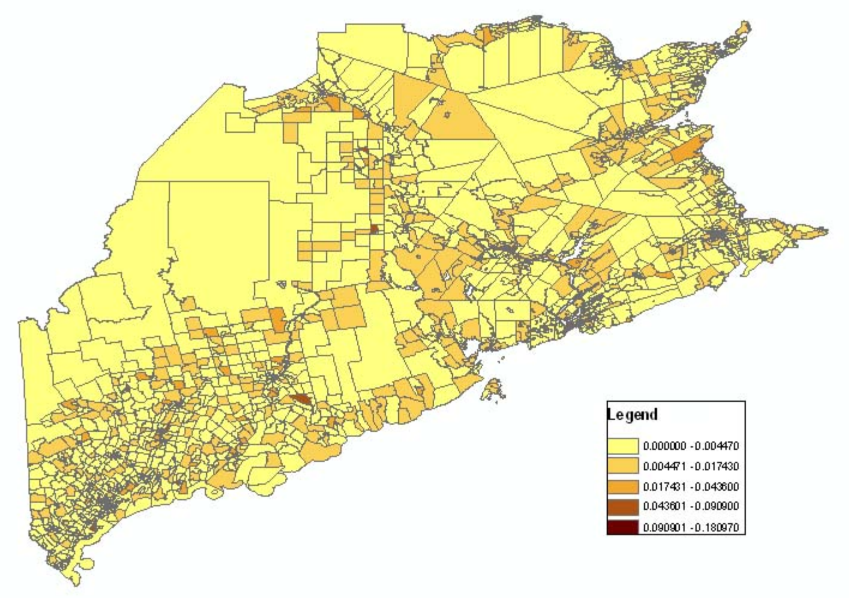


Figure 2.4: Crude Morbidity Ratio 2000

(It represents Crude Morbidity Ratio (population constant is equal to 1) distribution of all the cells with the parameters (Dissemination Area / Census Block Group level, year 2000, all age group, influenza).)

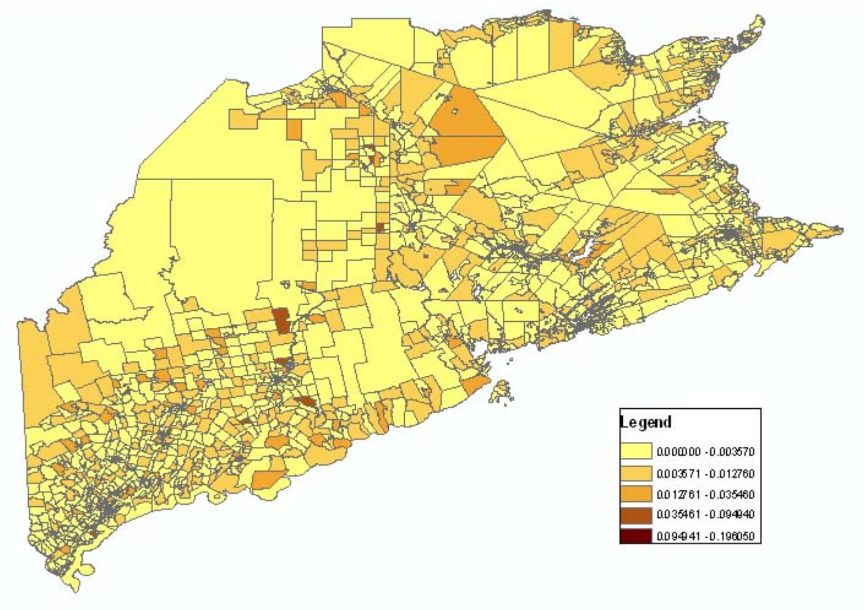


Figure 2.5: Crude Morbidity Ratio 2001

(It represents Crude Morbidity Ratio (population constant is equal to 1) distribution of all the cells with the parameters (Dissemination Area / Census Block Group level, year 2001, all age group, influenza).)

In addition, simulated influenza outbreak data (including the influenza cases, other data such as grocery retail, grocery supply, fuel retail, fuel supply, school, pharmacy and hospital beds occupation) based on influenza statistics from 1968 (approximately 35% infection rate) were generated and published through WMS. Hosted by the Emergency Measures Organization of the Province of New Brunswick, Exercise "High Tide" enlisted many participants to test this real-time decision making environment in the simulation of a disease outbreak. This environment simulates the diffusion of the disease at different days using animated mapping. The animation was achieved by using the time tag in WMS services. Users can select a start date and map switch interval to view the disease map animation, or choose a certain day to show the disease map. In the generation of the disease maps, this environment supports data aggregation and representation to certain levels, such as Maine/NB and Health Region, in different days. With the specified user request, mapping values in the database temporal tables (which stores the geometry data and mapping attribute values) will be updated synchronously with a lock mechanism and disease maps will be created. Meanwhile, the maps of facilities like grocery stores and ambulance locations could be obtained from a WMS. Figure 2.6 shows the school absenteeism chart obtained from a Web Map Service on top of the thematic disease map, and the background image was also retrieved from a WMS provided by Demis, a European company. The convenient disease map access and integration could be achieved by using the standard WMS.

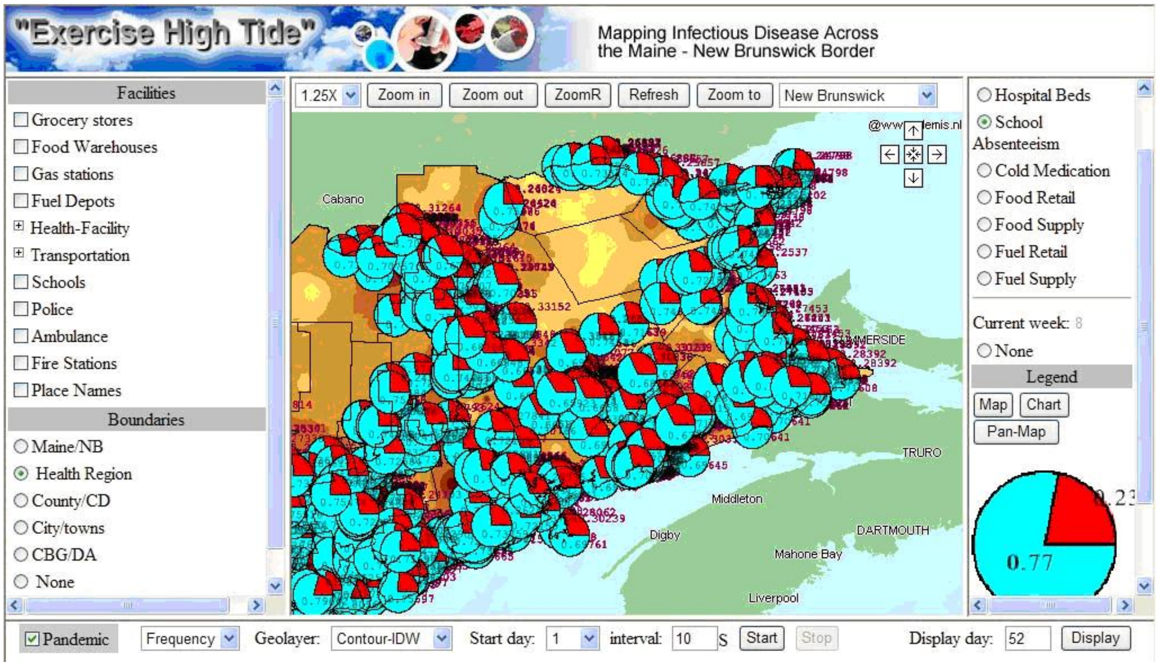
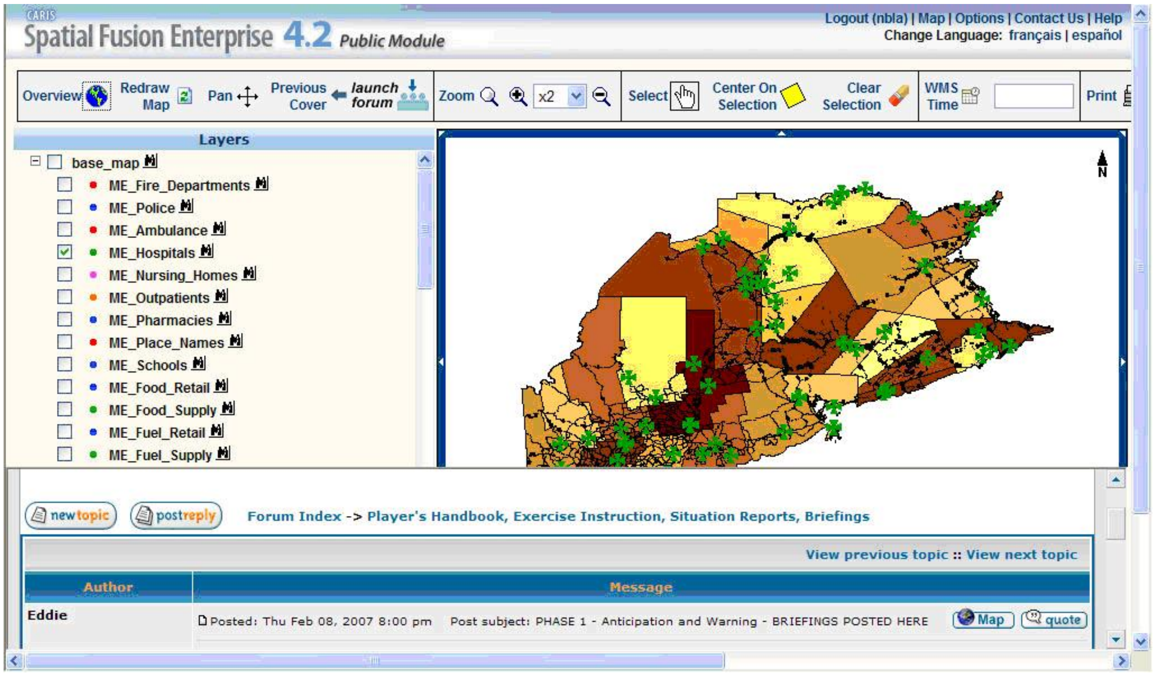


Figure 2.6: Web Map Service integration

(It is integrated from three WMS services that produce school absenteeism charts, thematic disease maps, and world boundary maps.)

2.3.2 WMC for Sharing Disease Maps

Collaboration is very important in disease decision-making. The sharing of disease maps allows users to discuss readily how to prepare for and respond to disease outbreaks. Following the previous work of developing an online GIS discussion forum for public participation [Tang et al., 2005; Zhao and Coleman, 2006], the senior authors integrated a discussion forum with CARIS Spatial Fusion Enterprise in a health portal, which can access and distribute disease maps from WMS. Compared with pure text, maps are more attractive in sharing certain types of ideas with others. The portal allows users to exchange ideas with text as well as maps (see Figure 2.7). The Spatial Fusion Enterprise is used for accessing disease maps from different WMS services. In addition to the ordinary forum functions, this forum provides the capacity to view disease maps and attach the current map view of Spatial Fusion Enterprise to a user's topic.



Forum Index -> Player's Handbook, Exercise Instruction, Situation Reports, Briefings

Eddie

Posted: Thu Feb 08, 2007 8:00 pm Post subject: PHASE 1 - Anticipation and Warning - BRIEFINGS POSTED HERE

Figure 2.7: Discussion forum for decision making

(After users click the "launch forum" button, they could log into the forum and share maps and text with others.)

The service level sequential diagram of this system is shown in Figure 2.8. After the users log into the health portal, they can request the disease maps that they need in their application. The health portal will invoke the appropriate WMS and show disease maps to the users. If users want to share the maps, they can launch the discussion forum and attach the disease maps to a posted topic. The health portal would generate a unique ID to the shared disease maps and save the parameters rather than the maps in obtaining the disease maps through WMC. WMC stores the parameters in XML with general element for layer-independent context and a sequential layer list for specific details about each shared layer. Afterwards, when other people visit the forum and click the map button in a certain topic, the health portal will parse the corresponding WMC document, obtain the disease maps, and show them in the viewer.

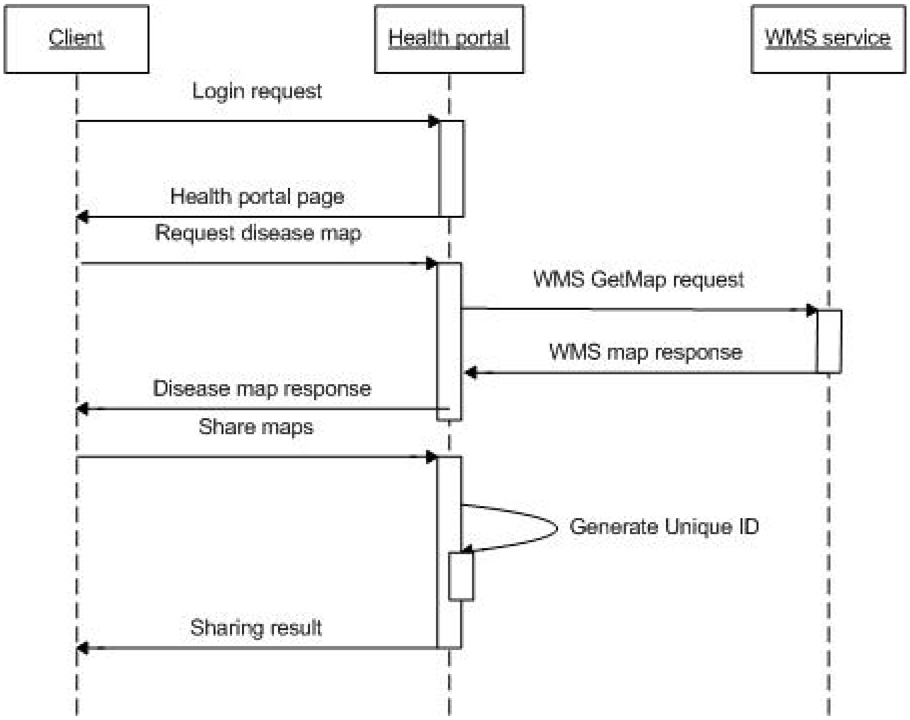


Figure 2.8: Service level sequential diagram for disease data sharing

(After users log into the forum, they can obtain disease maps and share them with others. Each shared map is given a unique identification.)

2.4 Discussion

With the implementation of the standard service oriented disease mapping architecture, sharing disease data through the distributed network can achieve high flexibility and interoperability. The health services could be defined in fine granularity and composed into service chains for satisfying the requirements of different applications. In disease studies, health organizations could generate their own disease mapping and processing services compatible with OGC specifications and register them in a common catalogue. In this way, the cost of disease data collection and analysis can be shared. At the same time, the ability and options for collaboration have been greatly improved.

Using the statistical methods for data processing, disease data can be aggregated to certain levels to be mapped. The thematic maps and map animation are used to show the disease information and protect the confidentiality of disease data. Disease information cartographic representation was generated in this project based on health users' needs.

By proposing an OGC-compliant architecture to implement Web-based health services, the issues of reusability, integration and interoperability of services were well handled in this project. Moreover, the services could be enriched based on the continuous development of OGC specifications. Other OGC standard services -- for example, Web Processing Service (WPS) for processing functions and Web Catalogue Service (WCAS) -- will be implemented in future health applications.

Data heterogeneity problems always occur in the data collection processes of different health organizations. This case study accomplished a low-level integration by converting the data from both sides to a common schema. It solved schematic and syntactical heterogeneity issues, but did little to address semantic heterogeneity. Building a standard ontology for the spatio-temporal disease data would enable the concept-based sharing of disease data, solving the semantic heterogeneity problems (cognition and naming differences).

The senior authors are currently integrating a health model with the OGC geospatial data model in generating standard ontology to support better sharing and integration of disease data. The heterogeneous data integration process will be implemented in two phrases. After considering the semantic issues of the text information, spatial pattern and topology will then be incorporated into the integration.

2.5 Conclusions

Recent disease outbreaks have demonstrated the need for GIS- and mapping-related applications in public health. The World Health Organization, American Centers for Disease Control, and Health Canada are all proactively engaged in mapping viral pandemics and applying GIS models to global and national health policy. This research designed and implemented a service oriented online disease mapping architecture which is loosely coupled and interoperable. This architecture supports reusability of health disease data mapping and analysis functions to lower the cost of building huge independent disease surveillance systems. It also enables cross-border map visualization, analysis, and sharing disease information through interactive maps or animation in a collaborative manner with multiple partners (public health officials, researchers, policy-makers and the public) via a distributed network. If a real disease outbreak occurs, this distributed disease mapping architecture can support public education, disease surveillance, health care planning, emergency coordination, spatial epidemiology, vaccine distribution, and policy initiatives at different administrative levels. If the disease data can be updated frequently, health practitioners could obtain real-time disease maps processed in accordance with different statistical methods and under different spatio-temporal conditions in order to understand both the current situation and the movement of disease. More effective collaboration with the support of disease maps over the Internet can secure a faster response to emergency situations. A case study of infectious disease mapping across New Brunswick and Maine has been implemented on the proposed architecture to cope with the disease data sharing, integration and representation challenges. More extensive implementation of standards-based Spatial Data infrastructure (SDI) in each country could enable effective collaborative decision making and policy planning. The development of SDI would further support this online disease mapping architecture for decision and policy making. To improve the effectiveness and efficiency of this architecture for disease applications, future research will concentrate on development of geospatial disease ontology to facilitate data integration and the construction of interoperable distributed disease services.

Acknowledgements

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Chapter 3. The Canadian Geospatial Data Infrastructure and Health Mapping[♣]

Abstract

Due to the recent outbreak of SARS and the danger of the pandemic Bird Flu, the ability to strengthen health surveillance and disease control is a growing need among governments. The development of the Canadian Geospatial Data Infrastructure (CGDI) has shown great potential in many industries such as emergency management, public health, disaster relief, environmental impact assessment, transportation, and land information systems. In this research, the aims are to use the CGDI and to identify its usability in supporting online health mapping. To identify the usability of the CGDI for health mapping, nine usability metrics were employed. The senior authors also designed an architecture based on the CGDI to support the basic functions for health mapping, and implemented an infectious disease simulation for New Brunswick and Maine. Within the CGDI framework, this research enabled cross-border visualization, integration, sharing, and exploring of an infectious disease outbreak through thematic maps. Based on the experience of the developers and the feedback from users, an evaluation of the usability matrix with the CGDI components (technical standards, national framework data, enabling technologies, and common data policies) was explored using this cross-border health mapping application. The use of the CGDI in health applications has great

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potential in supporting effective and secure health data sharing and integration. Enrichment of the CGDI would further facilitate the data sharing and improve decision making efficiency and effectiveness.

3.1 Introduction to the Canadian Geospatial Data Infrastructure (CGDI)

Spatial data have a reference to geographical locations in space, which helps in the understanding of the "where" problem, i.e., the spatial location and area of some features, and the spatial distribution and correlation of some phenomena. According to the United States General Accounting Office, almost 80 percent of all government information has a geospatial context [GAO, 2003]. Analyzing government information with spatial data has shown great prospects in many areas such as emergency management, human health and environment, disaster relief, transportation, land information systems, etc. Thus, it could be quite useful to integrate spatial data for decision making processes in public health practice.

The complexity of spatial data, the diversity and heterogeneity of spatial data sources and spatial data formats create barriers for users of the CGDI in the public health domain. With the rapid development of geospatial science and Web-based technology, it is now possible to share geospatial information through a distributed network. The CGDI is a framework that facilitates the sharing of Canada's spatial data through the Internet. Since spatial data are collected by different levels of government and organizations, housing all the spatial data in a central data warehouse would be too costly and risky. The CGDI does not host all the spatial information in a central data warehouse, but attempts to create an interoperable infrastructure that allows various communities to share geospatial information. The CGDI is composed of four key components: technical standards, national framework data, enabling technologies, and common data policies [GeoConnections, 2006a]. Technical standards guide the sharing of location based information in an interoperable way. National framework data is the base component of the CGDI, and it is integrated from different providers. Enabling technologies are used to develop online applications based on the endorsed standards. Common data policies are agreed by various agencies to reduce data duplication and support data sharing. The vision of the CGDI is "to enable access to authoritative and comprehensive sources of Canadian geospatial information to support decision making" [GeoConnections, 2005a].

3.2 Health Mapping and Geospatial Aspects

Since Dr. John Snow combined geospatial information to analyze cholera deaths about 150 years ago [McLeod, 2000], integrating disease studies with the geographical aspect has received great attention. Cliff and Haggett [1988] illustrated atlas of disease distribution (such as respiratory tuberculosis, malaria, and measles) in analyzing the epidemiological data. The geographical understanding and exploring of diseases are very useful with recent outbreaks of Human Immunodeficiency Virus (HIV) / AIDS and SARS [Gould, 1993; Banos and Lacasa, 2007]. Geographical studies in health can deal with many factors such as determining the disease distribution, spatial and temporal clustering, spatial and temporal trends, spatio-temporal disease modeling, and analyzing health facility capacity.

1) Disease mapping can represent disease incidences using locations, classify disease information into different levels, or display disease distribution information with charts. Choropleth maps are usually used to depict patterns of disease rates, and spatial continuity is assumed to generate smooth maps [Boulos, 2004].

2) The excess of cases in space (a geographical cluster), in time (a temporal cluster), or in both space and time is called a *cluster* [Boulos, 2004]. Spatial clustering helps in the detection of prevalence regions of the disease. Many spatial clustering algorithms have been implemented so far, such as the Geographical Analysis Machine method [Openshaw et al., 1987] and the spatial scan statistic method [Kulldorff, 1997], while others are for aerial data like the cluster detection based on Geary's c and Moran's I methods. Temporal clustering aids in understanding how the disease emerges in time. Spatio-temporal clustering is a challenge as it integrates the space dimension with the time dimension, and many knowledge discovery and data mining methods have been applied to it [Neill et al., 2005].

3) Analyzing spatio-temporal trends can explain how the peak of a disease moves from one region to another through time. Generally, two methods are used in visualizing the spatio-temporal trend of a disease [Cromley and McLafferty, 2002]. One is to use map sequences, a series of maps showing the disease distribution at different time points. The other way uses animation technology, with visualized maps of a disease as it passes through a certain time interval. Ogao [2006] mentioned three types of animation methods:

passive, interactive, and inference-based animations according to the levels of interactivity and complementary domain knowledge that each of them offers to the user.

4) Spatio-temporal modeling can be used to predict disease outbreaks and the diffusion of a disease. The approaches used in spatio-temporal modeling include stochastic modeling methods, logistic regression methods, Bayesian methods, etc [Kleinn et al., 1999; Yang et al., 2005; Yu and Christakos, 2006]. Moreover, some recent studies use artificial intelligence techniques in disease simulation [Yergens et al., 2006]. Various kinds of factors can be examined in the disease modeling process, such as Normalized Difference Vegetation Index (NDVI), air pollution, temperature, race, and income.

5) Health facility capacity analysis includes applications such as mapping health service locations and needs, identifying new sites for health facilities, and finding the nearest clinic location [Cromley and McLafferty, 2002].

3.3 Usability Metrics

According to the ISO-9241-11 standard, system usability is measured by “the extent to which the intended goals of use are achieved, the resources that have to be expended to achieve the intended goals and the extent to which the user finds the use of the product acceptable” [ISO, 1998]. Hunter et al. [2003] introduced approximately 40 elements about spatial data usability. Considering the geospatial aspects in health mapping, the important goal is to achieve effective and secure health data sharing. Taking this goal into account, the following nine elements were designed in evaluating the usability of the CGDI (including technical standards, national framework data, enabling technologies, and common data policies) in health mapping.

1. **Cost**. Cost means the users' expenses for their applications and plays an important role in the factors of usability. A flexible data sharing network could increase the reuse of data and service, which can reduce the cost of data collection. The relatively low cost of data access is very attractive to users.
2. **Accessibility.** Accessibility means the quality of accessing the standards, data, and services. Accessibility determines how users are likely to use the information. Common interfaces and well maintained metadata would facilitate the discovery and access of the required data and services.
3. **Response time.** In emergencies, timely access to data has received great attention. Processing time and transmission time are the two primary concerns in data dissemination. The increase in computer processing power and the development of optimal algorithms will improve the processing time. The transmission time depends on the network topology, data compression methods, and progressive transmission.
4. **Data quality.** Data are likely to be collected by different authorities or organizations, with different levels of resolution. According to ISO 19113 principles [ISO/TC 211, 2002], the quality elements of spatial data include completeness, logical accuracy, positional accuracy, temporal accuracy, and thematic accuracy. High resolution data are essential in the modeling and statistical analysis of geospatial health applications.
5. **Reliability.** The trust and quality of the data and service access are considered in many applications. Highly availability of the data and services is important in the use

of them.

6. **Exchangeability.** Exchangeability deals with the quality of the capacity to exchange information. Standards are useful in the exchange of information.
7. **Interoperability.** Interoperability is the ability to communicate, execute programs, or transfer data among various functional units, even though the user has little or no knowledge of the unique characteristics of those units [ISO, 1993]. Good interoperability ensures that the contents are understandable.
8. **Cartographic Representation.** The representations of spatially related information in two to three dimensional maps or graphics can give a vivid way to understand the information.
9. **Security.** Security is used to protect the privacy and confidentiality of data and services, and it is a fundamental principle for most applications. While considering the security factor, the efficiency of data access should not be greatly affected.

3.4 Design and Implementation of Health Mapping Applications on the CGDI

3.4.1 Standards in the CGDI

To address spatial data sharing and interoperability, international organizations such as the Open Geospatial Consortium (OGC) and ISO/TC 211 are working on the construction of basic standards and application specifications. The ISO/TC 211 group works more on abstract standards, while OGC concentrates on the implementation specifications [GeoConnections, 2005b]. The main standards that the CGDI adopts are from the ISO/TC 211 and OGC.

The CGDI-endorsed specifications fall into the following categories.

1. **Data representation**. Web Map Service (WMS) provides standard interfaces for producing maps [OGC, 2006a]. Styled Layer Descriptor (SLD) enables named or user-defined styles in symbolizing geospatial features [OGC, 2005a].
2. **Data access**. Web Feature Service (WFS) supports feature level geospatial data operation [OGC, 2005b]. Web Coverage Service (WCS) provides access to coverage data such as remote sensing images and digital elevation data [OGC, 2006b].
3. **Data manipulation**. Web Processing Service (WPS) supports spatially related data processing through the Web [OGC, 2007].
4. **Data discovery**. Geodata discovery service and catalog service are used for retrieving geospatial data and services. The Federal Geographic Data Committee (FGDC) Content Standard for Digital Geospatial Metadata (CSDGM) [FGDC, 1998] and ISO 19115 [ISO/TC 211, 2003] are used as metadata standards.

3.4.2 Architecture Design

Since disease outbreaks are usually spatially distributed, using the geographical information framework for the development of Web-based health systems could improve health data sharing, outbreak detection, and disease control. Based on the above mentioned metrics, the purpose of this research is to design an application to evaluate the usability of the CGDI in health mapping. The architecture design uses CGDI-endorsed standards for health data sharing and supporting health decision making. This architecture provides the basic functions for geospatial health applications including thematic mapping, spatio-temporal processing, spatio-temporal trend representation, and health facility distribution.

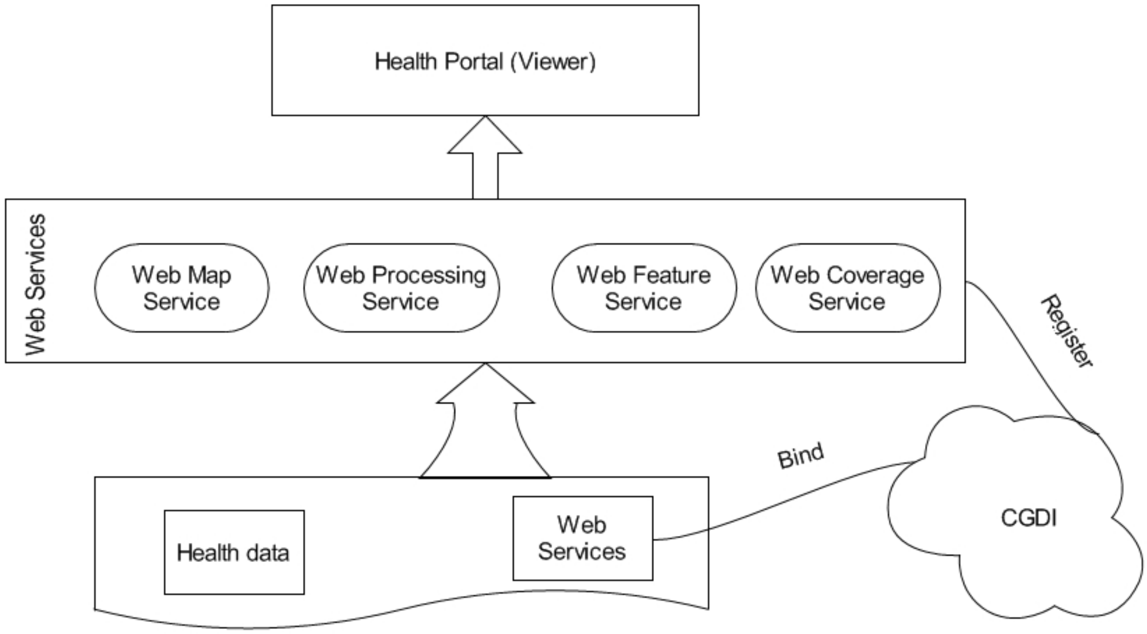


Figure 3.1: Architecture design

Figure 3.1 shows the architecture designed by the senior authors. Spatially related data can be accessed from the Web Services provided in the CGDI. In health applications, new Web Services such as WMS, WFS, WPS, and WCS can be created. These services can be registered to the CGDI. The health portal is used for service integration and map visualization.

3.4.3 Implementation of a Health Application

3.4.3.1 Study Sites and Data Description

Experience with infectious disease outbreaks, especially the recent SARS outbreak, has demonstrated the increasing concern with infectious diseases, which needs an international strategy [Fidler, 2003]. The Province of New Brunswick (Canada) and the State of Maine (USA) are the study sites, which share a common, highly traveled international border. Since people are more likely to visualize information based on jurisdiction regions, the administrative areas were used as the infectious disease mapping boundaries. Different health organizations or users require different levels of details of health data. Meanwhile, considering the privacy of health data, certain different health organizations or users can only access and track certain levels of health data. Thus, six level administrative/census areas that cover the entire territory of both sides of the border were chosen. The six levels of New Brunswick are Province, Health Region, Census Division, Census Subdivision, Forward Sortation Area, and Dissemination Area. In Maine, the corresponding levels are State, Health Service Area, County, County Subdivision, Zip Code, and Census Block Group. The province or state is the top level. The health region / health service area level is the location of the patient's hospital in the classification system. The census division / county level is the joint group of neighboring municipalities merged together for the purpose of regional planning and managing common services (such as police or ambulance service). The census subdivision/county subdivision level is the municipalities or areas treated as municipal equivalents for statistical purposes. The Forward Sortation Area /Zip Code is assigned to one or more postal zones. The dissemination area / census block group level is the relatively stable geographical unit composed of one or more blocks (the smallest geographical areas for which population and dwelling counts are disseminated).

The data used in both sides include spatial data, census data and patient data of New Brunswick and Maine. These data were acquired from different health departments and Web Services from the CGDI and the American National Spatial Data Infrastructure (NSDI). In addition, simulated influenza outbreak data for 120 days (including the influenza cases, other data such as grocery retail, grocery supply, fuel retail, fuel supply, school, pharmacy, and hospital bed occupation) based on influenza statistics from 1968 (approximately 35% infection rate) were generated for the spatio-temporal analysis. For health mapping, the essential task is the geo-coding process, which locates patient data from the recorded streets or postcodes. After the geo-coding, it is possible to roll-up the patient data or other data sets through the bottom-up choice using spatial operations to analyze spatial adjacency relationships such as point in polygon, polygon in polygon, etc. This also helps to protect confidential data sets by aggregating patient data to a health region or polygon.

3.4.3.2 Mapping Variables for Health Data Processing

The first step towards the understanding and explanation of any geographical phenomenon is thematic mapping [Benenson and Omer, 2003]. For decision making on disease outbreaks, there are many factors that would influence the mapping results, such as identifying population density, health inequalities, racial tendency, environmental pollution, social recognition, economic development, and cultural differences. In this research, the senior authors mainly concentrated on demographic factors and their influence on the disease outbreak. Other factors were not currently integrated, as low frequency values would negatively impact classification methods.

The following established statistical methods were employed in the analysis:

a) Crude Morbidity Rate (CMR): the total number of incidents relative to the total population in their population group (Equation 3.1). I is the sum of patients for each geo-cell, P_{risk} is the population-at-risk total for each geo-cell, and ρ_{const} is the Population Constant (e.g., 1, 1000).

$$CMR = \frac{I \times \rho_{const}}{P_{risk}} \tag{3.1}$$

b) Normalized Morbidity Ratio (NMR): the Z-Score of the Crude Morbidity Rate (Equation 3.2), with the value of the CMR geo-cell value minus the arithmetic mean of X (the total CMR geo-cell distribution), divided by the standard deviation (of the total geo-cell distribution).

$$NMR = \left(\frac{(\chi - \mu)}{\sigma} \right) \tag{3.2}$$

c) Age-Specific Morbidity Ratio (ASMR): the number of incidents (C_i) in age interval i, divided by the midyear population (P_i) in age interval i (Equation 3.3).

$$ASMR = \frac{C_i}{P_i} \tag{3.3}$$

d) Age-Adjusted Morbidity Ratio (AAMR): weighted average of the Age-Specific Morbidity Ratio (Equation 3.4) where the Age-Specific Weights (Equation 3.5) represent the relative age distribution of the standard population.

$$AAMR = \sum_i W_{si} \cdot ASMR \tag{3.4}$$

$$W_{si} = \frac{P_{si}}{\sum_i P_{si}} \tag{3.5}$$

e) Indirect Standardized Morbidity Ratio (ISMR): the crude ratio of the standard population (R_s) multiplied by the total number of influenza cases (C) in the observed population, divided by the age-specific morbidity ratio in age interval i in the standard population times the population (P_i) of age interval i in the observed population (Equation 3.6).

$$ISMR = \frac{R_s \cdot C}{\sum_i ASMR \cdot P_i} \tag{3.6}$$

f) Standardized Morbidity Ratio (SMR): the ratio of observed infectious cases to expected cases (Equation 3.7).

$$SMR = \frac{C}{\sum_i ASMR \cdot P_i} \tag{3.7}$$

g) Six kinds of univariate methods: the Summation, Mean, Standard Deviation, Variance, Skewness, and Kurtosis of the infectious disease cases.

The purpose of these statistical methods, which were suggested by the project partner, the New Brunswick Lung Association, is to provide a processing capacity for data representation that is consistent across jurisdictional and temporal layers. The above twelve statistical values are calculated. These values may be expressed by multi-dimensional vectors: temporal dimensions (e.g., 5-years, annual, seasonal, monthly, weekly, daily), data use dimensions (e.g., America or Canada separate data for standardization or both), gender divisions (e.g., male, female, both), age group (e.g., 0-

4, … 65+, total), geographical divisions (e.g., Dissemination Areas / Census Block Group, Census Divisions / County, State/Province, etc.), and disease types (e.g., influenza). The calculated values can be used to create thematic maps. A thematic map from selecting one value of each dimension, such as the parameters (Census Division / County level, Year 2002 week 1, age group 65+, Indirect Standardized Morbidity Ratio, male, influenza, and both data used – Maine and New Brunswick), can be generated. The calculated values can also be used to generate pie charts or bar charts, for instance, the three age group distribution of the parameters (Census Division / County level, Year 2002 week 1, Indirect Standardized Morbidity Ratio, male, influenza, and both data used).

3.4.3.3 Health Mapping Results

With the health facility data published by WMS, WFS, or WCS, and the statistical processing functions provided by WPS, health data could be accessed via the Internet. Moreover, the services can be integrated to support health surveillance. Figure 3.2 shows a map viewer integrating two WMS (hospital distribution) and a WPS (SMR rate at the health region level in 1999). Also, the time tag in the service could be used to achieve animated maps. Figure 3.3 shows the time tags included in WMS maps of simulated data on day 20 of the disease risk level and the hospital bed information. Figure 3.4 shows the WMS maps of the same data on Day 80.

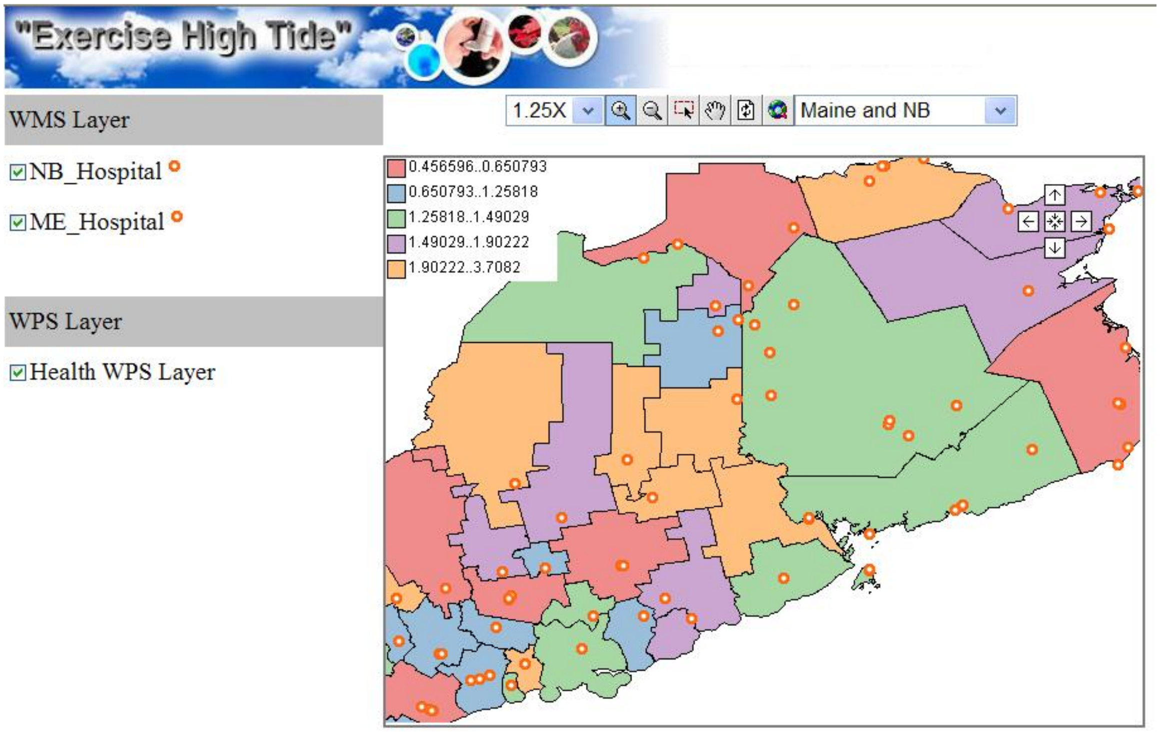


Figure 3.2: WPS and WMS integration

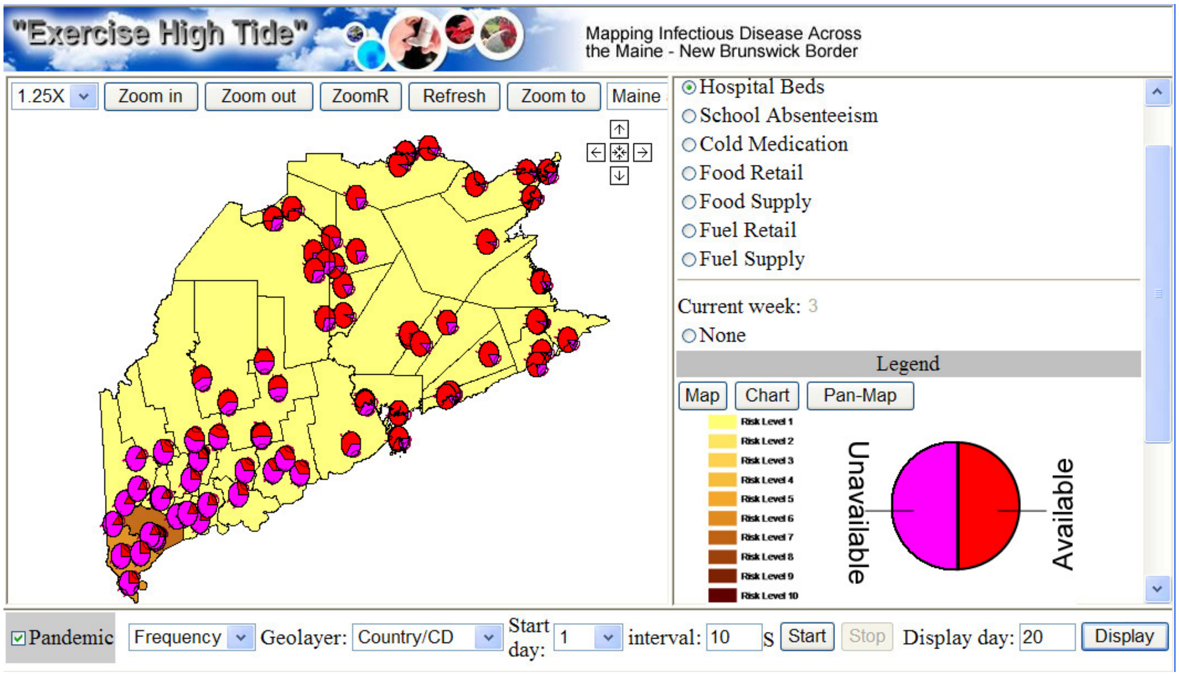
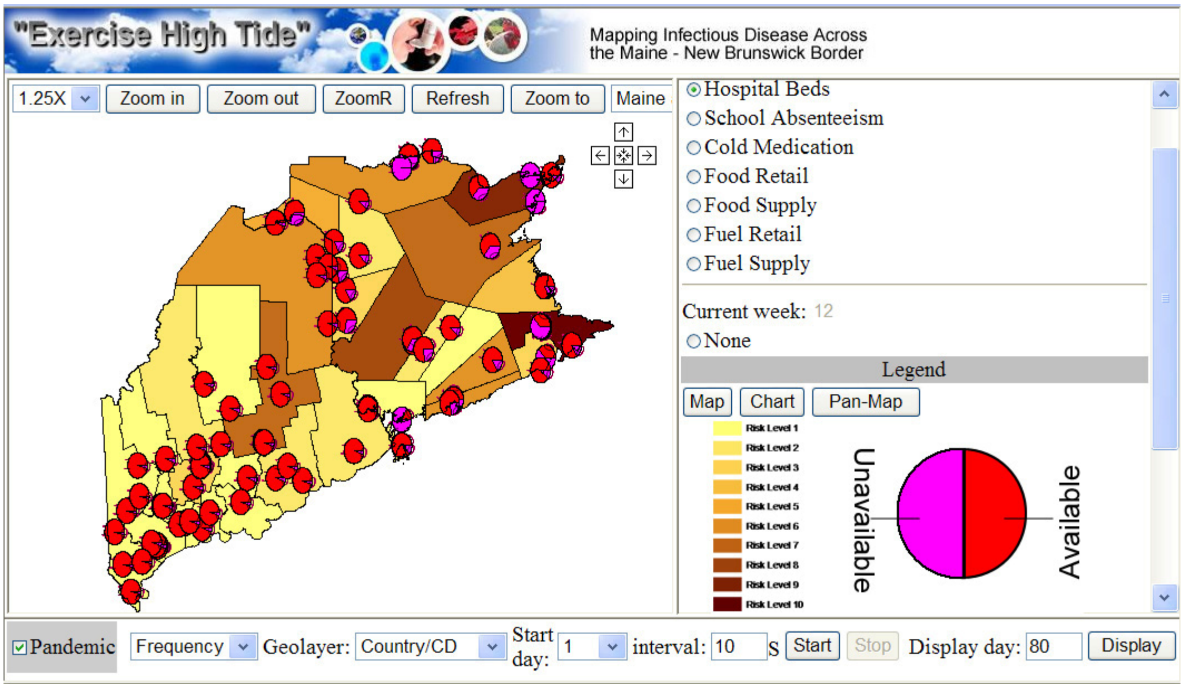


Figure 3.3: WMS with time tag for simulation on day 20



1.25X

● Hospital Beds
○ School Absenteeism
○ Cold Medication
○ Food Retail
○ Food Supply
○ Fuel Retail
○ Fuel Supply

Current week: 12
○ None

☑ Pandemic
Frequency
Geolayer: Country/CD
Start day: 1
interval: 10 S
Display day: 80

Figure 3.4: WMS with time tag for simulation on day 80

3.5 Discussion

Hosted by the Emergency Measures of the Province of New Brunswick, an exercise of “High Tide” enlisted many participants to test the decision making environment within the framework of the CGDI. With the experience from the developers in this health mapping application and the feedback from the users participating in the “High Tide” exercise, the senior authors developed a matrix that links usability metrics to the four key components of the CGDI in health mapping, as shown in Table 3.1.

Table 3.1: Matrix linking usability metrics to the CGDI components

CGDI Metrics	Technical standards	National framework data	Enabling technologies	Common data policies
Cost (to users)	Low	Low	Low	Medium
Accessibility	High	High	High	High
Response time	N/A	N/A	Medium	N/A
Data quality	N/A	Medium	N/A	N/A
Reliability	High	Low	High	Medium
Exchangeability	High	High	High	High
Interoperability	Medium	Medium	Medium	N/A
Cartographic representation	Medium	Medium	Medium	N/A
Security	Low	High	High	Medium

In terms of technical standards, the CGDI adopted many international standards in describing, publishing, visualizing, accessing, and manipulating geospatial resources. The standards are highly accessible through the Internet. Meanwhile, the standards are developed version by version with good reliability. In health mapping, sharing the data through the standard interfaces is convenient for data access. CGDI-endorsed standards have been successfully applied to health data mapping as described in this study. As a result, it is possible to keep low the development cost of standards-based health mapping applications within the CGDI framework. With these standards, access to health data could be achieved through standard interfaces which make the information exchange very easy between different organizations. However, these standards mainly solve the problems of syntactical heterogeneity, i.e., different data structures and formats in various systems. To achieve semantic interoperability in health fields still requires the development of geospatial health ontologies. As to cartographic representation, CGDI-endorsed standards support various representation formats, such as JPG, GIF, PNG, GeoTiff, so the cartographic representation of health data can be done without difficulty.

However, thematic mapping support is relatively weak in CGDI-endorsed standards. The SLD standard only supports classification maps, and gives no standard way in generating chart styles. Meanwhile, it is better to develop some thematic mapping standard for health mapping, such as defining some standard symbologies or color ramps in describing specific kinds of health information. Moreover, the development of multi-media standards including sound can support better understanding of social phenomena. In regard to security, currently there are few related standards under the CGDI.

The national data framework is the core of the CGDI. One principle of the CGDI is to "collect data once, share many times" [GeoConnections, 2006a]. It is estimated that up to 80 percent of the cost of geospatial applications is spent on the spatial data collection process. The spatial data collection cost used in health data mapping can be shared with many other departments who use these data, such as forestry departments, agricultural departments, emergency departments, etc. With the shared cost and less redundant work, the data collection cost is relatively low.

Through the GeoConnections Discovery Portal[1], geospatial data and services can be discovered using keywords, location, and/or theme. The CGDI encourages organizations that are closest to the source to provide the data. This encouragement could provide users with the data in good quality and precision, and eliminate duplication and overlap problems. Accurate spatial data is important for analyzing health information. Geo-

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[1] http://geodiscover.cgdi.ca/gdp/

coding is often used to map health records to their geographical locations. Spatial data are kept updating in the CGDI, and the feasibility to obtain data accurately and timely from it can be beneficial to health decision making. Sometimes, different versions of spatial data exist in the CGDI, and the update frequency is also a problem. Both difficulties lead to the reliability problem of data quality. As different laws govern access and use of public health information, the CGDI is not so comprehensive in providing health data. There are also some reliability problems with the CGDI. Although there are lots of geospatial data and services existing in the CGDI, the availability and performance of the data access are unknown.

In the health field, the current standards and rules for dealing with spatially visualizing confidential information are seriously limited [Leitner and Curtis, 2006]. This study used the statistical and geographical mask with data aggregations to certain levels for visualization to maintain the privacy of health information. When compared with original data, the aggregated results expressed to different levels of spatial resolution might show some differences. With the CGDI-endorsed standards (WMS, SLD, WFS, WPS, and WCS), health data could also be easily shared with different planning or health departments. Health data in the CGDI are exchangeable as shown in the cross border application, since the WMS service is compatible with the American NSDI as shown in the case study. The cartographic representation of the data, which conforms to the technical standards, is satisfactory for visualization. The SLD standard can solve the possible style problems with data access from different services. In the CGDI, data are stored in a distributed environment rather than a central database, so the security is greatly enhanced to overcome a central database crash.

Presently, the enabling technologies in the CGDI use the distributed service oriented architecture. The Web Service technology is mature and is easy to implement. These technologies are highly accessible and reliable in Web environments. Most geospatial health information systems have used thin client or thick client architectures, and it is usually difficult to reuse and integrate them. With the adoption of the service oriented architecture, reusability and integration can be greatly improved. However, the response time of Web Services is not so satisfactory due to their platform neutral implementation. The semantic based service and data integration is not mature yet; thus, the semantic interoperability still needs development. The use of Web-based technology is acceptable for representation and visualization, but it is not quite suitable for cartography, e.g., printing high quality maps. Cartographic consideration is often overlooked in many Web-based mapping applications. Since the enabling technologies protect security through Web secure services, good security could be achieved.

The common policies harmonize the access and use of geospatial information in the CGDI, and they have good accessibility for people to participate and use the CGDI. The policy making process in the CGDI considers the extensibility of the policies and the exchangeability of the policies among other countries as well. Different jurisdictions have different laws governing access and use of public health information, so specific policies need to be developed for cooperative mechanisms in preventing, tracking, and responding to the disease outbreak. Some policies still need to deal with reliability problems, such as whether the services are running or not and whether the data are updated or not. As to security issues, the policies do not mention at which level or type, geospatial data should be kept secure. The policies for public health data representation are highly valuable because of the confidentiality issues.

3.6 Conclusions

Recent disease outbreaks have demonstrated the need for geographical applications in public health. Public health is one of four priority applications at GeoConnections in the development of the CGDI [GeoConnections, 2006b]. In this research, health data sharing applications were implemented based on the CGDI framework to evaluate the usability of the CGDI in health mapping. This research will foster the use of the CGDI in health studies and the implementation of new Web Services for public health within the CGDI for online data sharing and access. The information provided by the CGDI will be more comprehensive with the enrichment of health data. Currently, few studies concentrate on the usability of Spatial Data Infrastructure (SDI), and this study might bring a novel approach by using the feedback of developers and users in the evaluation process. The CGDI usability metrics were measured mainly based on the applications. In the future usability evaluation of SDI, more comprehensive and in-depth metrics and methodologies should be considered for better evaluation.

The health mapping application based on the CGDI can lower the cost of data sharing, use the standard for data access, and provide real-time map visualization to users. This study shows the high usability of the CGDI in supporting disease management and decision making to local, provincial/state, and national officials, and the public. The quality of the cartographic representation in this application is limited by the capabilities of Web-based GIS, and it still has to be improved to enhance the understanding of disease phenomena by health practitioners and the general public. The future work will be devoted to advancing the usability of the CGDI in health applications for data sharing.

Acknowledgments

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Chapter 4. Towards Web-based Representation and Processing of Health Information[♣]

Abstract

There is great concern within health surveillance on how to grapple with environmental degradation, rapid urbanization, population mobility and growth. The Internet has emerged as an efficient way to share health information, enabling users to access and understand data at their fingertips. Increasingly complex problems in the health field require increasingly sophisticated computer software, distributed computing power, and standardized data sharing. To address this need, Web-based mapping is now emerging as an important tool to enable health practitioners, policy makers, and the public to understand spatial health risks, population health trends and vulnerabilities. Today several Web-based health applications generate dynamic maps; however, for people to fully interpret the maps they need data source description and the method used in the data analysis or statistical modeling. For the representation of health information through Web-mapping applications, there is still no standard format to accommodate all fixed (such as location) and variable (such as age, gender, health outcome, etc) indicators in the representation of health information. Furthermore, net-centric computing has not been adequately applied to support flexible health data processing and mapping online.

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The authors of this study designed a HEalth Representation XML (HERXML) schema that consists of the semantic (e.g., health activity description, the data sources description, the statistical methodology used for analysis), geometric, and cartographic representations of health data. A case study has been carried on the development of Web application and services within the Canadian Geospatial Data Infrastructure (CGDI) framework for community health programs of the New Brunswick Lung Association. This study facilitated the online processing, mapping, and sharing of health information, with the use of HERXML and Open Geospatial Consortium (OGC) services. It brought a new solution in better health data representation and initial exploration of the Web-based processing of health information.

The designed HERXML has been proven to be an appropriate solution in supporting the Web representation of health information. It can be used by health practitioners, policy makers, and the public in disease etiology, health planning, health resource management, health promotion, and health education. The utilization of Web-based processing services in this study provides a flexible way for users to select and use certain processing functions for health data processing and mapping via the Web. This research provides easy access to geospatial and health data in understanding the trends of diseases, and promotes the growth and enrichment of the CGDI in the public health sector.

4.1 Background

Population growth, rapid urbanization, environmental degradation, and the misuse of antimicrobials have disrupted the equilibrium of the microbial world, causing the rise of new emerging diseases [WHO, 2007]. Health information is very useful in helping people to understand health phenomena, mitigate disease outbreaks, and analyze disease etiology. However, most public health departments typically collect data as needed and maintain it locally, and this unavoidably limits the access to important public health data for health researchers and the public [Wu et al., 2005]. The World Health Organization [2007] pointed out that keeping disease outbreaks secret is no longer feasible and sharing essential health information is one of the most feasible routes to global public health security. Sharing health information through the Web provides flexible and real-time data access, and assists people to discover and use this information. Currently, many health departments have begun to provide public access to their health statistics via the Internet, and this promotes interest in user involvement and data-set exploration [Bell et al., 2006]. Some health information like morbidity and mortality indicators has become obtainable to health professionals and the public by means of the Internet [Toubiana et al., 2005]. With the new updated health cases collected from hospitals or surveys, the Web can distribute this information to users in real-time. Distributing and sharing health information via the Web can assist authorities and decision makers across health jurisdictions to collaborate in preventing, controlling, and responding to a specific disease outbreak at both the local and national levels. Current Web 2.0 technologies can further facilitate data sharing and collaboration between users, and the Web 2.0 mashups allow the combination of multiple third-party services over the Web [Boulos et al., 2008;

Cheung et al., 2008]. An example of a mashup is the combination of bird flu case data with Google maps to visualize the distribution of disease for health surveillance.

Health information is collected through two kinds of georeferences. One kind is the point data which record the coordinates of disease case location. The other kind is regional data which are collected as a summary for a geographical area. To represent health information, especially over the Web, privacy and confidentiality concerns are given considerable thought. Laws governing use and distribution of public health information should be respected in each jurisdiction, and yet the need for information to support critical decision making on public health threats like Tuberculosis, Avian Flu, and Influenza must be met. To keep the privacy of health information while maintaining highly informative data, health data should be represented at the aggregate level, with high privileges to see more detailed data.

Maps are powerful tools to classify, visualize, communicate, and navigate space and/or spatial relations in the data which would be hard to explore otherwise [Boulos, 2003]. With maps, it is easy to discover adjacent neighborhood similarities as well as spatial patterns that are hidden in health data. Two kinds of Web-based maps exist: view-only maps and interactive maps [Kraak and Brown, 2000]. The view-only maps are the cartographic representation of data in images such as GIF, PNG or JPEG format. Interactive maps can respond to some mouse actions on the map, with the technologies such as Scale Vector Graphics (SVG,) Extensible 3D (X3D) Graphics, and Virtual Reality Markup Language (VRML). Kamadjeu and Tolentino [2006] discussed the advantages of use the SVG in Web cartographic representation, such as smaller and more compressible files, pure XML, human readability, scalability, and support from major industries.

From the previous study for health mapping, the senior authors found that the quality of health data representation in Web-based GIS applications was still limited [Gao et al., 2008a]. Even though many Web-based health applications can dynamically generate view-only maps or interactive maps, certain information is missing for people to fully interpret the map such as the data source description and the method used in the data aggregation process. Consideration of the source and quality of the health data can help health practitioners, the general public, and policy makers to evaluate the trustworthiness of spatial analysis results [Bell et al., 2006]. In addition, scientific users want to know details about the methodology when evaluating representations. For the representation of health information to users, the following issues should be considered:

1) *The metadata of the health information*. The description of health data is important in understanding data sources and quality.
2) *The statistical methodologies used*. The description of the statistical methods for representing health data can be used to determine the quality of the results.
3) *The comprehensiveness of the representation*. The representation which can combine many kinds of representations (text, maps, graphics, etc.) will assist people in exploring the health phenomena with less misinterpretation.

4) *The consistency of the cartographic representation*. Health information should be mapped in the same pattern regardless of platform or system.

5) *The semantic meaning*. Shared vocabularies or styles can eliminate different interpretations.

Thus, a health data representation format needs to be developed to fulfill these five requirements and enhance the sharing of health information via the Web. In the health decision-making process, usually health data from heterogeneous sources need to be integrated. With a suitable health information representation model that catches all the aspects of health data, health information can be more easily understood by people and integrated from different sources.

Meanwhile, Web-based processing could take advantage of net-centric and collaborative computing and let users select the processing tools flexibly [Tao, 2001]. In the case that local health departments are not familiar with statistical methodologies in health data processing, it may inevitably take a steep learning curve to apply the processing methodologies [Elliott and Wartenberg, 2004]. In addition, it is hard to build a system that includes every complex function. Web-based processing allows users to select the cost-effective processing and mapping tools to accomplish a task, without the need to purchase advanced hardware or software. However, to date Web-based processing has not been adequately utilized for flexible processing of health data.

4.2 Methods

4.2.1 XML and OGC Web Services

The sharing of health information is critical for preventing diseases, responding to emergencies, and educating the public and policy makers. However, many health professionals and authorities do not have tools to map health information in some cases they cannot visualize health information to make time-sensitive decisions, since they do not have the time, money, or skills to statistically analyze vast amounts of distributed data and render aggregated results into a geographical interface for interpretation. XML, Web Services, and related standards have matured, yet confidence in such technology to visualize or share health information is only beginning to emerge.

XML, as a platform independent language, can support information interchange and representation through the Web. XML has many advantages, such as platform and application independence, extensibility, user-driven development, and an open standard for data interchange via the Internet [Yu et al., 2008]. Health Level 7 (HL7) standards promote health care information exchange through XML [HL7, 2010]. HL7 Clinical Document Architecture (CDA) is an XML standard used to exchange clinical documents. For example, an XML document can record the information of a patient's allergy to certain medicines. However, the primary domain of HL7 standards is clinical and administrative data, and explicit spatial information and health data mapping are not considered. Therefore, a standard format for sharing the representation of health information in time and space is needed.

To overcome the disadvantages of tightly coupled systems and improve their reusability, the concept of Service Oriented Architecture (SOA) has gained popularity recently. SOA provides a flexible way to share data as well as processing functions over the Internet to reduce costs of building complex systems. SOA has many benefits, such as better return on investment, better maintainability, higher availability, flexible service assembly, more security, and support for multiple client types [Stevens, 2010].

The Open Geospatial Consortium (OGC) initiated the Open Web Service (OWS) program based on service oriented architectures and Web Services (a common implementation of service oriented architectures), and has proposed several geospatial specifications to support geospatial data sharing and interoperability, such as Web Map Service (WMS), Web Feature Service (WFS), and Web Processing Service (WPS). WMS publishes its ability to produce maps rather than its ability to access specific data holdings, and generates spatially referenced maps dynamically [OGC, 2001]. WFS defines the interfaces for the access and manipulation of geographical features and elements through Geography Markup Language (GML) [OGC, 2005]. WPS provides standardized interfaces to facilitate publishing, discovering, and binding geospatial services that enable spatial processing functions across a network [OGC, 2007]. It regulates the connection rules of input request and output response that govern the geospatial processing event. The interfaces (GetCapabilities, DescribeProcess, and Execute) define how the client and server can cooperate in the execution of a process and generate the processing results. The data used in the WPS can be stored at the server side or acquired from a network.

Accessing health information through standard interfaces is important to achieve data accessing and interoperability. Using the standard geospatial service interfaces, the wide access of health information can improve the ability to intervene in health issues, inform the public of the availability of resources, strengthen the cooperation between different health organizations, and therefore reduce costs to the health care system.

4.2.2 HEalth Representation XML (HERXML)

The HEalth Representation XML (HERXML) schema is designed for the sharing of health data cartographic representation, data source description, and statistical methodologies used via the Web. There are different kinds of health activities, such as hospital observation, laboratory tests and results, health care and medication services, and training and education for patients. Since these activities are related to spatial location, the proper way to support mapping of these activities is a foremost concern in geographical health applications. In the mapping of health-related activities, statistical methods can be used to connect health-related activities with maps. The methods to generate maps from health-related activities need to be considered. The following statistical methods are applied in this research: Crude Morbidity Rate (CMR), Normalized Morbidity Ratio (NMR), Age-Specific Morbidity Ratio (ASMR), Age-Adjusted Morbidity Ratio (AAMR), and Standardized Morbidity Ratio (SMR), Summation, Mean, Standard Deviation, Variance, Skewness and Kurtosis. These statistical methods consider spatial, temporal, and demographic factors and their influence on health-related activities, which can show the health information distribution with spatial, temporal, age, and gender differences. Other statistical methods can be introduced to analyze other influential factors.

The intention is to make the HERXML schema able to support the Web-based representation of health information for users to interpret the statistical results. Three dimensions of representation are related with spatial data: semantic, geometric, and graphical [Bedard and Bernier, 2002]. Therefore, these three kinds of representations were included in the HERXML schema. Semantic representation describes the health-related activities, data sources, and the statistical methods used. Geometric dimension shows what type of geometry (point, line, or polygon) is used to represent these health data. Graphic representation defines what styles or symbols are used to generate health maps.

The design of the HERXML follows an iterative process, as shown in Figure 4.1. It starts with user requirement collection and analysis, such as the content of health information, related influential factors, and ways of representation. With the consideration of policy, privacy, and security issues, the main concepts used in the representation of health information are determined. Next, an XML design software tool, Altova XMLSpy [Altova, 2010] is used to encode the HERXML schema. After that, the HERXML schema is tested in application to validate user requirements. The iteration continues with a new version of HERXML schema until the end-users are satisfied. With the above cyclic development process, the preliminary HERXML schema used in this project was defined (refer to Appendix A).

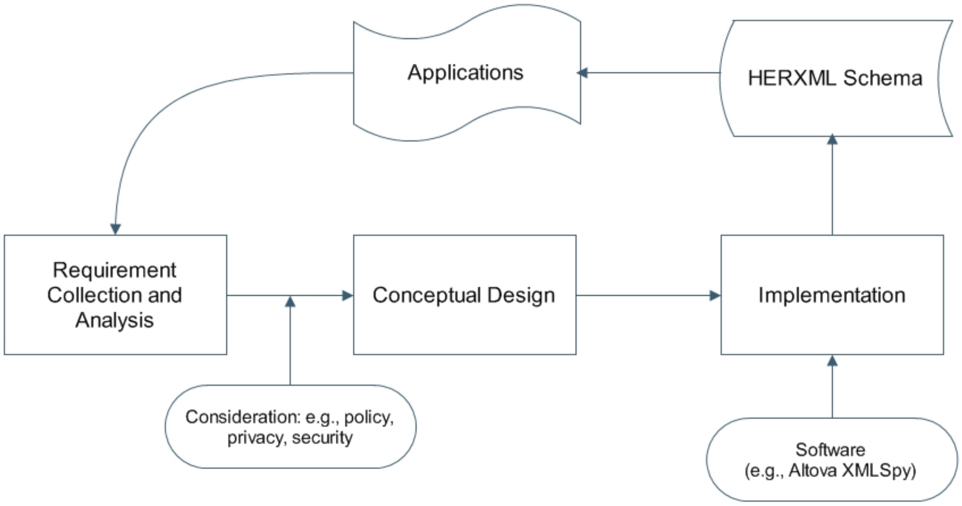


Figure 4.1: HERXML schema design process

(The HERXML schema design process follows a cyclic development. The steps include user requirement collection and analysis, conceptual design, schema implementation, and schema validation in applications.)

As shown in Figure 4.2, the designed HERXML schema includes three parts: health, mapping data, and representation.

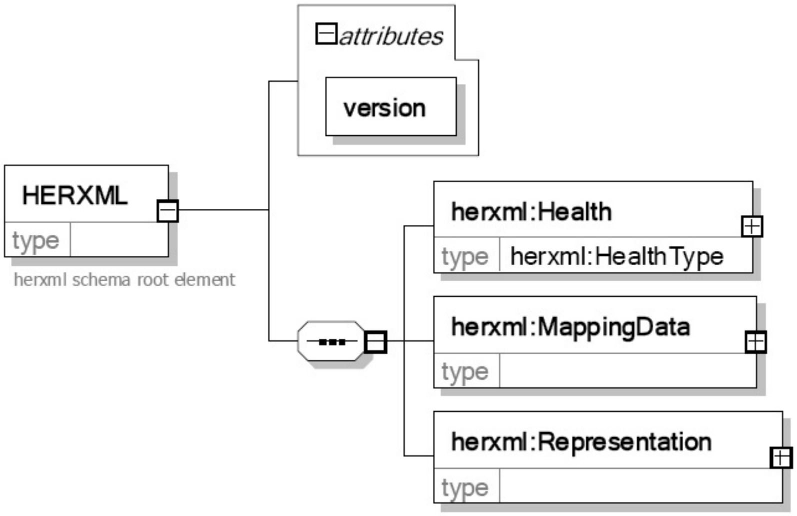


Figure 4.2: The HERXML schema

(The HERXML includes a “Health” part, a “MappingData” part, and a “Representation” part.)

The health part includes the basic information of the health-related activities, with the name, title, description, and keyword list elements, and a type attribute. HealthType is an abstract complex type. It can be extended to support disease observation or other activities.

The mapping data part mainly records the data used for mapping. As shown in Figure 4.3, it includes the bounding box of the data, the spatial data, the relation between spatial data and mapping values, and the mapping values.

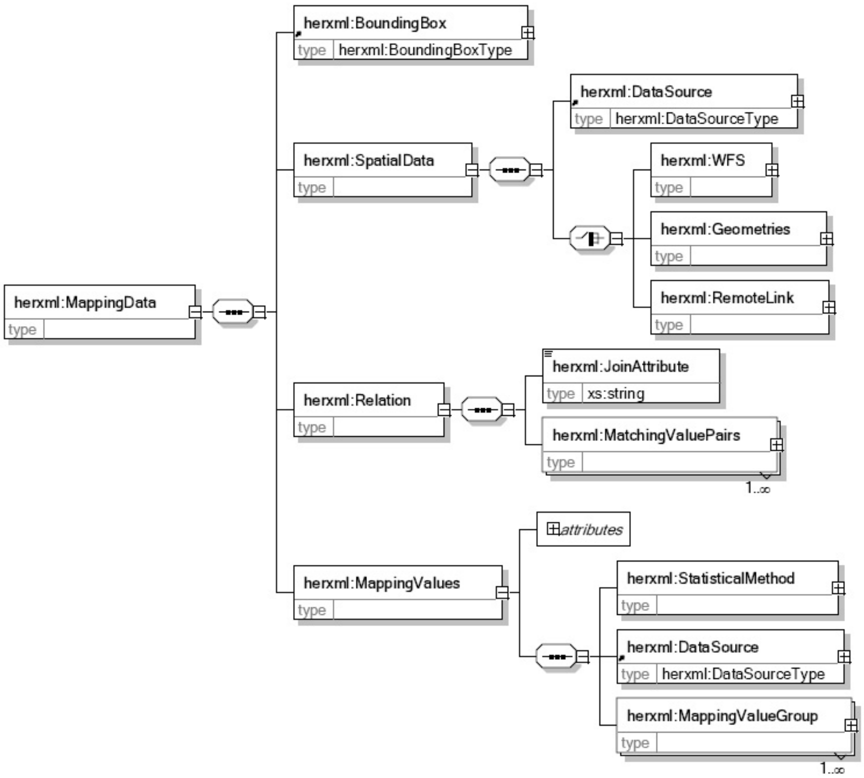


Figure 4.3: The mapping data part schema

(The “mapping data” part schema includes a “BoundingBox” component, a “SpatialData” component, a “Relation” component and a “MappingValues” component.)

- ✧ "BoundingBox" represents the spatial range of the mapping data.
- ✧ "SpatialData" could be GML from WFS services, GML records, or Xlink to GML databases. The data source item is used to show the metadata of the spatial data. The health data are statistical values and are linked with the spatial data through the joining attribute.
- ✧ "Relation" records the linking attributes and the matching ID values of both spatial data and mapping values.
- ✧ "Mapping values" includes the health data source description, the statistical method used and the mapping value lists. The statistical method part describes the name, title, description, and statistical parameters of the statistical method used. The data source description shows metadata of health information, such as the source of the data, the time range of data, and the contact information. Statistical methods are used to generate classification maps and charts for health-related activities. Some parameters are predefined from the spatial, temporal, and demographic aspects for public health, such as AgeFrom, AgeTo, and StartTime, which can show health distributions with spatial, temporal, age, and gender differences. Users can add additional parameters in the parameter group to support advanced statistical methods.

The Representation part defines the style used to represent health maps. It describes the default representation bounding box and style description. Depending on the kind of representation, the StyleType is extended to ChartStyleType, PointStyleType, LineStyleType, and PolygonStyleType. For instance, the PolygonStyleType includes the border and fill elements. The type of filling in a polygon can be gradient fill or range-based fill. For the range-based fill, the fill method can use color, pattern, and texture. The border element contains the color, line style, and line weight of the border.

4.2.3 WPS for Health Data Processing with HERXML

The procedure of WPS design is shown in Figure 4.4. The input includes health data and parameters. The health data for the Web-based processing could be stored in the server (in databases or files) or acquired through remote access (through Web Services or remote transfers). The parameters can be encoded by Key/Value pairs or XML, including the disease type, gender, age group, statistical method, time interval, spatial layer, and thematic mapping variables. The output of the processing could be either in the raster data format (JPEG, PNG, GIF) or in the vector data format (HERXML). The use of HERXML in processing can enhance people's understanding of the resulting health information mapped. In the configuration of the WPS, the access of WPS can be limited to certain domains or IP addresses. The WPS can be further divide into fine granularity, with one processing service for the statistical calculation and the other processing service for the thematic mapping.

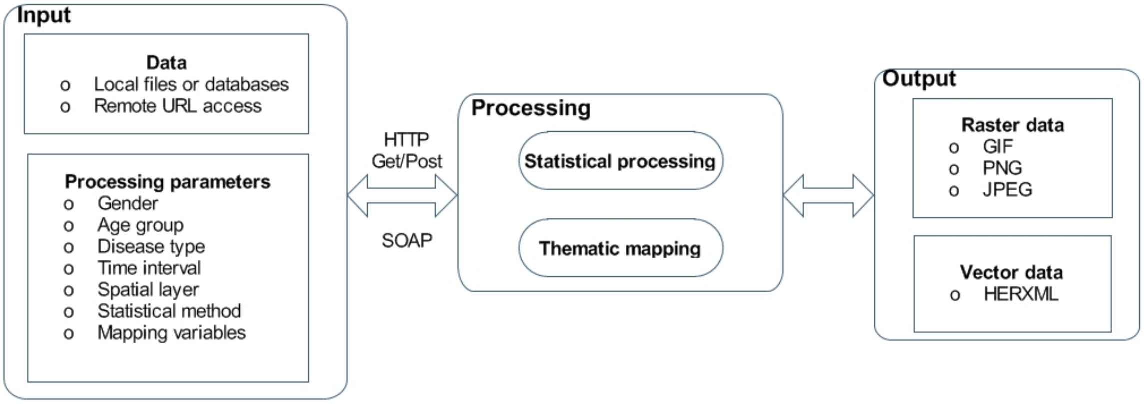


Figure 4.4: A WPS for health data processing

(The flow shows the input data, output data, and processing components of the designed WPS.)

4.2.4 Architecture for Health Data Processing and Sharing

To implement a Web-based application for statistical exploration of health information, service oriented architecture is an effective solution [Gao et al., 2008b]. In this research, the standard OGC services were implemented, including WMS, WFS, and WPS. The proposed architecture (see Figure 4.5) includes three tiers: a data tier, a service tier, and a Web portal tier.

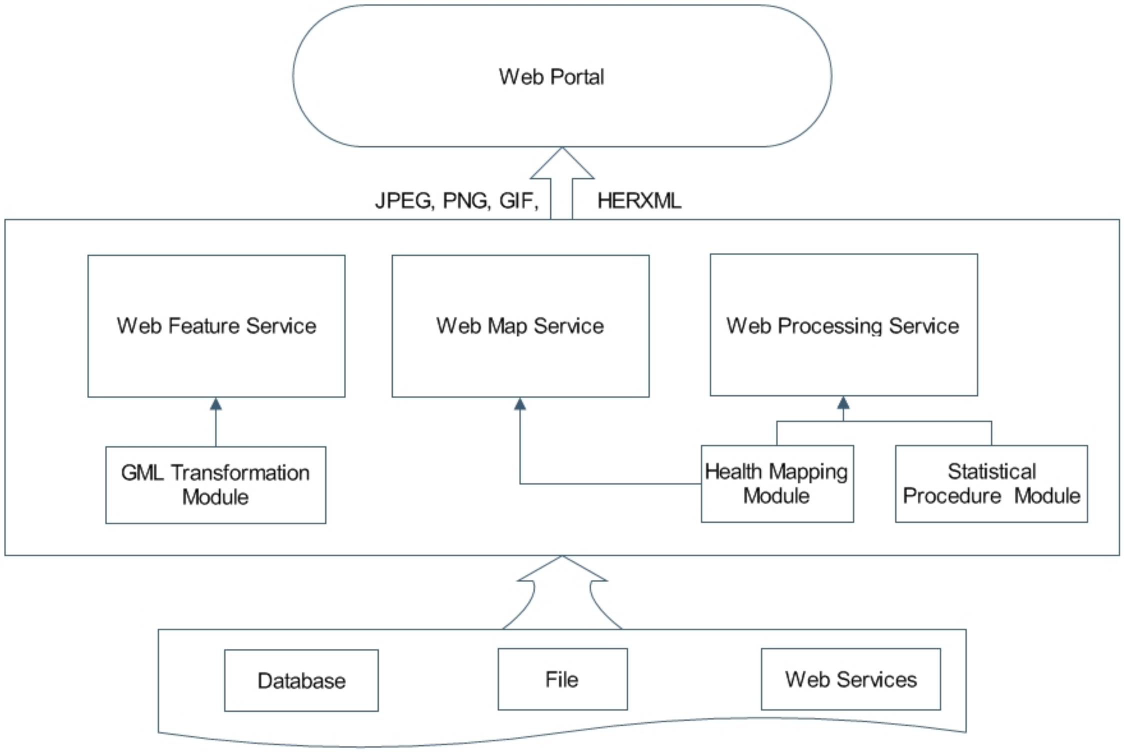


Figure 4.5: Implemented health data processing and sharing architecture

(The architecture contains a data tier, a service tier, and a Web portal tier.)

The data tier stores all the health data and related data for health studies. These data could be available from databases or Web Services.

The service tier implements WMS, WFS, and WPS for health studies.

✧ WMS provides standard interfaces to generate maps and charts for visualization of health information. It utilizes the health mapping module to generate maps to show event or facility distribution. The input data could be obtained from HERXML, GML, WFS, WPS, databases, or files.

- ✧ WFS uses the GML transformation module to share spatial data through GML. It can be linked with the mapping values (part of HERXML) to create thematic health maps.

- ✧ WPS is used to analyze spatio-temporal health data. The health data analysis supports data rolling up from a low spatial level to a high spatial level. WPS uses the health mapping module and statistical procedures. The input data of WPS could be obtained through WFS, GML, databases, or files.

The Web portal tier is a client for the visualization of disease data and maps. It can bring together different facets of health information into one location to improve health promotion, health care research, education, and policy making.

4.3 Results

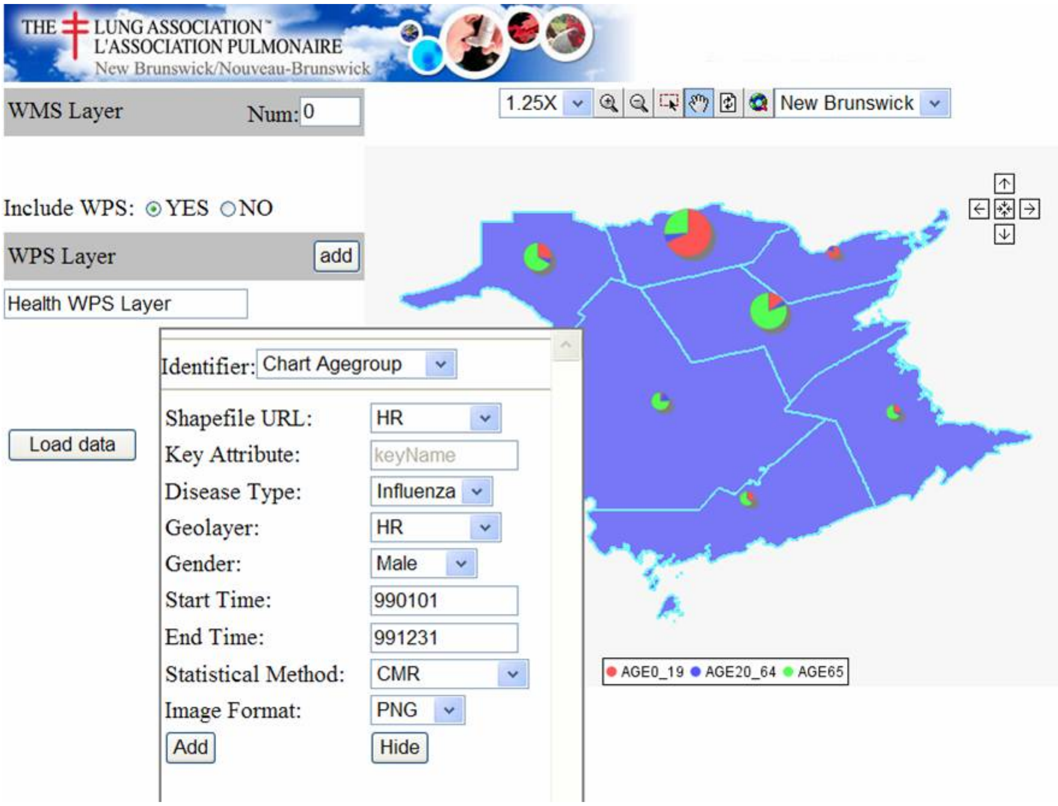
A case study has been carried on the development of Web application and services within the Canadian Geospatial Data Infrastructure (CGDI) framework for community health programs of the New Brunswick Lung Association. The Canadian Geospatial Data Infrastructure (CGDI) aims to support online access to location-based information which can efficiently help people in their decision making [CGDI, 2010]. One priority area of CGDI is to share location-based information for analyzing and monitoring public health. Sharing of health information in the CGDI will improve the ability to intervene on health issues, and inform the public of the availability of resources.

The health data used in this study include four kinds of respiratory disease data (Asthma, COPD, Influenza, and Cancer) collected by the New Brunswick Lung Association. The disease data are geo-coded to spatial position through the use of postal codes. The spatial data used include the six levels of spatial boundary data that cover the entire territory of New Brunswick. The six levels are "Province," "Health Region," "Census Division," "Census Subdivision, " "Forward Sortation Area," and "Dissemination Area" geo-layers. All the health data and geometrical boundary data are stored in an Oracle database. Low counts (i.e., less than five observations) or false counts are not represented to further ensure privacy and accuracy. WMS services are used to publish the health facility distribution maps. WFS services distribute the different levels of spatial boundary data. In this study, new Web Processing Services were provided in the CGDI to enable statistical representation of health information. The WPS services support the statistical calculation as well as mapping of the health data. Figure 4.6 shows an example of an HERXML document generated by a WPS, and Figure 4.7 presents a map representation generated from a WPS.

```
  <?xml version="1.0" encoding="UTF-8" ?>
- <herxml:HERXML version="" xmlns:herxml="http://nblung.ca"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://nblung.ca HERXML.xsd">
  + <herxml:Health xsi:type="herxml:DiseaseObservationType">
  - <herxml:MappingData>
    + <herxml:BoundingBox srsName="EPSG:4326">
    - <herxml:SpatialData>
      + <herxml:DataSource>
      - <herxml:WFS>
          <herxml:URL>http://131.202.98.45:8090/wfsservlet</herxml:URL>
          <herxml:LayerName>healthregion</herxml:LayerName>
        </herxml:WFS>
      </herxml:SpatialData>
    - <herxml:Relation>
        <herxml:JoinAttribute>name</herxml:JoinAttribute>
      - <herxml:MatchingValuePairs>
          <herxml:SpatialIDValue>Health Region 1</herxml:SpatialIDValue>
          <herxml:HealthIDValue>HR1</herxml:HealthIDValue>
        </herxml:MatchingValuePairs>
      + <herxml:MatchingValuePairs>
      + <herxml:MatchingValuePairs>
      + <herxml:MatchingValuePairs>
      + <herxml:MatchingValuePairs>
      + <herxml:MatchingValuePairs>
      + <herxml:MatchingValuePairs>
      </herxml:Relation>
    - <herxml:MappingValues>
      - <herxml:StatisticalMethod>
          <herxml:Name>CMR</herxml:Name>
          <herxml:Title>CMR</herxml:Title>
          <herxml:Description>Crude Morbidity Rate (the total number of
            incidents divide total population in their population group, and
            then multiply 1000)</herxml:Description>
        - <herxml:ParameterGroup>
            <herxml:StartTime>990101</herxml:StartTime>
            <herxml:EndTime>991231</herxml:EndTime>
            <herxml:AgeFrom>0</herxml:AgeFrom>
            <herxml:AgeTo>24</herxml:AgeTo>
            <herxml:Gender>Male</herxml:Gender>
            <herxml:Geolayer>HR</herxml:Geolayer>
          </herxml:ParameterGroup>
        </herxml:StatisticalMethod>
      - <herxml:DataSource>
        + <herxml:Contact>
          <herxml:DataSourceDescription>New Brunswick hospital admission
            data</herxml:DataSourceDescription>
          <herxml:DataSourceTime>Data range from 1990 to
            2007</herxml:DataSourceTime>
        </herxml:DataSource>
      + <herxml:MappingValueGroup>
      </herxml:MappingValues>
    </herxml:MappingData>
  - <herxml:Representation>
    + <herxml:BoundingBox srsName="EPSG:4326">
    - <herxml:PolygonStyle>
      - <herxml:RangeFill>
        - <herxml:DoubleRange>
            <herxml:MinValue>4.4532</herxml:MinValue>
            <herxml:MaxValue>8.6845</herxml:MaxValue>
          - <herxml:FillMethod>
              <herxml:Color>0xF18C8D</herxml:Color>
            </herxml:FillMethod>
          </herxml:DoubleRange>
        + <herxml:DoubleRange>
        + <herxml:DoubleRange>
        + <herxml:DoubleRange>
        + <herxml:DoubleRange>
        </herxml:RangeFill>
      + <herxml:Border>
      </herxml:PolygonStyle>
    </herxml:Representation>
  </herxml:HERXML>
```

Figure 4.6: An HERXML document generated from a WPS

(This HERXML document represents a processing result from a WPS.)



WMS Layer Num: 0

Include WPS: ● YES ○ NO

WPS Layer

Health WPS Layer

Identifier: Chart Agegroup

Shapefile URL: HR

Key Attribute: keyName

Disease Type: Influenza

Geolayer: HR

Gender: Male

Start Time: 990101

End Time: 991231

Statistical Method: CMR

Image Format: PNG

Figure 4.7: A map generated from a WPS

(This map represents a processing result in image format from a WPS. The chart represents age group health information distribution of New Brunswick with the processing parameters (Health region level, Crude Morbidity Ratio, year 1999, male, influenza).)

A configuration wizard (See Figure 4.8) was developed to allow health managers to configure WMS/WPS services for the end-users. The number of WMS layers and the parameters of the WPS layer can be set. A sequence diagram of the health information access is shown in Figure 4.9. After the export process, the generated HTML viewer allows easy and quick access to WMS/WPS services for visualization purposes. As shown in Figure 4.10, a CMR distribution map from WPS and some facility distribution maps from WMS are integrated. A clinic layer (NB_outpatients) was added as a default layer for locating the clinic locations. It provides users (researchers, health officials, practitioners, policy makers, and epidemiologists) with access to GIS functionalities for visualizing health data, and evidence-based decision making on disease outbreaks. The HTML viewer can be saved and used anywhere through the Web, as the JavaScript functions (Zoom in, Pan, etc), WMS services, and WPS services are accessed online.

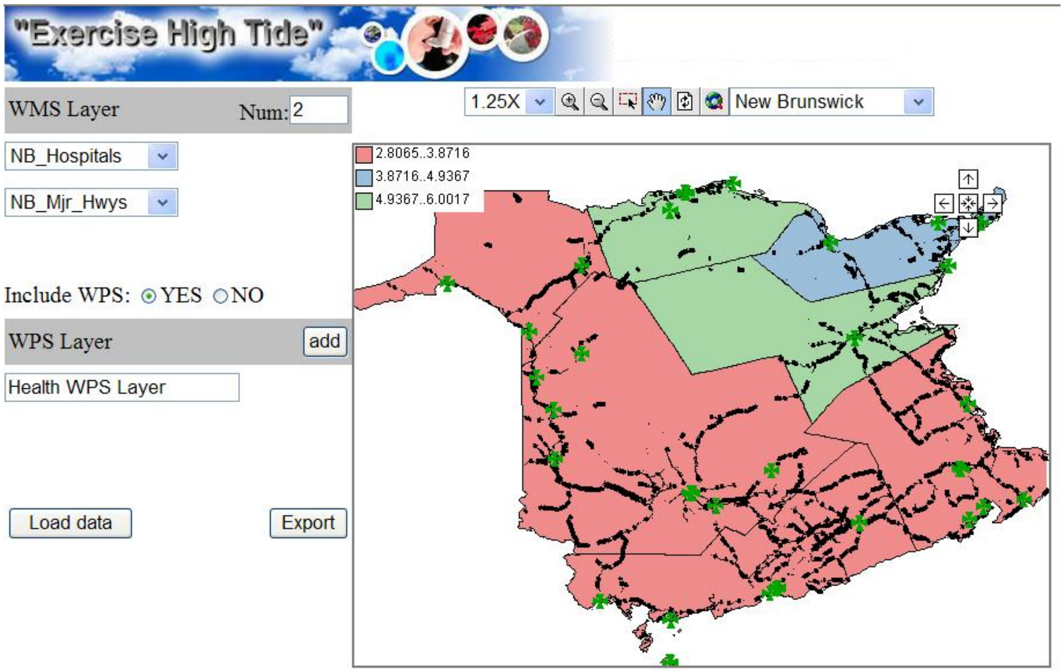


Figure 4.8: The configuration wizard interface

(The configuration wizard manages the WMS layers and the parameters for the WPS. The WPS layer represents health distribution of New Brunswick with the processing parameters (Health region level, Crude Morbidity Ratio, year 1999, male, age 0-24, influenza, equal-interval classification methods, 3 classes, color ramp from yellow-green-blue).)

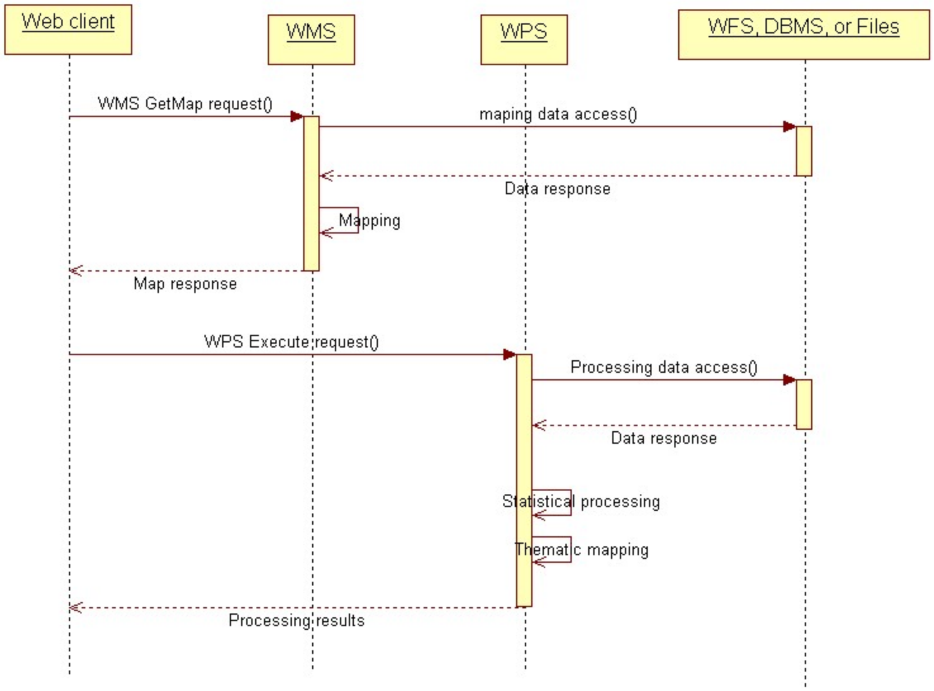


Figure 4.9: Service level sequential diagram for health information access

(The Web client invokes the WMS and WPS for health information access. WMS and WPS obtain the raw data from WFS, DBMS, or files, and then perform the mapping and processing operations.)

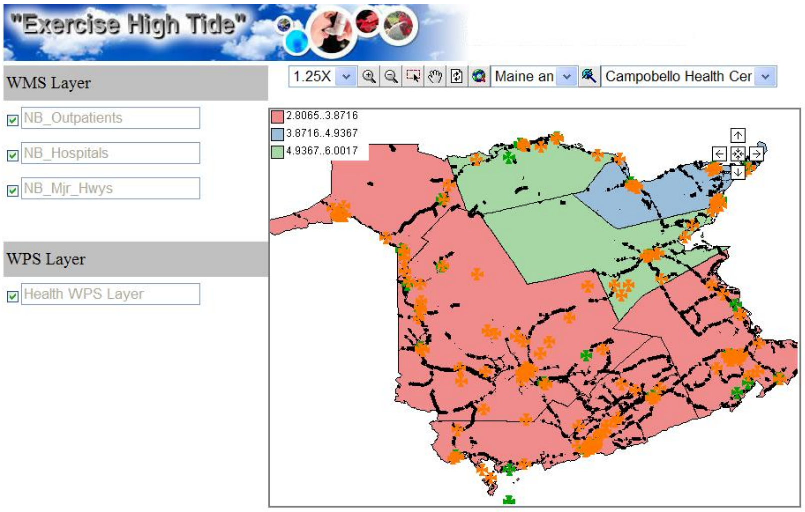


Figure 4.10: The exported HTML viewer

(This viewer provides quick access to WMS/WPS services for visualization purposes. The WMS layers provide the maps of clinics, hospitals, and highways in New Brunswick)

4.4 Discussion

The HERXML can be used to share the cartographic representation of health information (able to consider a variety of health activities), and describe health data sources and statistical methods. The implemented HERXML parser can utilize the representation styles in HERXML documents to generate health maps. The HERXML can be shared by users through the Web in many ways such as email, Web sites, Web forums, and Web Services regardless of platform or system (See Figure 4.11). Thus, health information can be easily represented and shared while keeping the secret of raw health information. If the users are interested in the detailed health information, they can contact the data source manager.

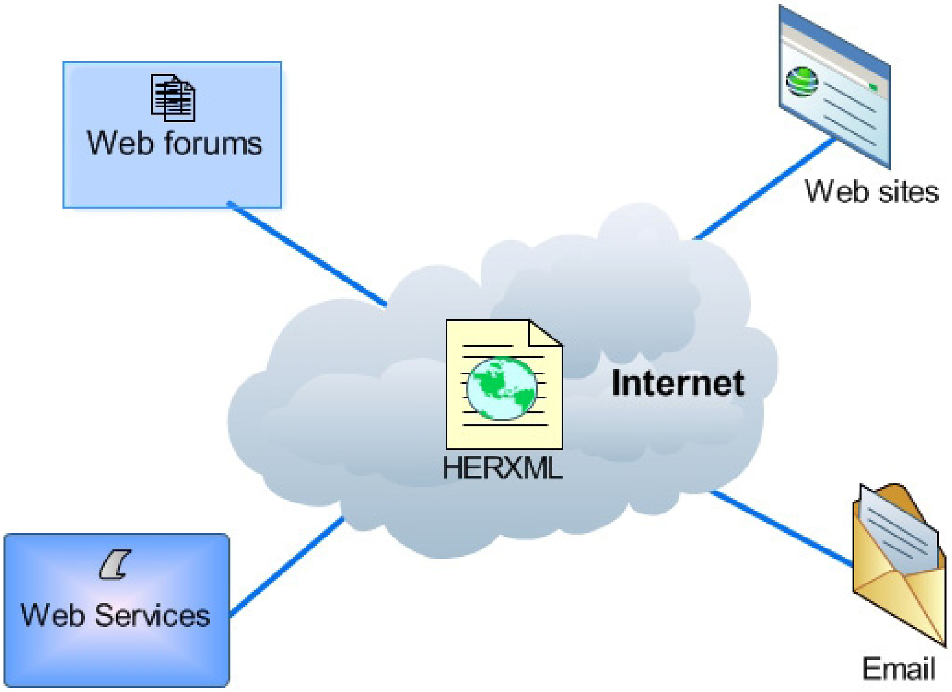


Figure 4.11: The sharing of HERXML

(HERXML can be shared via Internet by Web forums, Web sites, Web Services, emails, etc.)

Similar to GML and SVG, HERXML is pure XML (using ASCII file) and in a vector format. The ASCII file format makes it easy for humans to read, search, and edit. Although ASCII file format is much larger than the binary format, a number of XML compression techniques methods, namely gZip, XMill, XGrind, Xpress, and XComp, have been developed to improve the performance of transferring XML over the Web [Nair, 2010]. The vector format enables scalability and resolution independence. A file in raster format usually would be much larger in volume than a file in vector format at the same resolution [Chen and Lee, 2000]. The HERXML documents can be interpreted as view-only maps (e.g., JPEG) or interactive maps (e.g., SVG) with the attributes and defined representation style in them. Thus, the cartographic representation will be the same in any platform or system.

SVG is designed for computer graphics, and it lacks point feature representation elements and uses inverted y-axis coordinate system, making it unsuited for Web-based cartography [Dunfey et al., 2006]. In addition, SVG uses the graphical coordinate, and this leads to some problems in integrating data from different sources together if they do not have the same coordinates. Meanwhile, GML is able to model, transport, and store spatial information, but it can not provide the cartographic representation of spatial information. HERXML utilizes GML in modeling geospatial features and provide point, line, polygon, and chart styles, making it satisfactory in Web-based cartography. Moreover, HERXML integrates many kinds of attribute information together in a well-formatted structure, with the ability to be represented as text, maps and graphics.

Taking advantage of XML, HERXML is extensible, with the potential to add more health information tags to the representation in defining new health parameters or methods. HERXML is simple and well-structured, and the comprehensive description of health data representation will need more extensions. Meanwhile, to improve the semantic meaning in understanding the health information representation, a well defined ontology should be generated to represent shared vocabularies. The development of XML databases, which facilitates the efficient management of XML, will support the storage and manipulation of HERXML documents.

The WPS standard can support both synchronous and asynchronous requests in the execution process. An asynchronous request is very flexible for users in health data processing, especially when the process is computation expensive. During processing, the dynamically updated execute response document enables users to know the processing status. The results of WPS could use direct data output or a URL which points to the processing results in the server. For health data processing, it is possible for national health organizations to host some processing functions as well as some basic data (e.g., census data) in their server. If a local health organization wants to use the processing and/or mapping power, they only have to purchase it and make its data accessible to processing servers, and then they can get the processing results conveniently. To reduce the hardware or software investment costs at every local organization, it would be feasible to build a public health infrastructure to support processing power on the Web. In this way, users can flexibly choose the required processing services and assemble them based on their needs. However, regarding the data used in the processing services, the standard method of accessing health data and related data (e.g., temperature data) for Web processing still needed to be explored.

4.5 Conclusions

This research developed a HERXML schema to support Web-based representation of health information based on XML specifications, with consideration of semantic, geometric, and graphical aspects of health information. HERXML has been used by the New Brunswick Lung Association in the sharing of health representation information. It provides a suitable way to represent health information for sharing with other users through the Web. The HERXML can be utilized by health practitioners, policy makers, and the public in many areas such as disease etiology, health planning, health resource management, health promotion, and health education. The concept definitions and the richness of the vocabularies under the three categories of semantic, geometric, and cartographic still need to be improved to meet the requirements from the growing users. New applications and services have been implemented in CGDI for health surveillance, with many standard WMS, WFS, and WPS services. WPS provides a solution for publishing the health processing and mapping tools online. This case study enabled online heath data processing and sharing, as well as the reusability and interoperability of health services. The implemented application and services facilitate access to maps and visualization of disease prevalence, mortalities, and determinants of health, transmission patterns, and components of health care response. This research brought a new solution in better health data representation and initial exploration of the Web-based processing of health information, and will further promote the growth and enrichment of the CGDI in the public health sector. The future work will be on the improvement of comprehensiveness of HERXML in health information representation and investigation of data transmission for WPS services.

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Chapter 5. Geospatial-Enabled RuleML in a Study on Querying Respiratory Disease Information ♠

Abstract

A spatial component for health data can support spatial analysis and visualization in the investigation of health phenomena. Therefore, the utilization of spatial information in a Semantic Web environment will enhance the ability to query and to represent health data. In this research, a semantic health data query and representation framework was proposed through the formalization of spatial information. The geometric representation is included in Rule Markup Language (RuleML) deduction. Ontologies and rules were applied for querying and representing health information. Corresponding geospatial built-ins were implemented as an extension to OO jDREW. Case studies were carried out using geospatial-enabled RuleML queries for respiratory disease information. The research thus demonstrates the use of RuleML for geospatial-semantic querying and representing of health information.

5.1 Introduction

Geospatial location provides a solution to link multiple sources in the same area. The spatial component of health data can show the geographical distribution of disease

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outbreaks, hospitals, air quality, and census. Basic geometric information of location is recorded in spatial data collections, using spatial reference and coordinate arrays. Utilizing spatial information allows the spatial analysis and visualization of health data. For example, with the geometric information of the Georges L. Dumont Hospital in Moncton and the New Brunswick Route 15, the neighboring spatial relationship between them can be deduced. The Semantic Web aims to improve machine understanding of Web-based information and its effective management. By employing Semantic Web (e.g., Web rule) techniques, part of the meaning of the information can be captured by machines, thus enabling more precise information queries and interoperation. To enhance the ability to query health information, its spatial component can also be represented and deduced by rules.

The Semantic Web environment, in which data are given well-defined meaning, can facilitate health data query and knowledge discovery. Similar to the non-spatial attributes of data, the spatial attributes can also be represented in the Semantic Web. The use of spatial information in the Semantic Web can support dynamic spatial relation discovery for health data, and furthermore, new concepts and new instances can be generated. For example, from the locations of infectious disease outbreaks, sensitive areas that are within a certain distance from the disease outbreak locations can be determined. Because of the advantages in supporting the representation of a spatial component, this research endeavored to include spatial information in the Semantic Web environment to enhance the ability to query and to represent health data. This research built on and extended the eHealthGeo results in Gao et al. [2008], and included the geometric representation in RuleML to enhance information reasoning and inference.

5.2 Semantic Web and Geospatial Semantics

Semantics-level interoperability among heterogeneous information sources and systems can be achieved by the Semantic Web. According to Sheth and Ramakrishnan [2003], three kinds of important applications of the Semantic Web are (1) semantic integration, (2) semantic search and contextual browsing, and (3) semantic analytics and knowledge discovery. Ontologies, as shared specifications of conceptualizations [Gruber, 1993], constitute an important notion in the Semantic Web. Many XML-based languages, such as RDF(S) and OWL, have been developed for the representation of ontologies. Description Logic (DL) is usually used for ontology reasoning. When concepts are defined using ontologies, three types of relations can be distinguished: taxonomic, functional, and partonomic (part-of) [Luscher et al., 2007]. With the meaning and relations of concepts defined by ontologies, semantic data classification, integration, and deduction can be implemented. One limitation of DL is that it is impossible to represent relations between a composite property and another (possibly composite) property in the ontology representation; however, the use of rules can establish more complex relations between properties [Antoniou et al., 2005]. Rules encode machine-interpretable conditional knowledge ("if … then …") for automatic reasoning [Boley, 2007]. Rules can describe concepts by using the relation of instances through different property paths. Many different kinds of approaches in combining ontologies and rules have been surveyed (see Bruijn [2009]). RuleML [The Rule Markup Initiative, 2010] is the de facto open-language standard for Web rules.

Spatial relationships can exist between two spatial objects (concepts or instances), and exploring them can advance information query and discovery. Three types of major spatial relationships between spatial objects are topological, direction, and metrical relationships [Rashid et al., 1998]. Topological relationships formalize the notion of neighborhood; directional relationships require the existence of a vector space; and metric relationships are measuring distances. Topological relationships are invariant under continuous transformations while directional and metric relationships may change during these transformations. A well-known method by which to formalize topological relations between spatial objects in two-dimensional space is the Nine Intersection Model (9IM), developed by Egenhofer [1991], that considers boundaries, interiors, and complements intersection of two spatial objects. The further improved model, the Dimensionally Extended Nine Intersection Model (DE-9IM), considers the 9IM of two spatial objects with the dimensions of -1 (no intersection), 0, 1, or 2 [Clementini and Felice, 1994; Clementini and Felice, 1996]. The commonly known topological predicates described by the DE-9IM include overlaps, touches, within, contains, crosses, intersects, equals, and disjoint.

With possible spatial relationships existing in the data, several studies have been done on the capture of geospatial semantics for facilitating data integration, query, and discovery. Kieler [2008] discussed the feasibility of identifying semantic relationships between different ontologies by exploring the geometric characteristics of instances. To represent spatial relationships, the explicit storage or dynamic computation of spatial relationships is possible. Explicating all the possible spatial relationships between every two spatial objects is usually not necessary and may not be feasible. While the weakness of dynamic computation is that it is time-consuming, the weakness of explicit storage requires significant storage space and involves reliability issues because of the imprecise nature of relationships [Jones et al., 2003]. Klien and Lutz [2005] illustrated the definition of geospatial concepts based on spatial relations and automatic annotation of geospatial data using a reference dataset. The annotation process uses DL in reasoning and focuses on the concept level. Smart et al. [2007] distinguished multi-representations, implicit spatial relations, and spatial integrity of geospatial data, claiming that rule expression for geo-ontologies needs to consider spatial reasoning rules and spatial integrity rules. Kammersell and Dean [2006] proposed GeoSWRL, which is a set of geospatial Semantic Web Rule Language (SWRL) built-ins. GeoSWRL allows users to include spatial relation operators in queries; however, spatial data representation and processing abilities are not fully integrated in the GeoSWRL system.

In addition, spatial operations can generate new spatial objects from existing spatial objects, such as spatial intersection and spatial union. Because rules are able to describe relations through complex property paths, it would be feasible to represent spatial operations and spatial relations of geospatial objects as rules in knowledge deduction. Cartographic principles can also be applied as rules in the deduction. This research not only enabled geometric representation support for RuleML reasoning, but also applied ontologies and rules in health information reasoning, query, and representation. The respiratory disease information queries were used as examples.

5.3 Framework for Health Information Query and Representation

Health concepts can be described with semantic, geometric, and (carto)graphic components, as shown in Figure 5.1. The semantic component deals with the definition of the concepts. The geometric component provides shapes to locate the concepts. The cartographic component solves the issues of how to represent these concepts through maps. For example, in the case of a hospital, the semantic component can describe its name and attributes, the geometric component can describe its polygon shape, and the cartographic component can describe its map style. Moreover, relations, including non-spatial and spatial relations, exist between health concepts.

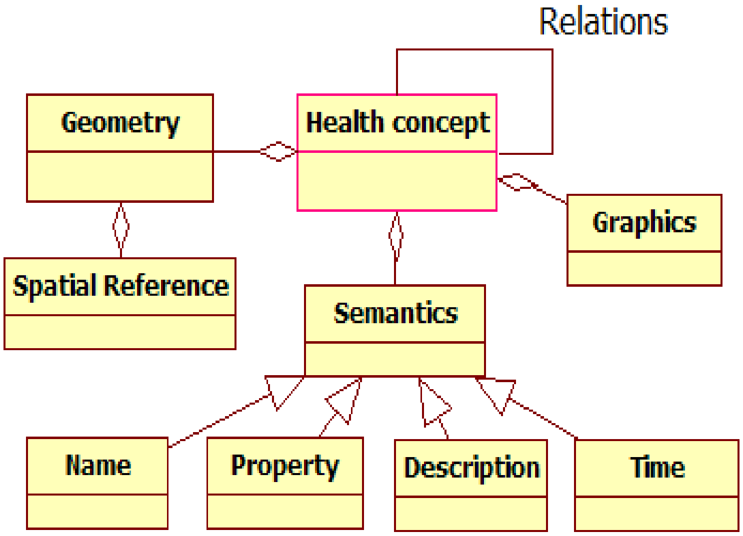

Figure 5.1: Metamodel of health concepts

5.3.1 Framework

Semantic health data queries need to find data with corresponding semantic and geometric attributes. Cartographic representation of the query results allows users to visualize health information. Figure 5.2 describes the framework for semantic health information query and representation, including a data tier, a fusion tier, and a presentation tier. (1) Data tier. The health data could be obtained from various organizations through files, databases, or (Geospatial) Web Services. Following the ontology implementation, data can be extracted to the knowledge base as facts. (2) Fusion tier. The fusion tier contains ontologies, facts, and rules. It queries and fuses semantic, spatial, and cartographic information for representing health data homogeneously. The ontologies are the representation of health concepts and their relationships in the semantic, geometric, and cartographic dimensions. Facts are generated from various health data and existing knowledge about health. Rules, supported by ontologies and facts, deduce health information and present the information to users. Two types of rules are considered: reasoning rules and cartographic representation rules. (3) Presentation tier. The user interface allows the input of semantic, geometric, and graphic criteria to retrieve health information.

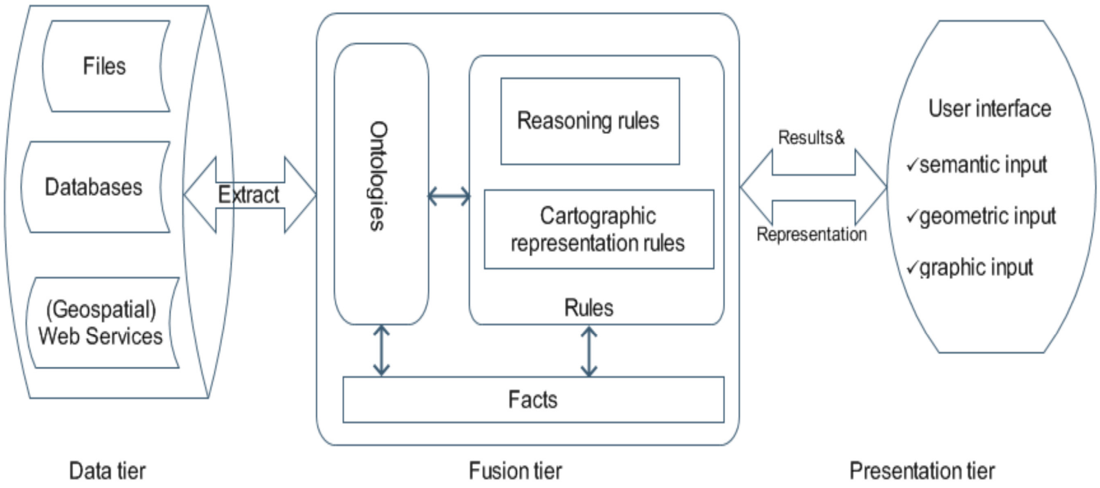

Figure 5.2: Health data query and representation framework

5.3.2 Ontologies and Rules in Health Data Fusion

A. Ontologies

Ontologies can be utilized to connect various concepts (e.g., subconcepts and superconcepts). Depending on the requirements, different application ontologies exist in health applications. To facilitate health data exchange and query, a global ontology could improve interoperability. Three types of ontologies are important in querying and representing health data: health domain ontologies, geometric ontologies, and cartographic ontologies.

Health domain ontologies are used for the definition of health information models, concepts, and terminologies. Many standards exist in this field, such as Health Level 7 (HL7), Systematized Nomenclature of Medicine-Clinical Terms (SNOMED-CT), and

International Classification of Diseases (ICD-9). Geometric ontologies should be able to describe basic geometry types, such as point and polygon. The European Petroleum Survey Group (EPSG, http://www.epsg.org/) coordinate system codes are widely used in the exchange of geospatial data over the Internet. Cartographic ontologies deal with the styles in representing information. For instance, the symbol of hospitals can be represented as point graphics to show the location of hospitals. With the existence of health domain ontologies, geometric ontologies, and cartographic ontologies, the application ontology definition can easily link to these semantic, geometric, and cartographic elements.

B. Rules

Based on the ontologies and facts, rules can define and deduce new information. Besides non-spatial attribute rules, spatial rules can also be applied in this framework. Although the definition of geometric ontologies follows the same methodology for non-spatial ontologies, the inference of spatial relations is different. The utilization of geometries can incorporate the spatial analysis and cartographic representation abilities in rules. Two types of rules are distinguished: reasoning rules and cartographic representation rules.

Reasoning rules cover semantic matching, spatial relation operators, spatial operations, and cartographic comparison of data. (1) Semantic matching rules deal with the domain knowledge for understanding health data. For instance, the manifestation of several symptoms could determine that a patient may have caught a disease. (2) Spatial relation rules are used to determine the topological, directional, and metric relations between geospatial components. For instance, rules can be used to evaluate the direction and distance from the location of an emergency to hospitals. (3) Spatial operation rules can generate new concepts and instances from existing health data. For example, spatial union can combine data from neighboring regions to assist in the comparison of disease outbreaks. (4) Cartographic comparison rules are able to fuse different cartographic representations into a homogeneous form.

Cartographic representation rules focus on the distribution of information to users more efficiently and effectively. Map scale is of great significance in the spatial representation of a concept. For example, a hospital will be shown as a polygon in large scale representation and as a point in small scale representation. Cartographic rules include concept-based rules, attribute-based rules, scale-based rules, priority-based rules, and cartographic generalization rules. (1) Concept-based rules determine graphic styles based on the health concept semantics. For example, standard symbols exist in representing the concepts in national or provincial cartographic design. (2) Attribute-based rules classify health concepts based on their attributes. For example, pie charts can show the age distribution of people in each health region. (3) Scale-based rules are essential in determining what information is represented based on scales. A concept can be stored with multi-representation in the data, and scale can be used to select the optimal representation. (4) Priority-based rules emphasize high priority information. (5) Cartographic generalization (simplification, exaggeration, and displacement) rules allow the dynamic generalization of spatial information.

5.4 Design and Implementation

5.4.1 Geospatial Support for RuleML Deduction

OO jDREW is an open source RuleML engine which was used in this study because it supports RuleML's Naf Hornlog sublanguage and backward/forward reasoning [OO jDREW, 2010]. RuleML's Positional-Slotted Language (POSL) presentation syntax is employed in the following. To use spatial information in the reasoning process, the representation of spatial information in the RuleML engine is needed. Therefore, a geometric ontology was designed to support basic geometry types: point, linestring, polygon, multipoint, multilinestring, multipolygon, and multimix, as shown in Figure 5.3. A polygon can have an out boundary and many inner holes (inner boundaries). Multipoint, multilinestring, and mulitpolygon can have one or more points, linestrings, and polygons, respectively. Multimix contains collections of points, linestrings, and polygons. Figure 5.4 lists examples of how to represent each geometry type. Coordinate reference systems are specified with EPSG codes, and coordinates are recorded in the order of (x1,y1,x2,y2,…). With the specification of geometries, the spatial operation (union, buffer, convexhull, difference, distance, intersection) and spatial relation operators (touches, contains, within, crosses, equals, overlaps, intersects, covers, coveredby, disjoint, iswithindistance) can be incorporated into rules.

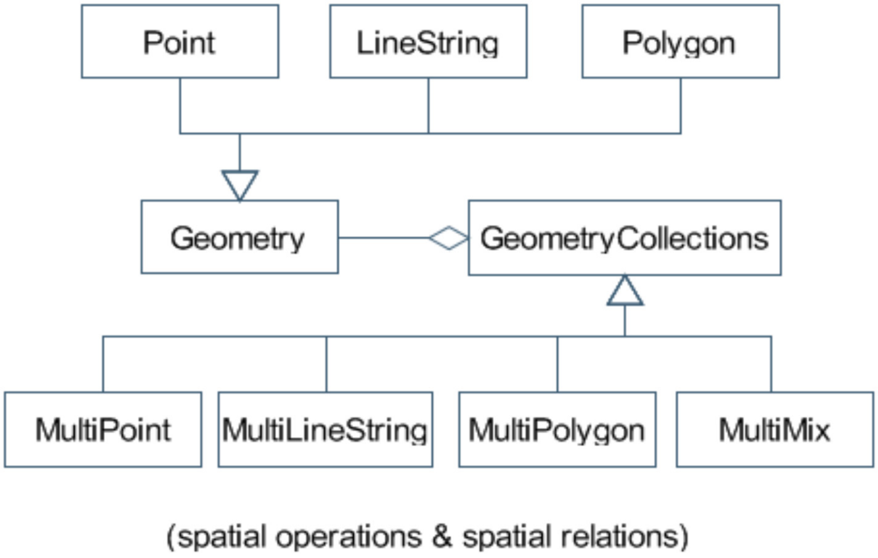

Figure 5.3: Geometry type designed for RuleML

Point:	**geo[EPSG4326, point[0.0,0.0]]:Geometry**
LineString:	**geo[EPSG4326, linestring[0.0,0.0,1.0,1.0]]:Geometry**
Polygon:	**geo[EPSG4326, polygon[outboundary[-1.0,-1.0,-1.0,1.0,1.0,1.0,1.0, -1.0,-1.0,-1.0], innerboundary[-0.5,-0.5,-0.5,0.5,0.5,0.5,0.5,-0.5,-0.5,-0.5]]]:Geometry**
MultiPoint:	**geo[EPSG4326, multipoint[point[0.0,0.0],point[1.0,1.0]]]: Geometry**
Multi-LineString:	**geo[EPSG4326, multilinestring[linestring[0.0,0.0,1.0,1.0], linestring[2.0,2.0,5.0,5.0,3.5,4.6]]]:Geometry**
Multi-Polygon:	**geo[EPSG4326,multipolygon[polygon[outboundary[0.0,0.0,0.0,1.0,1.0,1.0,1.0,0.0,0.0,0.0]], polygon[outboundary[-1.0,-1.0,-1.0,1.0, 1.0,-1.0,-1.0,-1.0]]]]:Geometry**
MultiMix:	**geo[EPSG4326, multimix[point[0.0,0.0], polygon[outboundary[-1,-1, -1,1, 1,-1,-1,-1]]]]:Geometry**

Figure 5.4: Examples of geometry representation

Based on this design, a geometry type was added and a parser was implemented for parsing geometries in OO jDREW. For the spatial operations and spatial relation operations, the JTS Topology Suite was used in this study. The JTS is an open source

Java API for two-dimensional spatial predicates and functions, using the DE-9IM model [Vivid solutions, 2010]. Several geospatial built-ins, such as the gpred_intersects, gpred_within, and gfunc_intersection built-ins, were created using the JTS library. The gpred_intersects built-in checks whether two geometries intersect or not; the gpred_within built-in checks whether a geometry is inside another geometry; the gfunc_intersection built-in computes the intersection of two geometries.

5.4.2 Data Sources and Ontology Definition

The health data used in this study were collected from different organizations, such as New Brunswick Lung Association, Service New Brunswick, Statistics Canada census, and Statistics Canada community health survey. Respiratory disease data were used as examples in this study. Following the disease taxonomy of respiratory diseases in the International Classification of Diseases (ICD-9), an ontology for respiratory diseases was created. A portion of the respiratory disease ontology is shown in Figure 5.5. Respiratory disease data are from hospital patient incidents, which record the time, postcode, disease diagnosis category, age, and gender. Different data could be collected in various spatial boundaries. Taking this study as an example, the disease rate data from the Statistics Canada community health survey were collected at *Health region* and the income data from Statistics Canada census were collected at *Census division*. From these data, the application ontologies of this case study were generated. Entities, such as *Health event*, *Hospital*, *Health region*, *Census division*, *Postcode*, *Disease rate*, and *Income* were also created.

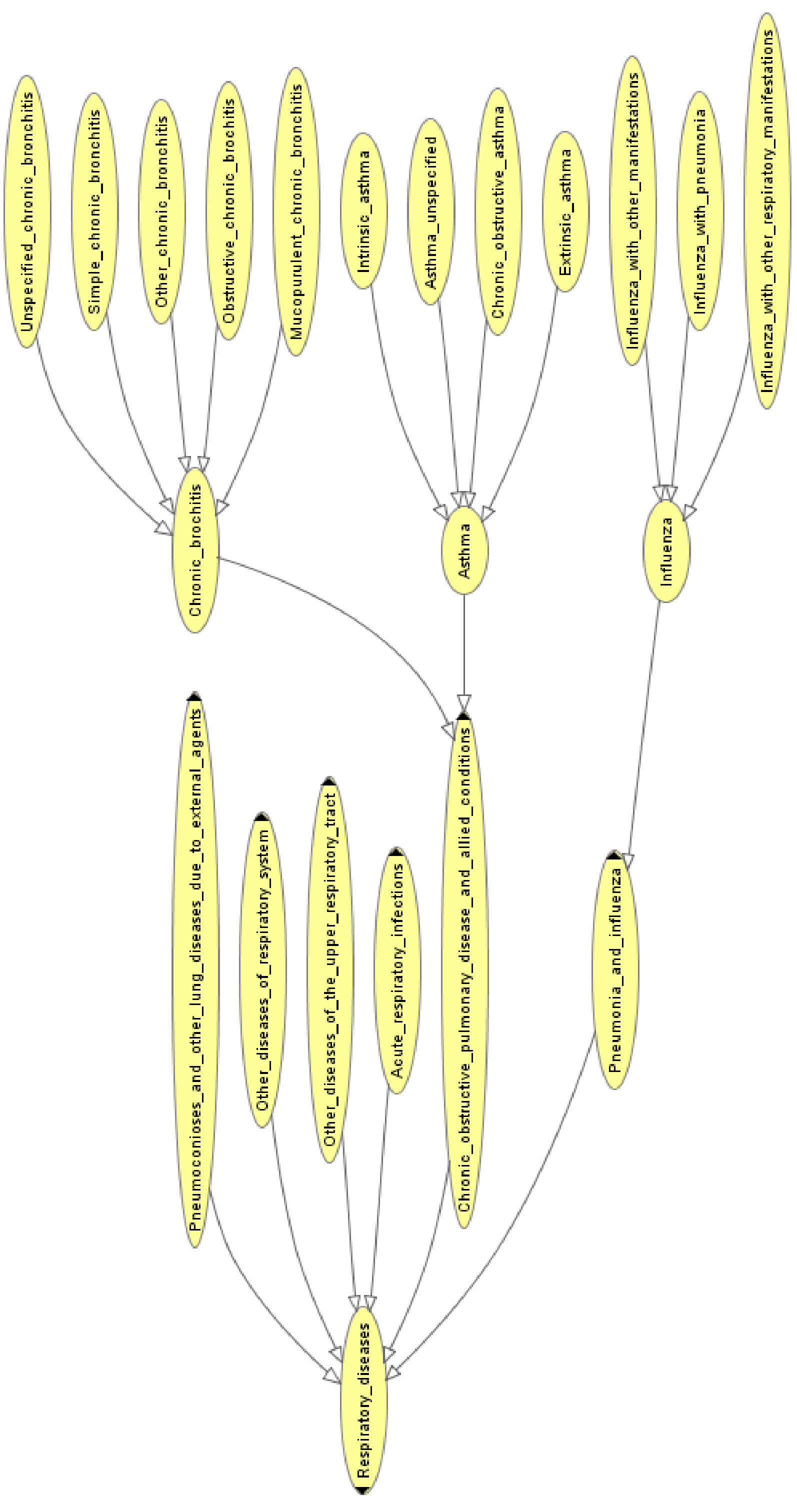

Figure 5.5: Fragment of ontology on respiratory diseases

Health event can describe a variety of cases, such as patient incidents, health training services, etc. The following properties (POSL: "->") associated with health events are shown here: the involved participants' age and gender, the admit date, the disease category diagnosis, and the postcode. Example with a variable (POSL: "?"):

```
health_event (disease->?:Influenza_with_pneumonia; age->88:Integer; gender->Female;
              postcode->E1C; admitdate->date[2000:Integer,1:Integer,1:Integer]).
```

Hospital introduces general information about hospitals, with attributes: name, address, city, province, telephone, and geometry. Example:

```
hospital (name->Dr_Everett_Chalmers_Hospital; address->700_Priestman_St; province->NB;
          city->Fredericton; telephone->5064525400; totalbeds->384:Integer;geometry->…).
```

Health region and *Census division* are two kinds of administrative boundaries. They have name, area, perimeter, and geometry attributes. Example:

```
health_region (name->Health_region_1; area->10455463176.5:Real;
               perimeter-> 844278.079968:Real;
               geometry->geo[EPSG4326, multipolygon[polygon[outboundary[…]],…]]:Geometry).
```

Postcode shows the central location of the three-digital postcodes. Example:

```
pcode3 (name->E1A;
        geometry->geo[EPSG4326,point[-64.7078903603,46.0967513316]]:Geometry).
```

Disease rate and *Income* show the value associated with the geometry name, statistical method, and year. Example:

```
disease_rate (disease->?:Asthma; geometryname->Health_region_1; statistics->average;
                year->2003:Integer; rate->0.104:Real).
income (geometryname->Saint_John_County; statistics->average; year->2003:Integer;
          incomevalue->32748.56028:Real).
```

5.4.3 Scenarios

Case 1. With the collected health events, it is possible to find disease cases fulfilling semantic and geometric requirements. Since disease cases include outbreak locations using postcodes, geospatial semantic query of diseases can discover whether the location of a postcode is inside any spatial boundary. The following disease_locator rule queries a patient's age, gender, and postcode within a certain health region, disease category, age type, and period:

```
disease_locator (healthregionname->?name; disease->?disease:Respiratory_diseases;
                      startdate->?startdate; enddate->?enddate; agetype->?agetype; age->?age:Integer;
                      gender->?gender; postcode->?postcode) :-
   health_event (disease->?disease:Respiratory_diseases; age->?age:Integer;gender->?gender;
                       postcode->?postcode; admitdate->?date),
   age (agetype->?agetype; age->?age:Integer),
   earlier (?date, ?enddate),
   later (?date, ?startdate),
   health_region (name->?name; geometry->?hrgeometry:Geometry!?),
   pcode3 (name->?postcode; geometry->?pcgeometry:Geometry!?),
   gpred_within (?pcgeometry:Geometry, ?hrgeometry:Geometry).
```

The *disease_locator* rule conjoins several subqueries for the semantic query of disease cases. The *earlier* and *later* queries search disease cases in which the admit date is between the start date and end date. The *age* query is used to determine to which age group a certain age belongs. The *gpred_within* built-in query is used to locate postcodes in health regions.

Case 2. Since data collected from different organizations may use different kinds of spatial boundaries, the ability to integrate those data is useful. New concepts and instances will be generated in the integration process. The below disease_income_correlator rule figures out the intersection between disease rate and income. For example, a user would like to know those spatial areas where the asthma disease rate is higher than 0.1 and the average income is above $30,000 in 2008.

```
disease_income_correlator (disease->?disease:Respiratory_diseases; year->?year:Integer;
                           minincome->?minincome:Real;   minrate->?minrate:Real;
                           geometry->?geometry:Geometry):-
  disease_rate(disease->?disease:Respiratory_diseases; year->?year:Integer;
               geometryname->?dgeometryname; rate->?rate:Real!?),
  income (geometryname->?igeometryname; year->?year:Integer;
          incomevalue->?incomevalue:Real!?),
  health_region (name->?dgeometryname;geometry->?hrgeometry:Geometry!?),
  census_division (name->?igeometryname;geometry->?cdgeometry:Geometry!?),
  greaterThan (?rate:Real,?minrate:Real), greaterThan (?incomevalue:Real,?minincome:Real),
  gfunc_intersection (?geometry:Geometry,?hrgeometry:Geometry,?cdgeometry:Geometry).
```

Case 3. To provide better representation of the information to users in the query process, it is beneficial to allow users to define queries with semantic, geometric, and graphic requirements. For example, a user wants to get the asthma rate in 2008 (semantic) in a spatial boundary geometry1 (geometric) with a graduated color ramp1 (graphic). Firstly, the user can define geometric and graphic requirements. The graphics here use graduated color with two categories. One category ranges from 0.0 to 0.2 in green; the other category ranges from 0.2 to 1 in red:

```
geometries (geometryname->geometry1;
            geometry-> geo[EPSG4326, polygon[outboundary[…]]]:Geometry).
graduated_colors (name->ramp1; startvalue->0.0:Real; endvalue->0.2:Real; color->0x00FF00).
graduated_colors (name->ramp1; startvalue->0.2:Real; endvalue->1:Real; color->0xFF0000).
```

Then, the user can use the disease_rate_finder rule to query disease rates. This rule deduces the graphics for disease rate instances within specified geospatial boundaries.

```
disease_rate_finder (disease->?disease:Respiratory_diseases; geometryname->?geometryname;
                         rampname->?rampname; year->?year:Integer;
                        geometryname->?healthregionname; color->?color):-
   disease_rate (disease->?disease:Respiratory_diseases; geometryname->?healthregionname;
                    year->?year:Integer; rate->?rate:Real!?),
   health_region (name->?healthregionname; geometry->?hrgeometry:Geometry!?),
   geometries (geometryname->?geometryname; geometry->?geometry:Geometry),
   graduated_colors (name->? rampname;startvalue->?startvalue:Real; endvalue->?endvalue:Real;
                         color->?color),
   greaterThanOrEqual (?rate:Real,?startvalue:Real), lessThan (?rate:Real,?endvalue:Real),
   gpred_intersects (?geometry:Geometry,?hrgeometry:Geometry).
```

Case 4. Depending on the scale of representation, the cartographic information represented to users could be different. For example, between the scale of 1:1,000 to 1:1, hospitals are shown as polygons. Between the scale of 1:1,000,000 and 1:1,000, hospitals are shown as points. With the scale smaller than 1:1,000,000, hospitals disappear. In this case, a minimum scale and maximum scale can be added to the hospital entity for the cartographic representation purpose. The following sample fact shows one geometric representation for the multi-representations of a hospital:

```
hospital (name->Dr_Everett_Chalmers_Hospital;address->700_Priestman_St;city->Fredericton;
            province->NB; telephone->5064525400; totalbeds->384:Integer; minscale->0.001:Real;
            maxscale->1:Real;
            geometry->geo[EPSG4326, polygon[outboundary[66.65654990041024,
                              45.93896756130009,…]]]:Geometry).
```

With a scale input by users, this rule finds the optimal representation of hospitals:

```
hospital_locator (name->?name; scale->?scale:Real; geometry->?geometry:Geometry;
                       totalbeds->?totalbeds:Integer):-
   hospital (name->?name; geometry->?geomery:Geometry; minscale->?minscale:Real;
               maxscale->?maxscale:Real; totalbeds->?totalbeds:Integer!?),
```

lessThan (?scale:Real,?maxscale:Real), greaterThanOrEqual (?scale:Real,?minscale:Real).

Complex queries can then be supported by combining the available predicates exemplified in the above cases. For example, users can define the spatial area of interest (using customized geometries of Case 3). Then they may like to know where high disease rate and low income values exist within the area of interest (using the disease_income_correlator of Case 2). After that, users can get the information about hospitals within the previously determined high disease rate and low income areas in a certain map scale (using the hospital_locator of Case 4 and gpred_within of Case 1). All these steps can be chained into complex rules to formalize user queries.

5.5 Discussion and Conclusions

This health data query and representation framework provides a solution for health experts to express knowledge as ontologies and rules (regarding semantic, geometric, and graphic dimensions) in health information integration and representation. The use of rule techniques enables health experts to exchange reasoning and representation rules on the Web. Much research has been done on semantic health information integration and query using non-geospatial information in the reasoning. However, fewer investigations utilize geometric information for dynamic spatial reasoning in this process. This research built an integrated system that supports geospatial-enabled semantic health information retrieval. A basic geometric ontology is designed for the spatial component representation. Spatial operations and spatial relations are expressed in RuleML for knowledge representation and deduction. Basic geometries, spatial operations, and spatial relation operators for RuleML are enabled through the extension of the OO jDREW engine. This implementation thus facilitates semantic health data integration and query with the use of both non-spatial and spatial operations and relations. Complex queries and reasoning processes can be implemented to allow the use of semantic, geometric, and graphic dimensions.

The current system implementation uses the interface of OO jDREW in the query process. More customized user interfaces in the presentation tier will be implemented to facilitate health information query and representation. Moreover, as dynamic spatial reasoning and computation has demanding time and memory requirements, the balance between caching computed results and dynamic spatial computation need to be optimized for efficient health information querying. In addition, the ontologies designed in this study were based on the data collected. Their implementation supports the transformation of various health data to facts in the knowledge base. To further improve data integration and query, upper-level or domain-level ontologies need to be investigated. Various health and geospatial standards can be taken into consideration, such as the HL7 ontology and Open Geospatial Consortium (OGC) standards.

With the rapid growth of health data, the semantic query of health data becomes increasingly important for health practitioners in understanding health phenomena. The support of spatial operation and relation operators by rule systems is useful for health data integration, query, and representation. In this study, an integrated semantic system has been built to support geospatial-enabled query and reasoning of health information.

With the use of RuleML, this research has enabled geometry types, spatial operation rules, and spatial relation rules for health information query. The case scenarios in this study demonstrate the benefits of including a geospatial component in semantic health data query, permitting the fusion of various kinds of data in the semantic, geometric, and graphic dimensions. This research fosters the use of ontologies and rules in representing these dimensions of public health information. It facilitates the deduction of information collected by different health organizations. The future work will be devoted to the exploration of ontologies and rules for further semantic integration, query, and representation of health information.

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Chapter 6. The Measurement of Geospatial Web Service Quality in SDIs♠

Abstract

Currently, increasingly large numbers of Geospatial Web Services are being built in Spatial Data Infrastructures (SDIs). Although services make it easy for users to access desired information, the quality of Geospatial Web Services will greatly affect the willingness of users in access of these services. Therefore, in order to improve the use of service oriented architecture for distributed geospatial data sharing, proper measurement of the Geospatial Web Service quality is highly valuable. In this research, the senior authors proposed to evaluate Geospatial Web Service quality from Geospatial Web Service activities and Geospatial Web Service usage. The Geospatial Web Service activities contain four layers: Geospatial Web Service commitment, Geospatial Web Service description, Geospatial Web Service process, and Geospatial Web Service outcome layers. To determine the Geospatial Web Service Quality Score, both objective measurement and subjective measurement were considered. Objective measurement can be generated from the comparison of actual service performance with application requirements. Subjective measurement determines users' attitudes towards the consumption of services. In conclusion, this study brought new perspective in evaluating

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Geospatial Web Services in SDIs. It provided a solution to calculate the Geospatial Web Service quality score from both objective and subjective measurement.

6.1 Introduction

The purpose of building a Spatial Data Infrastructure (SDI) is to avoid unnecessary duplication in harmonizing and standardizing geospatial datasets by promoting geospatial data sharing, and thus time, money, and effort can be saved in accessing geospatial data [Groot, 1997]. Geospatial data, which are useful for decision making in various fields of socio-economic developments (e.g., environment, transportation, public health), are substantial components of an SDI. Since the initial SDI development in some developed countries from mid-1980s, SDIs have been evolved from the product-based generation to the process-based (user-oriented) generation [Rajabifard et al., 2006].

The vision of building an SDI goes beyond geospatial data collection and sharing to the consideration of how to better enhance people in decision making. To answer various requests from users in different fields, SDIs need to be more driven by the ideas of sharing functionality encapsulated in services, which enable easy access and combination of functionalities offered by different providers [Bernard and Craglia, 2005]. The use of Geospatial Web Services makes the download of large irrelevant data no longer necessary, and enables users to obtain exact and value-added information. Currently, many Geospatial Web Services have already been built in SDIs. For example, the most popular standard Web Map Service (WMS), which is fostered by Open Geospatial Consortium (OGC) and International Organization for Standardization (ISO), has many instances in SDIs. More and more Geospatial Web Services will be created with the continuous growth of earth observation and user requirements.

While the number of Geospatial Web Services grows in SDIs, the quality is an important issue in the use of Geospatial Web Services. As services in SDIs are likely to be consumed by various users in their decision making, the quality of services is extremely important, especially in critical situations. Currently, while many Geospatial Web Services exist in SDIs, users do not know some essential details such as whether a service is running or not, and whether the results from a service are accurate or not. Therefore, the trust of service is low from the user's perspective. Many geospatial data providers claim that they publish data through Geospatial Web Services. However, as many uncertainties exist in the access of Geospatial Web Services, most users usually would rather obtain geospatial data directly from data providers than access them through Geospatial Web Services. Only a few of the Geospatial Web Services in SDIs are being used by many applications or users, and these Geospatial Web Services usually just serve as background images. Thus, in order to improve the distributed geospatial data sharing, reliable measurement of the Geospatial Web Services is highly valuable. A proper service quality evaluation framework can give users confidence in accessing the services that meet their requirements. At the same time, service providers can improve their service quality to attract more users.

6.2 Related Work

In the measurement of quality which is subjective in nature, there are subjective and objective quality issues [Nokia, 2008]. *Subjective* quality issues depends on users' perceptions, while *objective* quality issues can be determined independent of users, such as the response time of an application. The widely used multi-item scale for measuring service (SERVQUAL model) defines service quality as a discrepancy between a customer's expectations of services and his perceptions of services offered by a firm [Parasuraman et al., 1988]. It is focused on the subjective quality from users after they consume services. As the SERVQUAL model is a general method in evaluating user perceptions of services, it can be used for different services, such as banking services and car repairing services. However, the objective measurement of service quality needs to consider specific application requirements.

With the development of Web technologies, the research of service quality began to evaluate Web Services. The evaluation of Web Services generally uses the *objective* measurements, from both functional and non-functional view. The non-functional characteristics are concerned about the dynamic performance of Web Services. The functional characteristics are related to the quality of the information that Web Services provide. From a non-functional view of Web Services quality, Mani and Nagarajan [2002] listed seven major requirements, which are availability, accessibility, integrity, performance, reliability, regulatory, and security. All of these factors are related to dynamic transactions of Web Services in e-business vision. However, some of them are not very important or different in Geospatial Web Services, such as integrity and regulatory. Ran [2003] combined both functional and non-functional requirements in service quality and proposed four kinds of quality of services: runtime related service quality, transaction support related service quality, configuration management and cost related service quality, and security related service quality. The functional and non-functional requirements are mixed in the four categories, and the evaluation metrics still need to be established to quantify each service quality.

With the growing number of the Geospatial Web Services, Peng and Tsou [2003] focused their Geospatial Web Service quality on non-functional characteristics: performance and reliability. In SDIs, some work began to monitor Geospatial Web Service availability and other non-functional quality characteristics [Simonis and Sliwinski, 2005; Scheu and Rose, 2006]. In the access of Geospatial Web Services, the quality of geospatial data is also a great concern. Subbiah et al. [2007] proposed to incorporate a set of four geospatial attributes (accuracy, resolution, completeness, and data types) to describe geospatial service quality besides regular Web Service quality characteristics.

While the research mentioned considered the dynamic monitoring of the availability or performance of the Geospatial Web Services, these efforts have generally not considered the service activities during service consumption in evaluating Geospatial Web Services. In addition, subjective measurement of Geospatial Web Services quality still needs to be explored.

6.3 Proposed Geospatial Web Service Quality Framework

During service consumption, users/applications need to interact with the services. Five layered activities (from top to bottom: service commitment, service presentation, service acquisition, service process, and service value exchange) happen in a service event, and the occurring of a certain layer requires the existence of a higher layer [Ferrario and Guarino, 2008]. In Geospatial Web Services, similar service activities can be found. Because the service acquisition is triggered from the user side, this study didn't count it in the Geospatial Web Services activities.

In this research, the coverage of Geospatial Web Service activities is related to Geospatial Web Services themselves, including the Geospatial Web Service commitment, Geospatial Web Service description, Geospatial Web Service process, and Geospatial Web Service outcome layers, as shown in Figure 6.1. When a Geospatial Web Service activity happened in each layer, the content obtained from the service reflects service quality. Geospatial Web Service quality can be improved by service providers to enhance the interaction of each layer with users/applications. Besides service activities, the external view of service usage (how many people/applications use the service) can also mirror Geospatial Web Service quality. Thus, in this study, the senior authors proposed to combine the Geospatial Web Service activities and Geospatial Web Service usage in evaluating the quality of Geospatial Web Services.

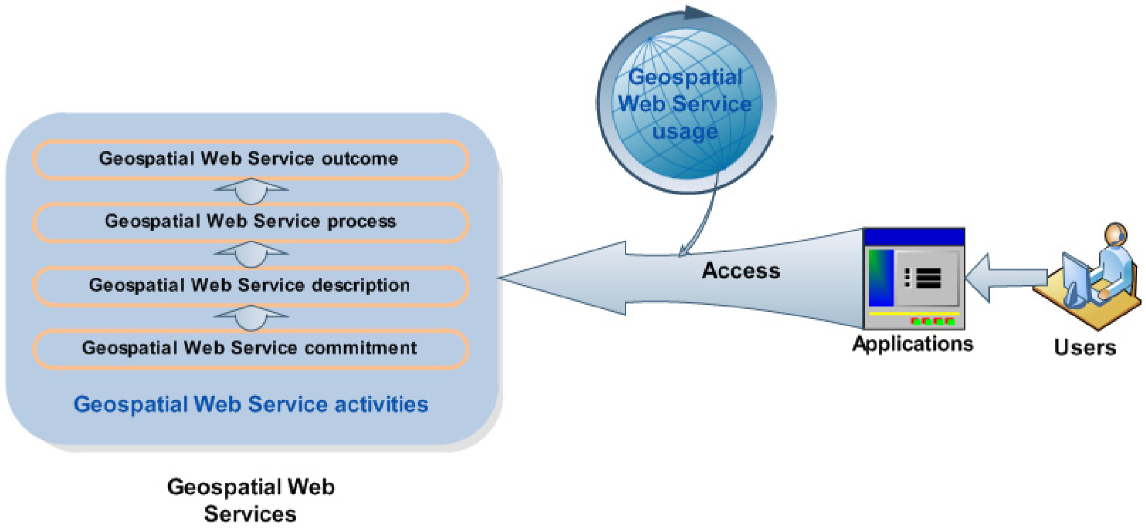

Figure 6.1: Geospatial Web Service quality evaluation framework

6.3.1 Geospatial Web Service Activities

The quality measures on Geospatial Web Service activities are related to Geospatial Web Service commitment, Geospatial Web Service description, Geospatial Web Service process, and Geospatial Web Service outcome layers. At different layers of Geospatial Web Service activities, different factors need to be considered.

Geospatial Web Service commitment guarantees the type of service that can be consumed by users at a certain time. The key issues in the service commitment are the hours that service is available, categories of services (e.g., map service), invocation address, access restriction, and characteristics in service value exchange. If a user wants to use a Geospatial Web Service, the service commitment information will be used at first to filter services that he can use. As Geospatial Web Services in SDIs will be used by people from different fields, the service commitment should be provided by services.

Geospatial Web Service description is important to let users/applications discover services, negotiate with services, and invocate services. One of the important characteristics of Web Services is the self-description ability. The service description information should give service interfaces, service content, service contact information, and cost. Service interface information describes all the service interfaces and their supporting parameters. Service content shows the existing geospatial data or processing functions in Geospatial Web Services. Service contact information enables users to contact the service provider when necessary. Cost is also a valuable issue before users start to consume Geospatial Web Services.

Geospatial Web Service process is the period that service is invocated by users/applications. During this time, the performance of services is an important concern. Commonly, the performance of the service processing can be evaluated through availability, time latency, reliability, error tolerance, and security. Availability shows that whether the service is able to be consumed by users/applications. Time latency is the time delay between a request and a response, including the transmission time and processing time. Reliability is to measure the failure times of services during a time period. In failure cases, while the services are running, the results are not correct. High error tolerance abilities make the service robust in handling service requests. Security in the service process deals with the abilities to support authorized access and encryption in message transmission.

Geospatial Web Service outcome is the results of service process. As the outcome is associated with geospatial data, the geospatial data quality is a significant issue. According to ISO 19113, the identified five criteria for geospatial data quality are positional accuracy, temporal accuracy, logical accuracy, thematic accuracy, and completeness [ISO/TC 211, 2002]. Positional accuracy covers the absolute accuracy and relative accuracy between the data and reality. Temporal accuracy depends on the currency of data collection and the rate of data change. Logic accuracy deals with the topological consistency, format consistency, and semantic consistency. Thematic accuracy relies on the correctness of the classification, qualitative attributes and quantitative attributes. Completeness indicates the possibility of omission and commission in the data. When a service meets some problems in processing, the error hints (such as wrong input parameters, and the reason of failure) in the outcome would be helpful.

6.3.2 Geospatial Web Service Usage

The service acquisition from users is the trigger of Geospatial Web Service process and Geospatial Web Service outcome. The service acquisition is users' responsibility and it reflects the willingness of users to use the service. Therefore, Geospatial Web Service usage is an empirical evaluation of the quality of a service. It considers how the service is consumed by users. A Geospatial Web Service can have good marks on service activities, but it may only be used by one application. From how many people/applications use the service and the general feeling about the service, it is possible to mirror the service quality. A service that has not been used by any application lacks value, and therefore its quality would be poor. Service usage can be evaluated from the summation of people/applications which use the service, the number of the service transactions, and the amount of exchanged information.

6.4 Geospatial Web Service Evaluation

To evaluate Geospatial Web Services from service activities and service usage, there are two ways. One is through objective measurement. In this case, the requirements of services are pre-defined, so the service quality can be verified by actual service performance. The other is through subjective measurement. Users are asked to express their attitudes towards using the service.

6.4.1 Objective Measurement

In the objective measurement of Geospatial Web Service quality, depending on the requirements of specific applications, the scoring items of Geospatial Web Service activities and Geospatial Web Service usage can be defined, as shown in Figure 6.2.

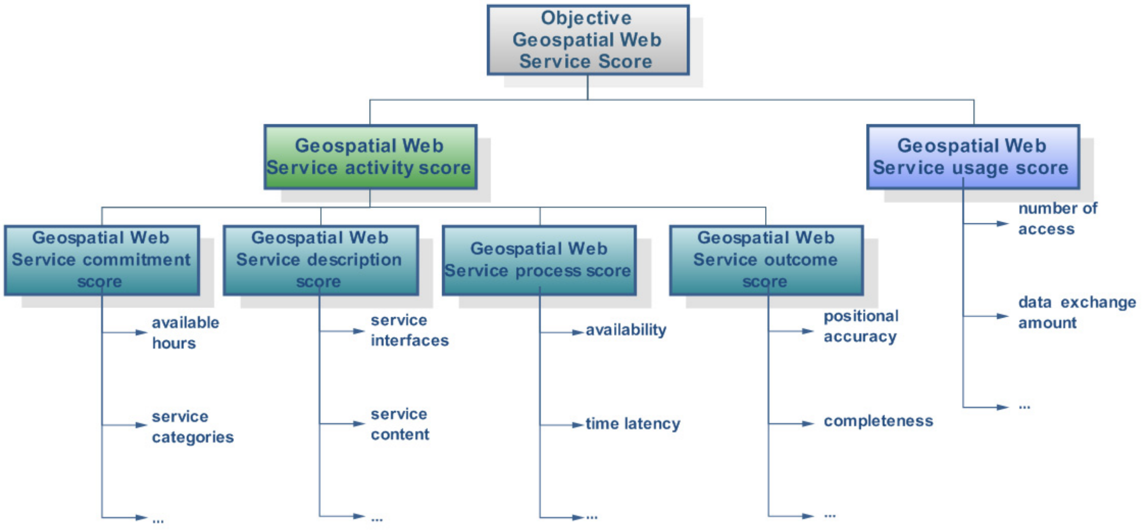

Figure 6.2: Objective Geospatial Web Service score

The items in different level of Geospatial Web Service quality framework need to be quantified based on the application. For example, the service content item under Geospatial Web Service description is set to be mandatory. For the item of time latency under Geospatial Service process, the acceptable value may have to be less than 10s in an application. The determination of scoring items as well as their quantification process can be done through experts and user questionnaires.

After that, comparing the actual service performance with the above quantification can assign a score to each scoring item. In this process, a deterministic model or a fuzzy model can be designed for each scoring item.

The Geospatial Service commitment and Geospatial Web Service description can be validated through simple checking. For example, the requirement of Geospatial Web

Service description should include service interfaces, service content, and service contact information. With such requirements, if the service content information is not provided by the service, the score of service content item under Geospatial Web Service description would be zero.

Three commonly-used methods to invoke Geospatial Web Services are: Key Value Pairs (KVP), Simple Object Access Protocol (SOAP), and REpresentational State Transfer (REST). KVP encoding uses key value pairs to send service requests. SOAP encoding uses the HTTP POST to send service requests. REST manipulates service resources using standard HTTP requests. Based on the enabled service invocation methods, dynamic monitoring can be applied. Machines can be used to evaluate service process by simulating lots of requests at different times and comparing the responses from services. The test of service process should cover all the service interfaces and service content that a service supports. The test results can record information such as the service connection time, transmission time, response or not, response code, response data volume, response data. By aggregating the above information, availability, throughput, reliability, and time latency of the service performance can be obtained.

The assessment of the service outcome needs the contribution of GIS experts. They can determine the geospatial data quality (positional, temporal, logical, thematic, and completeness) through field survey, investigation, and quantitative analysis.

The evaluation of Geospatial Web Service usage can be done by monitoring the service access and service data exchange for a time period. The more the access times and data exchange size are, the higher the Geospatial Web Service usage score will be. Usage implies the importance of a service to users/applications. In addition, Geospatial Web Service usage score is a general score for a service, as it is not application specific.

From the scores that assigned to each scoring items, the objective Geospatial Web Service quality score can be calculated. Usually, the weighted average method is applied, calculating the scores from the child level to its parent level. The weights can be determined by experts, user questionnaires, or fuzzy-based models. For instance, the Geospatial Web Service commitment score is computed based on the scores of the scoring items under it. For Geospatial Web Service activities, Geospatial Web Service commitment layer, Geospatial Web Service description layer, Geospatial Web Service process layer, and Geospatial Web Service outcome layer form a chain. If one layer doesn’t work well, it will affect the use of the next layer. Therefore, selecting the minimum score of the four layers as the Geospatial Web Service activity score is one solution.

6.4.2 Subjective Measurement

The subjective measurement of service quality considers the perceived quality of users in the consumption of services. Two kinds of users exist in SDIs in using Geospatial Web Services: developers and end-users, as shown in Figure 6.3. As Geospatial Web Services are application to application communication, they don’t need to have graphic interfaces.

Therefore, the evaluation of Geospatial Web Services depends on the applications implemented on services by developers. The applications will be finally consumed by developers and end-users to see the quality of services. To get their perceptions of services, the senior authors design separate questionnaires for developers and end-users with the consideration of Geospatial Web Service activities and Geospatial Web Service usage. As end-users only consume the service-based applications, the Geospatial Web Service commitment and Geospatial Web Service description are not applicable to them. The purpose of the questionnaire is to know the gap between users' expectations and the actual service abilities. Following the questionnaire designed in the literature [Parasuraman et al., 1988; Brooke, 1996; Li et al., 2002], the questionnaires were designed with five-point scale (strongly disagree, slightly disagree, neutral, slightly agree, strongly agree), with some positive and negatives questions to limiting the bias from users without thinking about them.

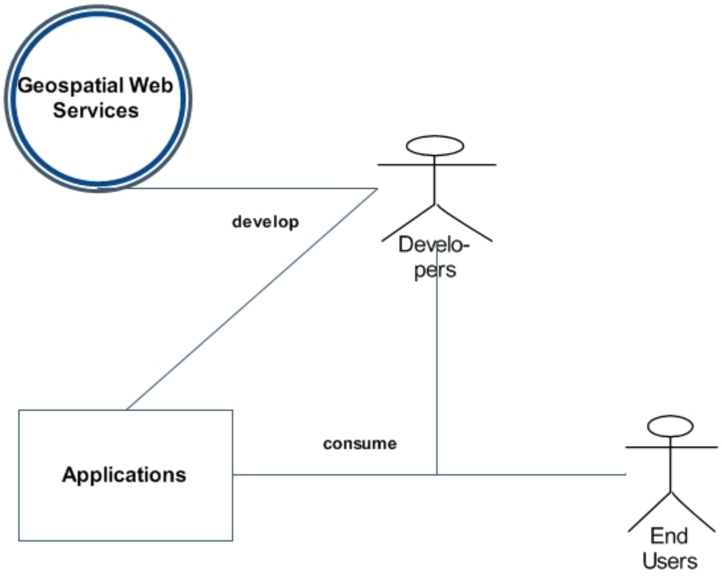

Figure 6.3: Users of Geospatial Web Services in SDIs

Questionnaires for developers.

Geospatial Web Service activities - Geospatial Web Service commitment

Q1 I think the available hours for this service are limited.

Q2 I found it is easy to find this service.

Geospatial Web Service activities - Geospatial Web Service description

Q3 It is hard for me to find what I need from this service capability description.

Q4 I imagine the content of this service would be used by many applications.

Geospatial Web Service activities - Geospatial Web Service process

Q5 I think the response speed from this service is slow.

Q6 I think I am confident to use this service.

Q7 I found the service had strict rules for inputs.

Geospatial Web Service activities - Geospatial Web Service outcome

Q8 I found the geospatial data quality from this service is bad.

Q9 I found the error messages from this service are helpful.

Geospatial Web Service usage

Q10 I found the use of this service is complex.

Q11 Overall, I am satisfied with this service.

Q12 I think I would like to use this service often.

Questionnaires for end-users.

Geospatial Web Service activities - Geospatial Web Service process

Q1 I found this service is always available when I use it.

Q2 I think the response speed from this service is slow.

Q3 I think I am confident to use this service.

Geospatial Web Service activities - Geospatial Web Service outcome

Q4 I think the geospatial data or function from this service hardly meet my requirements.

Q5 I found the results from this service are precise and accurate.

Geospatial Web Service usage

Q6 Overall, I am satisfied with this service.

Q7 I doubt this service is useful to other people.

Q8 I think I would like to use this service often.

In the questions, the senior authors assigned the score from zero to four for the positive questions and the score from four to zero for negative questions. The subjective Geospatial Web Service score can be calculated by averaging scores of all the questions from participating users.

6.5 Conclusions

In conclusion, this study provided a framework to evaluate Geospatial Web Services in SDIs from Geospatial Web Service activities and Geospatial Web Service usage. The objective measurement and subjective measurement were proposed in the evaluation of Geospatial Web Service quality. The measurement of Geospatial Web Service quality in SDIs will push Geospatial Web Service providers to improve their service quality. In addition, the quality information of Geospatial Web Services is also useful in service discovery and service matching. The ongoing work is to apply this framework to evaluate the New Brunswick provincial SDI.

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Chapter 7. Conclusions

7.1 Summary of the Research

This research has designed and developed methods to resolve the problems encountered in health information sharing using Web-based GIS. Three problems in health information sharing have been studied: data heterogeneity, resource deficiency, and health information representation.

Data Heterogeneity

Regarding health data heterogeneity, most of the current research focuses on the non-spatial semantics of health data, using ontologies and rules. However, the geospatial component in health data is not as widely examined. Machine understanding of spatial information can support the interpretation of health data semantics. Therefore, a geospatial-enabled approach has been proposed in this study for semantic health information retrieval. The research proposes a framework that uses ontologies, facts, and rules in health information reasoning and deduction from both geospatial and non-spatial aspects. Cases scenarios for respiratory disease information retrieval have been used to demonstrate this approach. Ontologies on the semantic, geometric, and graphic dimensions have been explored for the basic representation of health data resources from files, databases, or Geospatial Web Services. Topological relations and spatial operations were also enabled in a RuleML engine for the representation of spatial knowledge in the Semantic Web.

Resource Deficiency

The weaknesses of current geospatial health information systems are related to their separated and independent development and closely coupled architecture. Therefore, it is difficult to integrate the data from different providers. In addition, the abilities of these systems are mainly concentrated on the visualization of health data. Health data processing abilities and representation styles are not available to users or can not be easily utilized by users. The accessibility, interoperability, trust, and privacy issues of health resource access were explored in this research.

To allow the access of health maps and processing functionalities, Geospatial Web Services were proposed to enable a loosely coupled architecture design for cross-platform health data and function sharing. If the access URLs and interfaces of the Geospatial Web Services are known, resources can be accessed no matter what underlying platforms and development environment are used.

To support interoperability between different geospatial health applications, OGC standards were proposed to be utilized for health data processing and sharing. Therefore, these open-standard Geospatial Web Services which provide health data and processing functions can be easily accessed through Web browsers, OGC-compliant clients, or user customized applications. WMS allows the generation of disease maps with different parameters, including the time tag. SLD enables a user-defined style representation of maps. A Web portal was implemented for the access of various WMS from different service providers. Users can visualize the spatio-temporal pattern of disease data through maps or animations in the designed Website, which interacts with the WMS services. WMC eases disease maps sharing and user collaboration by recording the access parameters to Geospatial Web Services in XML. This study integrated a discussion forum within a map portal to support both text and map sharing for user collaboration. WPS supports the online processing of health information with the input of the health data, geospatial data, processing parameters, and cartographic styles from users. A configuration wizard was designed for health managers to customize the WMS and WPS for end-users. After the export process from the wizard, a generated HTML viewer, which can be saved and used anywhere through the Web, allows the access to WMS and WPS for visualization purposes with basic GIS functions.

To promote SDI and open-standard Geospatial Web Services in health, a study has been carried out to evaluate the CGDI for health. CGDI has adopted the standards mentioned above. Health applications can be easily built on top of CGDI, and the overall evaluation of CGDI for health is positive. Moreover, the development of SDI will lead to a great many Geospatial Web services. For the trust issues in health service access, a Geospatial Web Service quality measurement framework was developed. This framework provides a systematic analysis on the service activities that happened during the service consumption. A list of factors was discussed for the measurement of Geospatial Web Services. To evaluate the score of the Geospatial Web Services, methods of both objective measurement and subjective measurement were explored by comparing the service performance with the requirements and conducting user questionnaire surveys.

The privacy issues in health resource access were handled through several methods, such as applying statistical calculation on health data (using CMR, AAMR, etc.), thematic mapping of health information (using classification, charts, etc.), and showing health information at different spatial levels of detail with the consideration of privileges. These methods compromise the sensitive issues in health data and allow the distribution of health information to health practitioners and the public.

Health Information Representation

Most of the geospatial health applications rely on maps for the information sharing. Without proper map design and map description, maps can easily mislead people. To allow the exchange of georeferenced health information, an XML-based health information representation, HERXML, which can be parsed as maps, was proposed for information sharing. The platform-neutral characteristic of XML allows the easy exchange of HERXML through the Web. The statistical results of many health activities (e.g., disease outbreaks, hospital observations) can be shared with the consideration of many variables, including time and demographics. The use of statistics relieves the privacy issues in health information sharing. In addition, users can get detailed information by contacting the data source providers which are described in HERXML. The coverage of HERXML includes the semantic, geometric, and graphic dimensions. The semantic dimension considers health-related activities, statistical methods used, mapping variables, mapping values, and data source metadata; the geometric dimension is about the spatial data in which health statistical results are to be represented; the graphic dimension handles the cartographic styles including the classification schemes.

7.2 Major Achievements of the Research

Five contributions have been achieved in this research:

1) This research has proposed a semantic health information query and representation framework. This framework allows the consideration of both geospatial semantics and non-spatial semantics in health information integration and retrieval. Ontologies, rules and facts in this framework are used to support several functionalities, such as extracting health information from various sources, matching the data with the same semantics, reasoning in the spatial dimension with spatial relations and spatial operations, and fusing the information representation homogeneously. The RuleML engine OO jDREW has been customized to support all these functionalities in health information retrieval. Geospatial semantics was fully integrated into OO jDREW for semantic health information retrieval.

2) This research has designed and implemented an interoperable health information mapping and sharing architecture to overcome the difficulties in current health system integration and reusability for real-world applications. This architecture covers essential tiers: data tier, ontology tier, service tier, and map/animation tier for health information sharing. OGC Geospatial Web Services were proposed and implemented in this framework to allow interoperability in the sharing of health data and processing functionalities. Moreover, this research firstly introduced Web Processing Services to offer geospatial processing functionalities for health data via the Internet. This

architecture supports health data mapping and processing, and organization/user collaboration by sharing maps and text. It can be applied to real disease outbreaks if practical difficulties (especially the laws governing the access and the use of health information) in obtaining data from various health organizations are resolved.

3) This research has designed and implemented a health information representation model, HERXML, for the exchange and sharing of health information representation in semantic, geometric, and graphic dimensions to minimize the misunderstanding of the Web maps which are generated from current health applications using Web-based GIS. HERXML enables the representation of statistical results for various health activities and provides essential information for users in interpreting health maps.

4) This research has proposed a new framework for evaluating service quality from all the service activities that happen in their consumption. The framework provides a systematic consideration of the factors that would affect Geospatial Web Service quality. Based on this framework, a methodology on how to implement both objective service quality scores and subjective service quality scores was designed.

5) This research has implemented several user interfaces/portals for accessing health data and processing functionalities, such as the WMS portal to visualize the spatio-temporal disease information across the New Brunswick and Maine border, the Web portal that integrates a WMS client and a discussion forum for user collaboration, and the Web

portal which allows the customization of health processing parameters and data retrieval from WMS and WPS.

7.3 Recommendations for Further Research

Based on this research, recommendations for further research are given below.

For health data heterogeneity, suggestions include the improvement of the ontologies on the semantics, geometries, and graphics of health data, and the enrichment of human knowledge by rules for health data reasoning and deduction. The ontology- and rule-based health information integration and retrieval framework provides the basics on how to utilize both non-spatial and geospatial semantics for health, and the implementation steps in case studies demonstrate how a complete system could work. If the knowledge base can incorporate more ontologies and rules, it will make such a system ready for real health applications.

For resource deficiency, suggestions include the utilization of all available data for decision making and quality control in data sharing. With the recent rapid deployment of sensors, including human body sensors, air pollution sensors, climate sensors, and satellite sensors, huge health data sets could be available in real-time from Geospatial Web Services. This research has proposed the use of standard Geospatial Web Services in sharing health data and processing functionalities. Future efforts can be placed on the development of geospatial Web applications using all historical and real-time data to extract new knowledge and support real-time decision making for health professionals.

Moreover, the development of a Quality-of-Service tool that is running continuously for Geospatial Web Service monitoring would be beneficial.

For health information representation, suggestions include the generation of a standard vocabulary for HERXML and questionnaire surveying of the comprehensiveness of HERXML. A predefined vocabulary for HERXML could facilitate users in the sharing and understanding of health information representation. Carrying out a questionnaire survey for HERXML can prioritize information content and possibly incorporate new essential information.

Appendix A: XML Schema for HERXML

```
<?xml version="1.0" encoding="UTF-8"?>
<!--
By Sheng Gao, April 2008

Submitted as additional material for the IJHG article

This document is our preliminary HERXML schema, designed using Altova XMLSpy. This XML schema covers the semantic, geometric and graphic representations of health information.
-->

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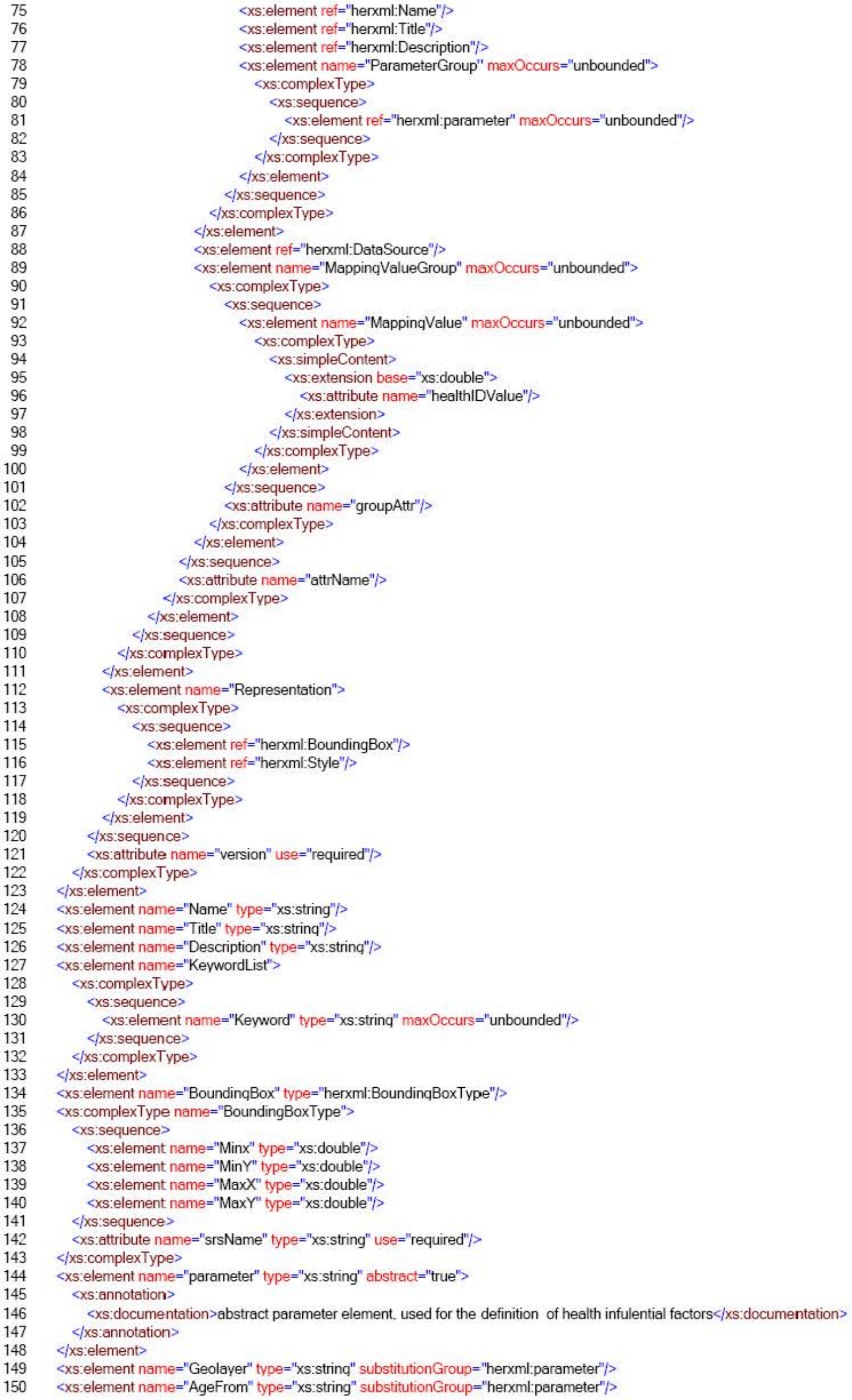

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```

Curriculum Vitae

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Conference Presentations:

Gao, S., D. Mioc, and X. Yi (2009). "The measurement of Geospatial Web Service quality in SDIs." *The 17th International Conference on Geoinformatics, Geoinformatics 2009*, Fairfax, USA, August 12-14.

Gao, S., D. Mioc, H. Boley, F. Anton, and X. Yi (2008). "Ontology-based querying and visualization of geo-referenced health information." *Joint ISCRAM-CHINA and Gi4DM Conference*, Harbin, China, August 4-6.

Gao, S., D. Mioc, X. Yi, F. Anton, and E. Oldfield (2008). "Geospatial services for decision support on public health." *ISPRS conference*, Beijing, China, July 3-11.

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