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Imaging and Communication in Medical and Public Health Informatics: Current Issues and Emerging Trends

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52.1 Introduction

Medical and public health informatics can be broadly defined as the use of computer technology to support clinical or public health practice, administration, education, and research [1-3]. The products developed in this field, "information resources," involve the hardware and software that facilitates the storage, retrieval, and optimal use of medical (or public health) information for problem solving and decision making [4, 5]. While the intended target audience for this book is the imaging community, end-user informaticists engaged in the interdisciplinary development and integration of developed tools in this field include physicians, nurses, and health care/public health administrators. Professional competencies of these individuals include [6-9]:

- Serving as a liaison to physicians, administrators, and other health care professionals in the use of current and emerging computer technologies;
- Using and evaluating commercial software products to manage medical or public health information;
- Creating and analyzing new and existing clinical data resources;
- Developing and deploying new software tools to meet the needs of a clinical or public health practice or administration.

This chapter examines current issues and emerging trends in the development and deployment of imaging and communication tools in medical and public health settings, from the perspective of the informatics professionals described here. In this context, we examine a subset of tools and summarize the issues affecting best practices and industry standards in these domains. Design trends in the area of usability/accessibility and visualization, as well as scalability/extensibility, interoperability, and security features are addressed. While usability/accessibility generally encompasses overall ease of use of a tool for the end user, scalability involves the ease and cost-effectiveness of adding larger data sources or users. Visualization in this context encompasses the system's support for overlays from multiple modalities and/or support for multidimensional data. This feature depends on the system's levels of extensibility and interoperability, in terms of the seamlessness with which customized capabilities can be added to the system to enhance visualization or to support additional data formats that may be exchanged during input and output. Finally, built-in security mechanisms are relevant features to both fields, given recent federal legislation such as the Health Insurance Portability and Accountability Act [10], and the increasing use of these tools in cases involving public health preparedness, emergency management, and homeland security [11, 12].

The primary objectives of this chapter are to

1. Examine the relevance and significance of communication and imaging applications used by the informatics communities in medicine and public health;
2. Explain the features of a subset of public domain and commercial tools that contribute to improved patient safety, communication, or quality of care;
3. Provide recommendations for researchers considering porting academic research endeavors in these areas to the marketplace.

The remainder of this chapter is organized as follows. Sections 52.2 and 52.3 discuss current issues and emerging trends in imaging and communication tools for the medical and public health domains, respectively. While it is impossible to individually discuss every application currently on the market, we have tried to sample a subset of recent open source and proprietary tools in each domain, along with unique or unusual examples of emerging tools addressing particular niche problems (e.g., enterprise-wide integrations, planning for public health preparedness, etc.). Finally, Sections 52.4 and 52.5 provide a discussion and concluding recommendations for the imaging community.

52.2 Imaging and Communication in Medical Informatics

Historically, the evolution of marketplace medical informatics systems in the United States has been driven in part by government-based initiatives and calls to action. The Institute of Medicine (IOM) in its revised 1997 report, *The Computer-Based Patient Record: An Essential Technology for Health Care,* advocated built-in and flexible communication protocols in emerging electronic record systems, to include protocols to support physician to patient, physician to non-text-based content (e.g., imaging data), and physician to physician interaction [13]. Predicting the emerging overlap with public health applications that would require tracking of subgroups, the report similarly urged built-in population management tools. The envisioned tool suite thus included disease management guidelines and care plans, query-based system databases, and clinical research support [14].

Noting the tens of thousands of Americans that die each year due to errors in their care, the IOM's 2000 and 2001 reports, *To Err Is Human: Building a Safer Health System* and *Crossing the Quality Chasm: A New Health System for the 21st Century,* emphasized the need to translate knowledge into practice [15, 16]. The emphasis in these reports was for the health care industry to directly and significantly use information technology to improve quality of care and administrative and clinical processes. Health care organizations recognize that poor decisions affecting patient safety are often the result of missing or incomplete information, and as such, many hospitals have independently explored ways to link computerized decision-support programs to computer-based patient records to study and address factors that impact quality of care [17, 18]. The built-in communication mechanisms within these specialized tools and the increasing need to support multimodal data in the form of varied imaging sources within a patient's historical record have led to an explosion of products with features that change as rapidly as hardware vendors can supply new technologies. For a good review of traditional medical image processing and analysis software that has attempted to address the need to support multidimensional and multimodal data, see [19]. In this chapter, we explore a subset of applications in the area of electronic health records and additionally examine them in the context of enterprise-wide integrations.

An "electronic medical record" (EMR) is simply information regarding a patient's health status and health care, stored electronically. Alternately, the term "electronic health record" (EHR) is used to refer to an EMR with connections to lab systems, radiology, picture archive communication systems (PACS), and possibly regional health information organizations (RHIOs). Inexpensive electronic health record options for small physician practices can be purchased for under $3000, with additional charges for support, maintenance, and add-on capabilities. The options available in this price range target the workflow of small clinical practices and deemphasize features such as expandability (e.g., scalability for a greater number of users), granularity (e.g., security for different user roles), and customization or cross-specialty functionality (e.g., extensibility or built-in support for varied input/output formats from different user roles). These options also target basic and enhanced communication features (e.g., e-prescribing functionality that allows physicians to directly communicate to a patient's pharmacy of choice) and visualization capabilities that support multiple imaging modalities. The latter includes support for digital X-rays, optical character recognition for notes and lab reports, etc. (20]. Imaging capabilities in inexpensive systems may involve single-page JPEG files but are increasingly allowing multiple pages. In addition, communication support includes basic reminders in inexpensive systems to enhanced features that allow tracking physicians' orders from initial record to final result or features that allow pieces of the record (including images) to be attached for different user communications.

In the following sections we examine the features of several commercial and public domain EHR systems in the context of understanding the current industry capabilities in the area of system integration of communication protocols and imaging formats. Of note is that the overall integration across the health care industry is still in its infancy, but several hospitals are making significant contributions in their bid for "most-wired" status. The speed of progress across the field has been fueled in part by the establishment of industry-wide communication protocols, such as the Digital Imaging and Communications in Medicine (DICOM) standard initiated in the mid-1980s for communication in medical imaging (including storing, transmitting, and printing) and the Health Level Seven (HL7) standard for exchanging and creating interoperable electronic health records. While specific hospitals, sometimes with custom-designed in-house systems, have made excellent strides in integration, the industry as a whole is approaching newer levels of integration due to the proliferation of vendors developing products to address these evolving standards.

52.2.1 Open Source Product: VistA

Released in October 2005, the open source and free VistA outpatient electronic health record and health information system was developed by the U.S. Department of Veterans Affairs [21]. It is currently used at institutions in the United States, Mexico, Nigeria, Finland, Germany, and Egypt, with an expanding usage base. WorldVistA, a nonprofit corporation in the United States, serves as the worldwide advocate for the collaborative improvement of the VistA system. Notable features of the system cited in the *VistA Monograph 2005-2006* include the following [22]:

- Communication features include built-in comprehensive clinical reminders.
- Sophisticated imaging features include multimodal image display options from specialties including cardiology, pulmonary and gastrointestinal medicine, pathology, radiology, hematology, and nuclear medicine (allowing simultaneous viewing of electrocardiogram, endoscopy, chest X-ray, and MRI images).
- It processes textual reports from the hospital information system, including scanned documents and images acquired from digital cameras.
- Imaging quality using diagnostic display software (called V*IST*ARad) allows filmless interpretation of radiology studies, with a full range of image display and manipulation features for radiology (and nuclear medicine images).
- Electronic patient records support complete studies from DICOM-compliant modalities (CT, MRI, digital X-ray, ultrasound, etc).
- Specialized display tools are provided for CT, MRI, and angiography exams, including cine viewing, series linking, and series synchronization.
- Multiple exams can be displayed concurrently, allowing for comparisons with prior studies.
- Additional DICOM-compliant support for ophthalmology, dental, endoscopy, pathology, cardiology, and other specialties is under development.

52.2.2 Commercial Products

As stated previously, the adoption and widespread use of DICOM and HL7 standards have fueled the development of a myriad of electronic health record systems for small- and large-scale practices. A complete review of these systems is beyond the scope of this chapter, but various vendors provide ratings at their sites, derived from electronically published surveys by various health informatics-related organizations. As a sampling, SOAPware® is an inexpensive electronic health record designed for small practices [23]. This system is implemented in Microsoft Access and SQL, with a remote hosting option available. Interoperability features in the communication domain include integration with voice recognition systems and automatic charting of vital sign data. Add-on imaging functionality includes optical character recognition for document management, customized graphing, and additional document management for patient data in the form of text, video, audio, and PDF.

Alternately, vendors such as Allscripts™ are building electronic health record systems for both small- to mid-sized practices with fewer than 25 physicians to large medical groups [24]. In addition, this vendor is a leader in physician communication tool development with its Allscripts™ eRx NOW product, a separate electronic prescribing program that is web-based and accessible by computers, handheld devices, and cell phones. The program includes automatic population of Drug Enforcement Agency prescription history for the provider, real-time notification of insurance formulary status, and real-time connectivity with pharmacies for orders and refills. Finally, more imaging-based capabilities are expected to evolve from vendors such as General Electric Medical Systems, with its Centricity® Physician Office EMR in its efforts to build a more full-featured (and therefore expensive) electronic health record system [25]. This vendor (and others in this category) benefit from multiyear histories of developing DICOM-compliant imaging-based solutions and PACS for various specialties including digital mammography, cardiology, and molecular imaging.

52.2.3 Enterprise-wide Integrations

The integration of the DICOM standards by both PACS and EHR vendors is continuing to break down the proprietary barriers that previously hindered the deployment of image-enabled EHR systems [26]. In addition, web-based distribution of PACS-based data is creating new opportunities for such enhanced systems. For example, Johns Hopkins Hospital, Baltimore, was successful in 2004 in deploying an image-enabled EHR prior to full PACS implementation [27]. The hospital's EHR system is entirely home-grown and supports images derived from ultrasound, general radiology, MRI and CT, as well as nuclear medicine. In addition, its system deploys all full-resolution images at the request of clinicians concerned over lossy compression. Indiana Heart Hospital, opened in 2002, is another notable player in this arena as the world's first all-digital hospital, completing all charting, order entry, monitoring, and documentation electronically since opening day [28].

52.3 Imaging and Communication in Public Health Informatics

As one can see in Figure 52.1, while medical practitioners help to diagnose and treat diseases, public health officials are tasked with mapping out and assessing the distribution of diseases, as well as biological or environmental risk factors. In the domain of public health informatics, increasing attention has been paid to integration issues as syndromic surveillance has become a permanent part of homeland security planning. While surveillance has traditionally been associated with detecting changes or trends in population health by analyzing nontraditional data, syndromic surveillance refers to the collection and analysis of any data (not necessarily just syndrome-related data) that may indicate a potential event of public health concern has occurred (29, 30]. Events include early warning signs of any biologic terrorism, as well as possible resurgence of virulent forms of infectious diseases [30, 31].

For a summary of vendors developing applications utilizing surveillance of electronic health record data with other disease-related data sources to support public health planning and intervention in this area, see [32]. One of the early players in this area was the Electronic Surveillance System for the Early Notification of Community Based Epidemics (ESSENCE) system, launched in 1999 by the Walter Reed Army Institute of Research, with support from the Department of Defense's Global Emerging Infections {33]. ESSENCE works by capturing data on military ambulatory visits and prescription medications and merging them with civilian emergency department data, along with additional data sources such as school-absenteeism, prescription and nonprescription medication sales, health department requests for influenza testing, etc. Comparing generated graphs to calibrated historical data determines the relevance of alerts issued to health care professionals for further investigation. Applications of this system include the Montgomery County (Maryland) Department of Health and Human Services for its use in county hospital accreditation. This use encompassed characteristics such as using ESSENCE to respond to mass casualties resulting from terrorism, identifying foodborne outbreaks, providing general knowledge of the county's health status, and other uses such as managing an influenza-vaccination program [30].

Software solutions that contain features to support syndromic surveillance as a utility for detecting outbreaks associated with bioterrorism (e.g., abilities to capture, store, analyze, and archive health-indicator data to identify abnormal health conditions) are consequently in high demand across the nation. Additionally, the U.S. government remains an active player in seeking additional and standardized solutions. For example, the

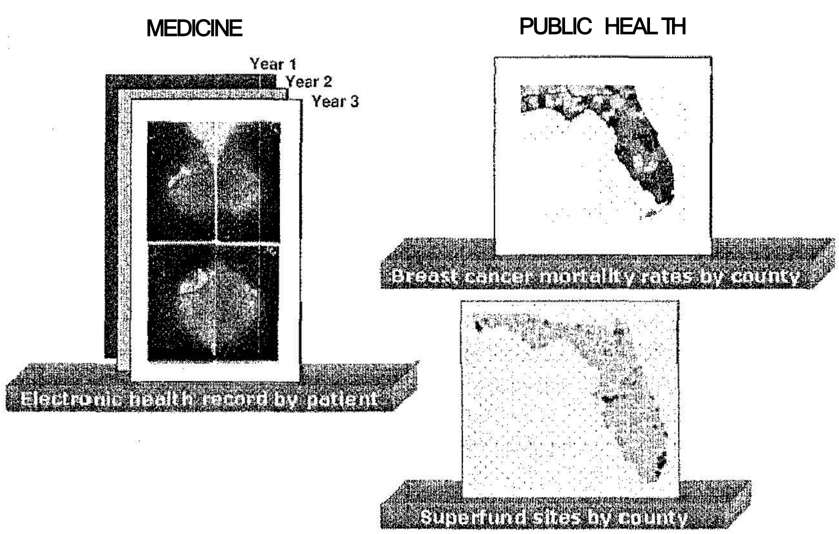

FIGURE52.1 Vvhile images in electronic health records are used in medicine to diagnose and treat diseases, GJS-based images are used by public health officials tasked with mapping out and assessing the distribution of diseases as well as biological or environmental risk factors.

U.S. Centers for Disease Control and Prevention (CDC) investigated communication and data standardization issues in its 1988 report, "Guidelines for Evaluating Surveillance Systems" [34]. In its "Updated Guidelines for Evaluating Public Health Surveillance Systems" in 2001 [35], top priorities included evaluation criteria in the areas of interoperability and scalability. This report emphasized the need for the establishment of data standards to ensure integration of surveillance and health information systems, ease of electronic exchange of health data, and increased ability to incorporate emerging public health threats (e.g., new diseases).

In 2003, the CDC commissioned a 3-year evaluation study on best practices and industry standards in web-based data dissemination systems [36]. It is not surprising to note that themes of interoperability, scalability, usability, and accessibility are emphasized as primary considerations. In the public health domain, interoperability issues include ability to integrate with other public domain or commercially available graphical information systems and statistical packages. In addition, this domain is rich with existing (and varied) datasets from other government (e.g., Medicaid) and non-government-based sources (e.g., hospitalization data), so interoperability priorities also encompass support for similarly rich capabilities for dataset importing [7]. Scalability concerns address the ability of the systems to handle new program-specific or disease-registry driven sources. As is the case in medical informatics-based applications, queries based on International Classification of Diseases (ICD) codes are *also* emphasized in public health toolsets.

Like the field of medical informatics, tool design and development in public health informatics advances at the rate governed by the adoption and widespread use of data standards, including the Open Database Connectivity (ODBC) standard, an application programming interface (API) standard for accessing databases, and Open Geospatial Consortium's (OGC) standards for developing interoperable geospatial technologies and tools. In the following sections we examine visualization and communication applications employed in public health, with an emphasis on those employing basic to advanced imaging capabilities and supporting ODBC and OGC compliancy. We additionally examine several case studies providing a window into current application venues of both national and international concern.

52.3.1 GIS in Public Health Syndromic Surveillance and Applied Spatial Epidemiology

Visualization in the public health arena has evolved under the domain of "geographic information systems" (GIS). As defined by the World Health Organization, a geographic information system is "a computer-aided database management and mapping technology that organizes and stores large amounts of multi-purpose information" [37]. We can trace GIS-based problem solving to the days of John Snow in his mapping of the cholera cases in London in the mid-1800s [38]. Snow used the map of the Soho neighborhood of London to plot all the cases of cholera relative to the household's source of water, as shown in Figure 52.2. Current uses of automated public health surveillance systems for the early detection of naturally or bioterrorism-related outbreaks aim to reduce the time between when an outbreak starts and when it is detected, to allow additional time for investigation and intervention for disease control [39]. \Nhile the uses of GIS in public health and medicine are endless, they fall within these general areas [7, 37, 38]:

- Determining the geographic distribution of diseases;
- Analyzing data for spatial and temporal trends;
- Mapping populations at risk;
- Stratifying risk factors;
- Assessing resource allocation;
- Planning and targeting interventions;
- Monitoring diseases and interventions over time.

As noted by Maguire *et al.* [40], the multitude of software types on the market for GIS, spatial analysis, and modeling is driven by the served interest groups of these toolsets (in their case, advanced researchers, professional analysts, and end users). In the follmving sections we examine the three most commonly used toolsets in public health and evaluate the effectiveness of communication and imaging capabilities in the context of features that support usability/accessibility, enhanced visualization, scalability, extensibility, interoperability, and security.

52.3.1.1 Public Domain Software: Epi Info™

Vendor Information Visit http://www.cdc.gov/epiinfo for additional information on pricing, versions, and add-on packages [41].

Minimum Requirements Epi Info™ has the following hardware and software system requirements:

- Hardware: 200 MHz processor for non-XP machines; 300 MHz processor for Windows XP; 32 MBytes RAM for Windows 98 or ME; 64 MBytes RAM for Windows NT 4.0, 2000, or XP; 260 MBytes disk space for install; 130 MBytes disk space for post-install.
- Software: Windows 98, ME, NT 4.0, 2000, or XP.

Overview and Notable Feature(s) Epi Info™ is a public domain software package developed by the CDC for public health practitioners and researchers and is available for free download [41]. In 2000, the program was enhanced with a mapping program called Epi Map. The software supports database construction and analysis with epidemiologic statistics, maps, and graphs. This toolset addresses usability/accessibility issues with simplified commands for programming options. The

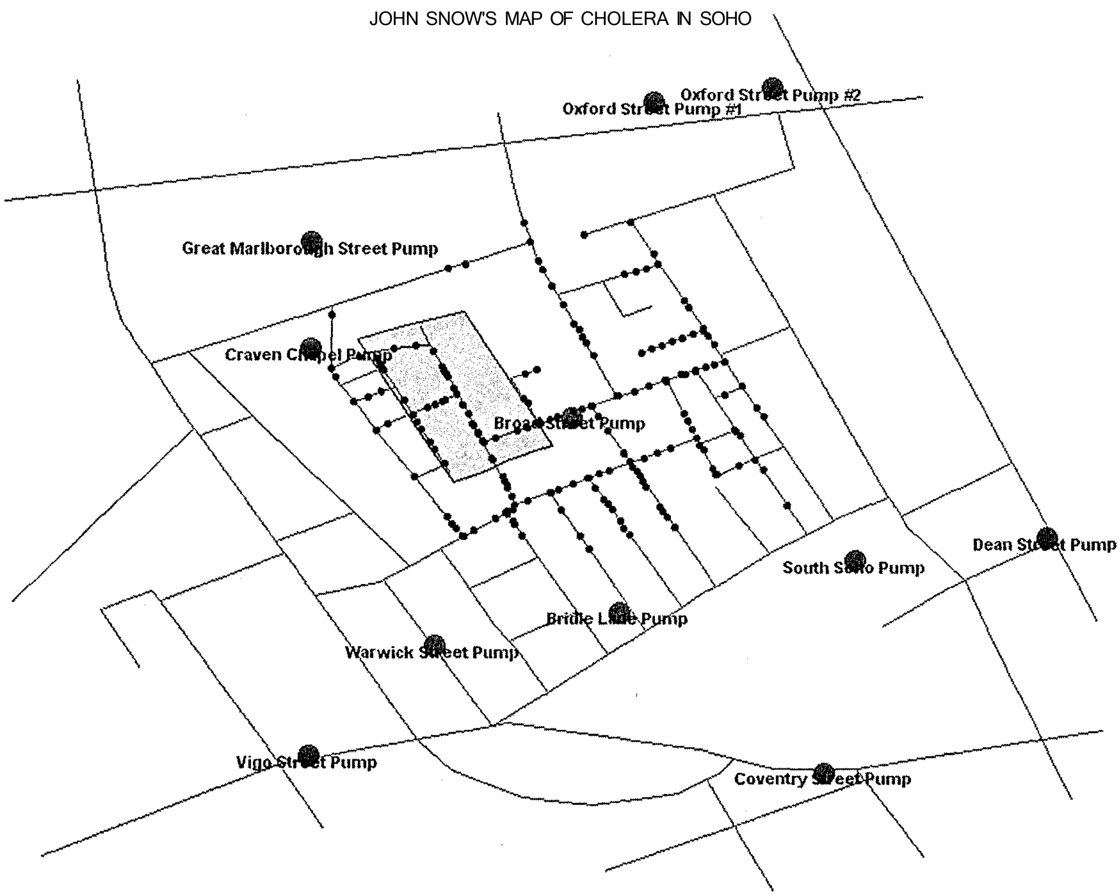

FIGURE 52.2 Map based on CDC's Epi Info data. Source: Mbizo, based on the CDC's Epi Map 2000 program settings.

manuals and programs have been translated into 13 languages, and according to the website listed at the beginning of this section, in 2003, there were one million downloads of this software from over 180 countries. Visualization capabilities include the Epi Map feature that allows the creation of GIS maps, and the software additionally supports overlaying survey data on GIS maps.

In terms of scalability and extensibility, Epi Info™ supports Microsoft Access and other SQL and ODBC databases, as well as Visual Basic. It allows customized forms for questionnaires or data entry and also allows customized modules to be connected. Interoperability includes the Epi Report feature that combines analysis data with data in Microsoft Access or SQL, as well as other file types. In addition, Epi Map is also ArcView® -compatible (i.e., with software described in Section 52.3.1.3). Security features include Epi Lock, which implements password protection, encrypting, and compression of Epi-Info™ data. Specifically, notable features of Version 3.3.2 of Epi-Info™ that relate to imaging and communication in public health include:

- Support maximum compatibility with industry standards, including Microsoft Access and other SQL and ODBC databases; Visual Basic, Version 6; World Wide Web browsers and HTML.
- Support extensibility, allowing organizations outside CDC to produce and integrate additional modules.
- Designed with Epi Map as an ArcView® -compatible GIS.
- Interoperable with NutStat, a nutrition anthropometry program that calculates percentiles and z-scores using either the 2000 CDC or the 1978 CDC/WHO growth reference.
- Support logistic regression and Kaplan-Meier survival analysis. Additionally, Data Compare feature does double data entry comparison.
- Support password protection, encryption, and compression of Epi-Info, Version 3.3.2 data.

52.3.1.2 Commercial Product: Maptitude®

Vendor Information Visit http://www.caliper.com for additional information on pricing and current version status [42].

Minimum Requirements Maptitude® has the following hardware and software system requirements:

- Hardware: DVD-ROM, 32 MBytes RAM, 161 MBytes disk space for program files; 2.0 GBytes disk space for basic geographic data; 3.0 GBytes to install all geographic data (instead of accessing data from the DVD).
- Software: Windows 2000 or XP.

Overview and Notable Feature(s) Maptitude® is a geographic information system created for the Windows environment that is also useful for mapping solutions for public health. In health services research, Maptitude® is especially suited to addressing visualization techniques to promote understanding of distributions of resources, such as health professional shortage areas or medically underserved populations or areas. Maptitude®, like many GIS software packages, has the capability to overlay maps with multiple layers to assist in the visual understanding of barriers communities face in accessing needed health care resources. For example, data layers showing such barriers as highways, railroads, and travel time from residences to the point of care can be enabled. Additional notable features of Version 4.8 of Maptitude® that relate to imaging and communication in public health include:

- Support map data from dBASE files and text files directly or data from any ODBC-compliant data source (e.g., Access, Btrieve, DB2, INFORMIX, INGRES, Interbase, NetWare, SQLBase, SQL Server, Sybase, etc.).
- Support import of geographic data from other desktop mapping, GIS, and CAD packages (e.g., ARC/INFO, Defense Mapping VPF & ITD, Intergraph DGN, ArcView, Digital Line Graph, Mapinfo MIF/MID, Atlas GIS, ETAK MapBase, Ordnance Survey NTF, AutoCAD DXF, Excel, and TIGER/Line).
- Integrate a built-in interface to global positioning system (GPS) devices, allowing tracking and recording of location information.
- Bands/areas of influence features: Allows creation of bands or areas of influence around map features for functions such as determining accessibility to facilities and estimating areas that are under- or overserved.
- Surface analysis feature: Allows analysis and display of surfaces in 2D or 3D. Creation of contour maps of elevations provides viewshed information that can be used for evacuation-specific planning, such as developing alternate protocols for weak service areas around a transmission tower. This feature also allows creation of surfaces that represent measures of air pollution or other chemical agents.
- Density grids feature: Allows visualization of point data by transforming the points into a regular grid that can be weighted. For example, this feature could be used for analysis of the pattern of victims around a hazardous site by weighting victim data with a measure for severity of symptoms.
- Adjacency Tools feature: Allows identification of the neighbors of an area of interest and creation of bands of adjacent neighbors. This feature can be used for planning evacuations or tracking disease outbreaks.

52.3.1.3 Commercial Product: ArcView® GIS

Vendor Information Visit http://www.esri.com for additional information on pricing and version options [43].

Minimum Requirements Minimum hardware and software system requirements for ArcView® GIS are based on the product version and platform configuration the user has installed on his or her system, as follows:

- Hardware: 1 GHz processor; PC-Intel (ArcView®)/Intel Pentium or Intel Xeon Processors (ArcEditor)/Intel Pentium or Intel Xeon Processors (Arclnfo); 512 MBytes RAM (1 GByte recommended for ArcEditor and Arclnfo);
- Software: Windows 2000, XP, and NT 4; Microsoft Internet Explorer Version 6.0 or higher (for ArcEditor and Arclnfo)

Overview and Notable Feature(s) ArcView® GIS is a commercially available software application package for desktop mapping and GIS-based data integration and analysis developed by the Economic and Social Research Institute (ESRI). Visualization is implemented with web-integration features that allow information to be overlaid. Scalability and extensibility-based features allow importing of personal geodatabases stored in Microsoft Access, as well as live web-server-based data sources. These visualization techniques provide display of live map feeds, which can then be used to enable other features, (e.g., map routing).

Interoperability issues have been addressed extensively by this software. ArcView® GIS supports integration with various enterprise databases, including SQL Server, Informix, Oracle, Oracle Spatial, and DB2. The system allows interfacing with servers supporting OpenGIS® specifications, such as web map service (WMS), web feature service (WFS), and geography markup language (GML) standards. Additionally, ArcWeb Services allows interfacing to subscription-based services that can be accessed on demand (e.g., overlaying current meteorological data). Security-based functionality includes coding of restrictions and logging for users with assigned privileges and roles. Specific notable features of the software products that comprise ArcView® GIS to create, edit, import, map, query, analyze, and publish geographic information include [43]:

- *ArcInfo:* Provides tools for data integration and management, visualization, spatial modeling and analysis, and high-end cartography. Supports single-user and multiuser editing and automates complex workflows. Supports spatial analysis for geographic relationships and tools for publication-quality maps.
- *ArcEditor:* Provides advanced editing, data validation, and workflow management tools to maintain data integrity. Supports sophisticated spatial analysis and simultaneous multiuser data access.
- *Arcview:* Allows users to visualize, explore, and analyze geographic data, revealing underlying patterns, relationships, and trends with tools to create maps, manage data, and perform spatial analysis.
- *ArcReader:* Integrated as a free viewer for maps authored using the other ArcGIS Desktop products with support to explore, query, view, and print all maps and data types created using ESRI software.
- *ArcGIS Desktop Extensions:* Allows users to perform tasks such as raster geoprocessing, three-dimensional visualization, and geostatistical analysis.

52.3.2 Current Challenges in Public Health Informatics: Case Studies

In the areas of infectious or communicable diseases, GIS is critical in several ways, such as mapping out the scope of the disease, identifying clusters of diseases, and ecological analysis. However, even with the software packages discussed previously, there remains a need for better interoperability and visualization solutions for effective communication between existing tools. Targeted prevention programs would also benefit from the application of traditional pattern recognition techniques to public health data on vectors and the environment to provide additional means for discerning patterns linking risks to human populations. In the next sections we examine several case studies to consider the limitations of current approaches and the need for new directions. This will help to set the stage for how computer scientists, health care organizations, and public health officials can work together to address problems with regional and global public health impacts.

52.3.2.1 Extensively Drug Resistant Tuberculosis (XDR-TB) and AIDS/HIV

Tuberculosis continues to plague communities throughout the world. During the 1990s, multidrug-resistant (MDR) tuberculosis (TB), defined as resistant to at least isoniazid and rifampin (first-line antituberculous medications), emerged as a threat to TB control, both in the United States and worldwide [44]. In the spring of 2005, a study conducted at a rural hospital in KwaZulu-Natal, a province of South Africa, revealed the presence not only of multidrug-resistant (MDR) tuberculosis, but also what came to be called extensively drug-resistant (XDR) tuberculosis [45, 46]. Cases of extensively drug-resistant tuberculosis have since been reported in the United States, given the increased population migration from developing nations to the United States, coupled with efficient air travel.

Prevention of tuberculosis is insufficient and impossible once drug-resistant tuberculosis strains have spread [45]. As a result, vigilant surveillance systems such as ESSENCE and the World Health Organization's Global Outbreak Alert and Response Network (GOARN) are part of the solution. The Global Outbreak Alert and Response Network is one global network of more than 130 partners working together to address public health problems by integrating data from multiple jurisdictions and responding in a coordinated manner [47]. GOARN has also pushed for standards to international epidemic response and operational protocols to standardize epidemiological, laboratory, clinical management, research, logistics support, security, evacuation, and communications systems. However, more work is needed to spatially link all confirmed cases of XDR-TB within a global monitoring system so public health officials can monitor the movement of cases and create surveillance buffers.

When public health planning for XDR-TB in the United States is considered, ESSENCE integrated with geographic information system applications such as those described previously can provide the information needed to track cases and their contacts while monitoring secondary cases and implementing control measures. However, to be effective, the surveillance has to be linked to rapidly changing drug-susceptibility data to ensure a quick diagnosis, adequate treatment, and disruption of the transmission of the disease [45]. Further, because drug-resistant TB has higher rates of treatment failure and longer periods of infectiousness in part due to the time lapse between TB diagnosis and obtaining drug-sensitivity test results [48], surveillance and visualization tools to monitor the quarantine status of cases are also needed. In a pilot study, Dwolatzky *et al.* [49] investigated the feasibility of using a global positioning system (GPS) receiver linked to handheld computing technology (such as personal digital assistants or PDAs) to enhance the tracing of patients within a TB control program. Global positioning technology has also been investigated with cell phones used to facilitate the tracking of HIV/AIDS patients in underserved populations for emergency alerts, as a means to send text message reminders regarding medications and to track drug stock levels [50].

52.3.2.2 Malaria and Lyme Disease

Malaria is a mosquito-borne disease of global concern with 1.5 to 2.7 million people dying each year and many more suffering from it [51]. According to the World Health Organization [52], of those who contract malaria, over 80% of the deaths annually will occur in Africa. Malaria has become the leading cause of death in Africa and will remain so for sometime. In the United States, malaria is a reportable disease to local and state health departments and the Centers for Disease Control and Prevention through the National Malaria Surveillance System (NMSS).

Lyme disease, caused by the tick-borne spirochete *Borrelia burgdorferi,* is the most common vectorborne disease in the United States [53-55]. According to the CDC, in 2002, the number of reported cases of Lyme disease increased 40% to 23,763 cases, yielding a national incidence of 8.2 cases per 100,000 [56]. Surveillance for Lyme disease started in the early 1980s, and by 1991 it was designated as a nationally reportable disease by the Council of State and Territorial epidemiologists [54].

The key to addressing these and other vectorborne diseases is real-time visualization techniques using both GIS and remote sensing technologies [53, 57]. For example, in a number of studies in Africa, GIS has been used to generate models of malaria occurrence [58] and to map out vector habitats [59, 60]. Effective surveillance of Lyme disease has similarly involved an understanding of the need to include spatial analysis and visualization of suitable habitats [53, 55]. With this disease, GIS provides an effective tool for mapping out habitats and other climatic conditions such as humidity and temperatures where the vector reproduces. For example, Kitron and Mannelli [61] used a geographic information system to map distributions of human Lyme disease cases, ticks, and degree of vegetation cover in Wisconsin to help focus public health prevention efforts on those identified areas that provide a suitable environment and conditions for the vector. Guerra *et al.* [62] used a geographic information system to study the distribution of *I. scapularis* in the upper Midwest based on data from Wisconsin, northern Illinois, and the Upper Peninsula of Michigan. This analysis was then used to explain the environmental factors that facilitate or inhibit the establishment of *I. scapularis.*

These two case studies in particular demonstrate the vast capabilities of geographic information applications, spatial analysis tools, and remote sensing technologies in the study, prevention, and control of vectorborne diseases. The ability to create buffer zones and map out areas where the vector propagates allows public health professionals to destroy the habitat for the vector, thereby breaking the life cycle of the vector and reducing the risk of contact with humans.

52.3.2.3 Cancer

Finally, cancer is one disease that is also well suited for spatial analysis, well-designed visualization tools, and new innovations in image-based analysis. Cancer is the second leading cause of death in the United States, affecting over half a million people annually, second only to heart diseases. Cancer rates also vary by state and region of the country. For example, for several decades, compared to other parts of the country, higher breast cancer rates were observed in the northeastern United States [55]. Increasingly, place has become an important factor in cancer studies because of geographic differences in environmental exposures, cultural attitudes towards risky behaviors and preventive health care, local public health policies, availability of services by socioeconomic level, and means by which residents obtain health information [63].

The National Institutes of Health recognized the impact imaging and GIS will play in this field in the establishment of its core group of scientists working on GIS [64]. The specific aims of this group's mandate are to deploy GIS technologies in order to:

- Identify and display the geographic patterns of cancer incidence and mortality rates in the United States and their change over time;
- Create complex databases for the study of cancer screening, diagnosis, and survival at the community level;
- Conduct environmental exposure assessment through satellite imagery;
- Generate spatial statistical models for estimating cancer incidence, prevalence, and survival for every U.S. state;
- Communicate local cancer information to the public and public health professionals through interactive web-based tools;
- Identify health disparities at the local level through the comparison of cancer outcomes across demographic subgroups; and
- Develop new methods of displaying geospatial data for clear communication to the public and for examination of complex multivariate data by researchers.

Using new interoperable GIS systems and image-based tools to integrate data from multiple sources, researchers and practitioners will be able to map areas with the highest prevalence of risk factors for the disease and then tailor prevention, early screening efforts, and even specialized drug or treatment clinical trials to the identified areas.

52.3.3 Enterprise-wide Integrations

In an effort to deliver geospatial information and functionality throughout an enterprise, organizations are also choosing to extend their traditional desktop GIS implementations with innovative server-based GIS solutions that provide content and capabilities via web services. There are a number of advantages to these approaches, including [55]:

- Lower cost of software ownership and increased return on investments through single, focused GIS applications (such as web applications) that scale to support many users;
- Integration of GIS functionality with other enterprise systems in an effort to better manage resources and assets;
- Enhanced workflows with geospatial capabilities to offer greater insights into information, increased efficiency, and improved accuracy;

- Creation and deployment of centrally managed GIS applications and services to support cross-departmental and enterprise requirements.

The ability to provide data over the Internet, however, poses some challenges. The challenges posed by GIS technology range from data availability and completeness (i.e., data quality), to the availability of a trained workforce [55]. When data completeness cannot be guaranteed, it raises questions about the validity and reliability of the results of GIS analysis, further stressing the need for the national data standards mentioned previously.

52.4 Discussion

The Office of the National Coordinator for Health Information Technology's 2004 vision for consumer-centric and information-rich care is becoming a reality [65]. This is demonstrated by the different types of informatics-based systems in use in medical and public health domains currently, and by the suite of web-based, patient-accessible portals to electronic medical information currently on the market, or proposed to have a marketplace presence this decade. As indicated in the IOM report from 1997, interdisciplinary teams in both medicine and public health must continue to recognize that patient electronic records will continue to evolve in resources outside direct patient care, in areas such as studying "the effectiveness and efficiency of clinical processes, procedures, and technologies" (13]. While quality-based assessments and concerns for patient safety are part of the driving forces behind these changes, the implied long-term implications for savings in administrative, labor, and pharmacy costs are simply too great for health care organizations or government agencies to ignore [66].

Data standards are continuing to evolve and will continue to drive the evolution of products. The demand for EHRs, like GIS systems, to increasingly communicate in real time to live (and varied) information resource sites will continue to rise, including interoperability with voice-input, voice-recognition systems, text-processing and image-processing systems. In the public health domain, visualization encompassing dynamic modeling of multidimensional data will continue to improve [40J and may lead to innovation in mainstream EHR systems to incorporate visualization capabilities for more complex patient historical data (e.g., visualization of time sequences of stored data, such as digital mammograms).

52.5 Conclusion and Future Trends

The broader impacts of this chapter include a call to action for the imaging community to consider additional avenues for technology transfer to the fields of medicine and public health. We should expect to see additional real-time linking capabilities in both EHR- and GIS-based systems, and our academic data should be readily available at our host sites, using accepted data standards (e.g., standards described by HL7, DICOM, OBDC, OGC, etc.), when such data can be used to significantly impact patient safety, patient communication, or overall quality of care of individuals or populations. The Internet-availability of data from our research is indispensable to other scientists and administrators charged with developing patient-centric solutions and cost-effective management strategies. Even when organizations are slow to adopt these systems, patients will increasingly seek out data portals for their own personal recordkeeping.

In 2004, the Public Health Data Standards Consortium similarly issued a call to action for the public health community to become more broadly involved in "(1) ...the national effort to standardize clinical and public health data and systems and (2) to describe public health perspectives on the EHR." As the health care industry becomes more patient-centric, EHR systems will continue to integrate more point-of-care-based services to improve patient communication and realize greater time (and therefore cost) savings [17].

In addition, as GIS-based decision making expands into additional applications in medicine and public health related to homeland security, visualization of data uncertainty will become an expected component of these systems [40]. The imaging community should respond accordingly and similarly set high standards for accurately providing data in standard formats, with related details regarding any measurement uncertainty. Researchers in academia need also to consider a richer vision of data accessibility, with considerations for how data might be incorporated into portals utilized by patients who are handicapped or seriously ill [68, 69].

Just as importantly, we need to consider the development and integration of academic research into mobile and wireless solutions in the domains of medicine and public health, as studies have shown that mobile computing technologies can increase use of clinical practice guidelines and decision support tools [70]. GIS technology has long been valued for enhancing communication and collaboration in decision making. The case studies examined in public health in this chapter thus underscore the practical applications and opportunity for spatial analysis, visualization, and mobile solutions to be part of systems designed for integration of data from different sources [71]. Databases are often effective for understanding biological risk factors, but visualization tools and imaging are invaluable for deriving insight into the role of environmental factors in disease causation. Since John Snow generated his map of the cholera cases in the London outbreak of the mid-1800s, spatial display or analysis of disease distribution has been a key feature of public health research and will continue to evolve in this manner. This is particularly relevant now, given continued emerging threats such as multiple drug resistant tuberculosis, and ongoing diseases of great public health concern such as AIDS/HIV, malaria, Lyme disease, and cancer.

Finally, remote web-based access to a host picture archive communication system (PACS) has been implemented in many specialties, most notably radiology [72]. With the implementation of successful security protocols, the convenience of data warehousing associated with EHR systems (especially those that are available with application service provider hosting) will also allow clinical researchers to increasingly use web portals to conduct collaborative clinical research from diffuse geographic locations [73]. This should additionally drive new innovations in all fields that benefit from medical imaging.

52.6 References

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