Envisioning a Future for a Spatial-Health CyberGIS Marketplace

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ABSTRACT

In this position paper, we describe a vision for the future of a so-called "Spatial-Health CyberGIS Marketplace". We first situate this proposed new computing ecosystem within the set of currently-available enabling technologies and techniques. We next provide a detailed vision of the capabilities and features of an ecosystem that will benefit individuals, industries, and government agencies. We conclude with a set of research challenges, both technological & societal, which must be overcome in order for such a vision to be fully realized.

Categories and Subject Descriptors

C.0 [**Computer Systems Organization**]: General – *Systems specification methodologies.* H.1.2 [**Information Systems**]: User/Machine Systems – *Human information processing*. H.2.8 [**Information Systems**]: Database Applications – *Spatial databases and GIS.* H.3.4 [**Information Systems**]: Systems and Software – *Distributed systems*

General Terms

Algorithms, Measurement, Performance, Design, Reliability, Security, Human Factors, Standardization, Legal Aspects.

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Data Integration; Environmental Monitoring; Health Interventions; Individual Health; HealthGIS; Online Analytics; Public Health; Sensors; Streaming Data.

1. Introduction

The complementary and rapid advances in Cyber-Enabled Geographic Information Systems (CyberGIS) [1] and individual & environmental sensor technologies have the potential to revolutionize the way in which people, governments, and industry deliver and consume health care services and data in the goal of promoting wellness in society. In this position paper, we describe a vision for the future of a so-called "Spatial-Health CyberGIS Marketplace" (Spatial Health Marketplace) which would be composed of an interconnected set of actors (individuals, industries, and agencies), sensors, services, and data that would enable spatio-temporal analysis, visualization and modeling capabilities to enhance the efficacy of personal and public health activities and initiatives.

The remainder of this paper is organized as follows. We first situate our proposed new computing services ecosystem within the set of currently-available enabling technologies and techniques. We next provide a detailed vision of the capabilities and features such an ecosystem would provide. This is followed with a set of application domain examples which illustrate how these new technologies and techniques could be used to benefit individuals, industries, and government agencies. We conclude with a set of research challenges, both technological and societal, which must be overcome in order for such a vision to be fully realized.

2. Vision

The vision of the Spatial-Health CyberGIS Marketplace (Spatial Health Marketplace) is to develop and deploy an integrated ecosystem of sensors, software, hardware, and spatio-temporal analysis, visualization and processing services to provide a platform for the secure and confidential exchange and utilization of personal and environmental health data.

This platform will empower individuals to take control of their levels of physical activity, personal health exposome [2], and exposure to health threats. To accomplish this goal, a first step is to establish a framework of standards and security measures that enable health services to be targeted to the context of an individual and made relevant to individual choices. Once in place, this platform will be leveraged by individuals, industries, and government agencies who want to promote wellness and healthy lifestyle choices.

2.1 Enabling Technologies and Techniques

Technological challenges that may have been barriers to the vision described a decade ago are quickly being broken down.

2.1.1 Personal Sensors

Sensors capable of monitoring, recording, and transmitting real-time data about personal activity levels are now integrated and available in nearly every mobile phone. Data collected by an individual about his/her surrounding environment, physical activity, and perception of the world around him/her have been a reality since the introduction of the first sensor-enabled smart phones over a decade ago [3]. The pervasive reach of cellular networks and the penetration of these devices into the modern consumer marketplace in most developed countries represent individual and public health opportunities unparalleled at any prior point in history. Moreover, the success of location-based services such as the social networking sites Foursquare[1] and Yelp[2] has proven that smart phone users are comfortable with providing location data to online services when they receive benefits from their participation [4].

2.1.2 Environmental Sensors & the Smart City

Environmental sensors of all kinds now pervade the daily lives of individuals worldwide. Traffic cameras and loop sensors embedded in transit networks monitor traffic and provide real-time data for adaptive traffic modeling and routing. Air monitoring stations distributed in rural and urban locations provide air quality information that is for decision making about the healthfulness of being outdoors. External and internal sensors combined with dedicated phones/tablets and sensing applications (apps) turn phones and tablets into stations for remote environmental monitoring [5]. The "Smart City" has gone from concept to implementation in many regions of the world, providing citizens with direct information and feedback about their interaction with the city and vice versa [6].

2.1.3 Electronic Health & Medical Records

Electronic health and medical records were created as a remedy to a cost-inefficient and error-prone health industry. These systems are being implemented with incentives for meaningful use [7]. When linked with personal health records (PHR), citizens have direct access to and ownership of medical information about themselves. A future is at hand where these data become the personal property of the individual and as such could be amended and utilized as deemed necessary and beneficial to the individual [8].

2.1.4 The Connected World

Networks that suppoer 802.11 (wifi) and various cellular data standards are now commonplace in most urban areas throughout the globe. These facts have spawned a new phenomenon – that internet traffic via hand-held and portable devices are projected to overtake internet traffic via wired desktop computers [9]. Portable sensing devices, such as the cell phone in the majority of the developed world's pocket are quickly becoming the platform of choice for developers looking to capitalize on the most prominent and pervasive data collection and consumption endpoint.

2.1.5 The Big Data World

Coincident with the explosion of mobile devices is the rapid expansion of data streaming from these devices. Upon installation of a mobile application (app), it is now more commonplace for a user to be prompted to authorize the app to "use your location" than it is not to be. Millions of cell phone users readily allow their location data and other information about themselves to be transmitted to these application service providers in exchange for services. These users produce massive data streams that must be aggregated, processed, stored, and queried in order for these services to hold up their end of the bargain [10].

2.1.6 Analysis and Visualization of Streaming Data

Streaming data is nothing new in the computing world. Partial queries and best-available results have been in use for some time in the online-querying database community [11]. However, it was not until recently that the public at large has had personalized sensor data available about and to themselves. FitBit[3] and other consumer grade health and fitness devices come with data extraction and visualizations. Consumers of these technologies have become adept in analytics and expect to see minute-by-minute charts and graphs of energy expenditures as well as correlations with other personal data such as sleep, exercise, and dietary data.

2.2 A Framework for Smart Health

We propose a framework for this new industry where individuals choose to participate, have access to and are in control of rich spatio-temporal data that capture their life course. These data would include their activity patterns, the environmental conditions in which they live, work, and recreate, and biometric patterns that characterize their level of healthiness. These data would have to be controlled by the individual, and once that is established, could be useful in a variety of ways. They could be integrated with personal health records, environmental sensors, and anonymized data from other individuals. They could be provided to government agencies, commercial organizations, and/or health researchers to understand one's health in new ways and enable personalized decision-making to promote sustained wellness.

At its fundamental level, this system will be composed of networked individual and environmental sensors linked in real-time to personal health and administrative records. Individuals can

[1] https://foursquare.com/

[2] http://www.yelp.com/

[3] http://www.fitbit.com

choose to share these data with their doctors and health coaches for better prevention, diagnosis, and treatment of disease.

Public health agencies can use anonymized versions of these data in aggregate to understand built-environment drivers that encourage healthy behaviors and promote wellness. Individuals can use aggregate data as benchmarks to understand how well their health, behavior, and activity compares to others.

Commercial organizations can utilize these data to build applications that incentivize activities that lead to healthy lifestyles through real-time, personalized commercial health-related service delivery.

Health science researchers could use this previously unimaginable volume and specificity of data to further refine models of health and wellness at both the individual and population scales.

2.3 A Brave New Health Service Ecosystem

We envision that a Spatial Health ecosystem will lead to an industry that will foster innovation across the full spectrum of devices, software and algorithms. These goals will require security and data integration as well as national and international standardization and collaboration. These advances would benefit the full spectrum of actors – from the individual who seeks to better his or her own health; to the academic researcher seeking to develop and test more effective interventions; to the public health agency seeking to plan and execute better health-policy decisions; to the health management organization looking to incentivize members to lead more active, healthy lifestyles. Below we illustrate one use-case for each:

Individual Health – Lifestyle Comparative Assessment & Forecasting

Individuals may often have a difficult time judging the healthfulness of one's own life. "Am I better/worse/average than others who are just like me"? "If I'm worse, how much worse, what are the consequences given the data that has been gathered, and how will my outcome change if I take a specific action"? We envision that participants of a Spatial Health Marketplace could, as the most basic step, quickly and intuitively compare themselves to their peers in order to determine if their lifestyle will lead to a better or worse health outcome. The framework proposed herein would provide a secure, confidential way for a user to participate in a system where an individual submits lifestyle data in return for comparative health analyses as well as forecasts of health consequences due to current behavior.

Health Research – Targeted Interventions

Ecological momentary assessments (EMAs) – qualitative and quantitative assessments of individual health, happiness, context, etc. taken *in situ* – have been in use as a health data collection instrument for decades. In recent years, smart phones have become the platform of choice for operationalizing this form of data collection. The future of mobile computing brings targeted intervention strategies based on social, physical, behavioral, and/or emotional context. Using the sensor data streaming from a smart phone, researchers can "listen" in real-time for signals predictive of specific health behaviors and alerts with preemptive interventions.

Public Health – Planning and Service Provision

Given a large enough market penetration, public health practitioners and policy-makers should be able to gather enough data from participants in a Spatial Health Marketplace to understand use of public spaces. For example, using GPS & accelerometer data from a large population, city planners might begin to understand which physical activity spaces are under- and over-utilized. When activity data is combined with qualitative survey data, this will provide more insight as to which areas are used and why people prefer them.

Industry – From Illness to Wellness

In the US, leading health management organizations (HMOs) have long ago realized that it is cheaper to maintain wellness than it is to treat illness. As such, some of these organizations have begun promoting wellness-maintenance programs such as diet, physical activity, and proactive mental health counseling. We envision that a Spatial Health Marketplace will provide the software, hardware, data, and processing capabilities to enhance and extend these initiatives already underway. Similar to the discounts on car insurance which cautious drivers in the US receive (measured by a GPS installed in one's vehicle by a car insurance company), we envision health service benefits being delivered to Health Spatial Marketplace participants who already lead or make strides toward a more healthful lifestyle.

3. Research Challenges & Opportunities

Successfully implementing a Health Spatial Marketplace ecosystem of devices, data, and services to facilitate the capabilities described herein would require fundamental international research and collaboration on a number of fronts. The fields which would need to participate include Computer Science and Engineering, Health Informatics, Geographic Information Science, Electrical Engineering, and the Social Sciences.

To name just a few of the areas of potential innovation: Confidentiality and privacy to ensure one's data cannot be stolen, faked, or otherwise abused; Sensors miniaturization and battery-life extensions; Real-time analytical method development; Real-time fusion of heterogeneous multi-modal data sources; Design of visualization techniques to make a full lifetime of rich spatio-temporal data understandable and usable by individuals and their doctors; Extension of health intervention strategies to make use of streaming real-time data that trigger context-specific recommendations.

Also needed are the integration frameworks that will form the backbone for collecting, fusing, storing, and making massive individual-level data understandable and usable for individuals, agencies, and the commercial sector. The development of a prototype end-to-end ecosystem architecture will lead to the creation of algorithms and visualization capabilities for informed individual-level decision-making, state-based health observations, outreach, and intervention, and commercially-based health-promotion programs and applications. The fundamental research needed in each of the aforementioned areas will extend the current state-of-the-art across numerous scientific disciplines, leading to a foundational ecosystem of data, standards, and devices that will permit sustained innovation in an entirely new industry well beyond the scope of this initial project.

The following list comprises the most pressing challenges that must be overcome in order to realize such our vision for a Health Spatial Marketplace.

- **Goal 1:** Development, refinement, and miniaturization of personal- and environmental-level sensors. Sensing

of pollutants and pathogens will be distinct challenges within this goal.

- **Goal 2:** Development of international data standards and ontologies for the storage and transmission of health-linked sensor data.
- **Goal 3:** Development of hardware and software to enable the secure data exchange of individual-level sensor data linked with electronic health records.
- **Goal 4:** Development of confidentiality- and privacy-preserving algorithms to facilitate the secure integration and aggregation of population sensor data.
- **Goal 5:** Development of real-time classification algorithms to recognize short- and long-term health/activity patterns.
- **Goal 6:** Development of methodologies to prompt individuals with personalized health-promotion strategies based on spatio-temporal health context.
- **Goal 7:** Development of real-time data integration frameworks to securely fuse and aggregate massive spatio-temporal personal exposures and activity data with environmental, commercial, and administrative data.
- **Goal 8:** Execution of demonstration studies that employ the Health Spatial ecosystem in the context of aging populations to monitor health and promote wellness.

4. Conclusions

This paper has described a vision for an end-to-end industry that supports individualized data collection and its use in both public and individual health. The primary outcome of such an initiative would be the creation of a software/hardware ecosystem that permits the real-time integration of personal-level activity and environmental sensor data with personal health records for use in a new wellness promotion industry focused on the promotion of individual wellness. Accomplishing this ambitious goal would require the development of sensor technologies, data standards, and software and hardware infrastructures.

Despite the technological and societal challenges that stand in the way of its development (and we realize there are many), such a software, data, and service infrastructure would encompass a complete and personalized health management and maintenance framework that has the potential to motivate and sustain healthier longer-living populations.

End-users would participate in the platform (i.e., submit anonymized) voluntarily and frequently by being sufficiently motivated by the individual benefits they receive; Industries would spring up to consume these data and provide commercial services that individuals found worthwhile; Public health organizations would utilize these data to better serve the general public though improved health service provision and planning; and health science researchers could utilize the platform to test and assess the effectiveness of novel intervention strategies.

The challenges that stand affront our initiative are not unique to us. Privacy & confidentiality are paramount to all health applications; partial queries and real-time data analytics & visualization are vital to any time-sensitive or mission-critical application; multi-modal, variable quality sensor data integration is critical to any platform attempting to make sense of heterogeneous data sources; the quality, reliability, and truthfulness of crowd-sourced data is an issue in any large-scale data collection & analysis project utilizing citizens as sensors [12].

We propose a research agenda focused on the design, implementation & testing of algorithms, systems, and techniques to tackle core fundamental issues in each of these domains such that the overall sum of a Health Spatial Marketplace is greater than any of the individual parts.

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