



Improving Healthcare with Interactive Visualization

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Visualization and visual analytics researchers can contribute substantial technological advances to support the reliable, effective, safe, and validated systems required for personal health, clinical healthcare, and public health policymaking.

Evolving health informatics systems promise to revolutionize health and healthcare programs worldwide. However, turning this hope-filled vision into a reality will take enormous effort from thousands of designers, analysts, software engineers, usability specialists, and medical professionals.

While there are many challenges to overcome, the focus here is on the central role of information visualization and visual analytics processes.^{1,2} These disciplines offer algorithms, interactive designs, and analytic processes that support exploration, monitoring, insight discovery, professional collaboration, and comprehensible presentations to patients, clinicians, policymakers, and the general public. A 2011 report from the US Institute of

Medicine focused on improving patient safety through “cross-disciplinary research” on “user-centered design and human factors applied to health IT.”³ The report sharply noted that “information visualization is not as advanced in parts of clinical medicine as compared with other scientific disciplines.”

STATE OF THE ART

Over much of the past century, medical imagery initially based on x-rays, and then later on technologies such as CT scans and MRI, transformed medical care by providing accurate 3D volume visualizations that highlight problem areas. Other successes include visualization-supported surgical planning, telesurgery, pharmaceutical drug discovery, chem-informatics, and genomic expression analyses. In addition, information visualization amplifies the benefits of health informatics databases and networks by dramatically expanding the capacity of patients, clinicians, and public health policymakers to make better decisions.⁴

Health 2.0, a term that suggests contemporary strategies that are Web-based, participatory, and mobile, provides a useful framework for analyzing health informatics technologies.⁵ These strategies employ social media, personal sensors, and mobile devices, as well as big data

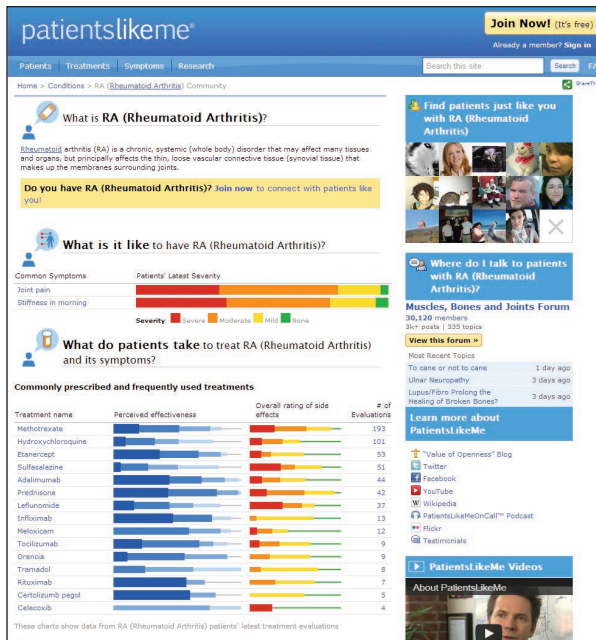


Figure 2. A PatientsLikeMe report on rheumatoid arthritis based on contributions from more than 3,000 participants.

their evolving health to assess their treatment plans or to understand their struggles to adhere to diet or exercise plans.

As devices improve and designers come to understand motivational structures and persuasive strategies, more patients can successfully monitor their diabetes, control obesity, or stop smoking. Applying social media through mobile applications enriches the possibilities for engaging users to understand the common practices of people like them.

As Figure 2 shows, the experience with sharing encouraging success stories such as those posted on the PatientsLikeMe website (www.patientslikeme.com/conditions/52-ra) suggests that fresh approaches can be transformative. The site initially focused on a small number of chronic diseases, but it has expanded to cover more than 1,000 conditions. Instead of the usual privacy policy, PatientsLikeMe has an openness philosophy that encourages members to report in great detail on their treatments and side effects.

Presenting visual patient histories that have sufficient detail, yet remain comprehensible to patients and physicians, remains a challenge. Developing strategies to find patients with a certain sequence of events, such as suffering a stroke, receiving a blood thinner, and then having severe headaches within 72 hours, requires advanced visual analytics tools to perform a search and display the results of exact matches and near misses.

Personal sensors are also gaining adherents among those devoted to the quantified-self movement (www.quantifiedself.com), who advocate detailed data collection



Figure 3. UbiFit Garden's glanceable display: (a) at the beginning of the week, (b) after one cardio workout, (c) a full garden with variety, and (d) a full garden on a mobile phone's background screen. Butterflies indicate met goals.

on topics such as health, exercise, and diet. Products such as Fitbit (www.fitbit.com) collect movement data, and the associated website shows retrospective temporal patterns, which help users change their behaviors. As Figure 3 shows, while some patients are satisfied with simple timelines, others prefer more playful metaphoric imagery with sound and animation.⁶

Clinical health information

Physician training continues to improve, but the vast knowledge of specialized conditions, numerous medications, and professional guidelines emerging from research make it very difficult for physicians to learn all they need to know. Further, the increasing amount of data recorded by patients, stored in EHRs, and captured from medical lab tests challenges the capacity of physicians to grasp an overview of the patient's history while seeing specific data values that alert them to potential problems. Designers who learn enough about medical decision making have the potential to enable clinicians to make more accurate and rapid decisions.

Designs for single-patient visual histories have been explored, but no widely accepted strategy has emerged.⁷ As the example shown in Figure 4 indicates, temporal histories with various forms of timelines are becoming common, as are body maps showing the location of previous and current conditions, surgeries, or injuries. Some innovative designs such as www.mscai.net present lab test results to steer user attention to abnormal readings

or to changes from previous tests, but there are no widely used or authoritatively validated practices for highlighting or comparative presentations. A longtime visualization success story is the use of growth charts to compare a child's trajectory with relevant populations (www.cdc.gov/mmwr/preview/mmwrhtml/rr5909a1.htm).

Organizations are under pressure to demonstrate adherence to clinical guidelines and must analyze their own performance data. For example, as Figure 5 shows, a large health organization might want to investigate patterns in readmission rates in patients with asthma for whom long-acting beta-agonist asthma medication is prescribed according to new guidelines. Interactive visualizations are beginning to help clinicians and patient safety managers query EHR databases to understand use patterns. They soon will be able to study medication adherence rates by examining prescription refill patterns or study switching rates and dose reductions after US Food and Drug Administration (FDA) warnings about drug interactions.

While clinical trials remain the workhorse of clinical research, there is now a shift toward the use of existing clinical data for discovery research, leading researchers to analyze large warehouses of patient histories (www.btrsi.nih.gov). Visualization can reveal data quality problems, which are common when repurposing clinical data for secondary analysis. Temporal patterns are critical to this research, and interactive visualizations are beginning to support powerful temporal queries, present rich result summaries, and offer fluid interactions to identify the clinically relevant temporal patterns hidden in the data.⁸ Visualizations also help clinicians identify cohorts of patients who match selection criteria for clinical trials (www.i2b2.org).

Public health information

The huge volume of information collected by the National Center for Health Statistics, the Centers for Disease Control and Prevention, the US Census Bureau, the US Department of Health and Human Services, the World Health Organization, and other agencies



Figure 4. The Wand Timeline view of a patient record in Allscripts' ambulatory EHR iPad application. Used with permission: Allscripts, www.allscripts.com.

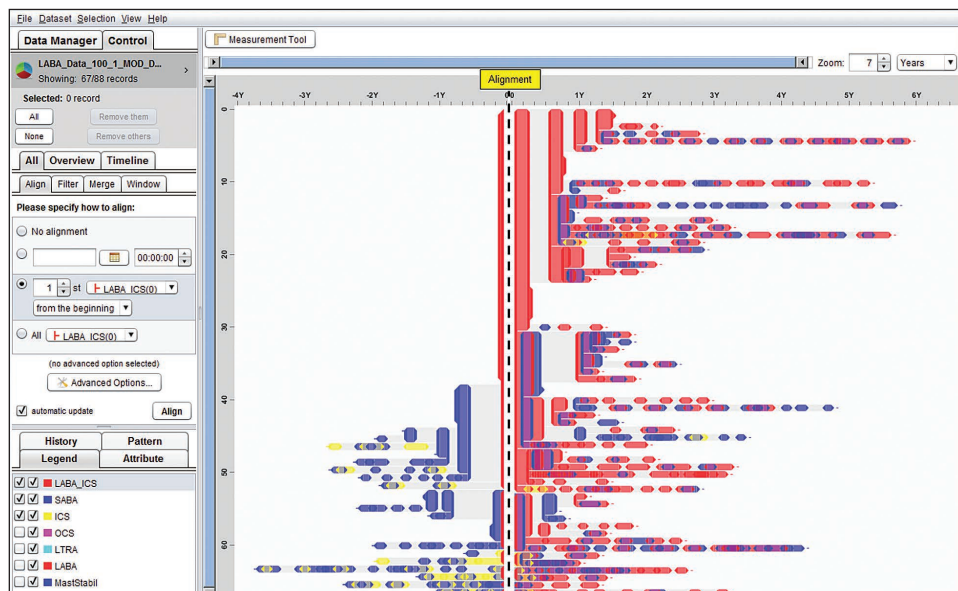


Figure 5. Exploring prescription patterns of three asthma drugs (LABA in red, SABA in blue, and ICS in yellow) for 100 patients in EventFlow (www.cs.umd.edu/hcil/eventflow). Visualization helped reveal that guidelines regarding the use of LABAs were not adequately followed. For example, when all records are aligned by the start of the first LABA (dotted vertical line), about one-half of the records have no drugs prior to the alignment point, which means that those patients did not receive the other less potent drugs prior to the start of the LABA. The figure also illustrates the chaotic nature of the temporal patterns and the need for better summaries that combine interval sequences based on similarity, as opposed to exact matches.



is available at websites such as www.healthdata.gov, www.data.medicare.gov, www.seer.cancer.gov, and www.data.euro.who.int to guide public policymaking.

However, exploring the datasets and correlating between them to derive insights remains a challenge. The data is inherently geospatial (ranging from individual households to entire states) and temporal (ranging from minutes to decades), increasing the difficulty of finding patterns, relationships, clusters, gaps, and outliers. In some cases, researchers have developed compelling ways to present outcomes that influence policymaking decisions. For example, the Maryland Environmental Public Health Tracking Network formed an online collaboratory to help public health researchers extract value from visualizations built through geographic information systems (<http://ideha.dhmd.maryland.gov/OEHFP/EH/tracking/SitePages/Home.aspx>) and to use that data for informing state and community policy.

Integrating reliable data from multiple sources and supporting complex temporal geospatial and multivariate data remains a challenge.

Improvements in multivariate data analysis tools are already facilitating the analysis of survey data,⁹ and in turn helping decision makers gauge populations' access to healthcare, identify eating habits to adjust nutrition guidelines, or take action to curb alarming trends such as the rapid increase in obesity.

Retrospective analysis of state and county health patterns is useful to both residents and public health policymakers. For example, the Community Health Map provides simplified access to health data that supports easy exploration and comprehensible presentations.¹⁰ Current visualizations integrate temporal pattern analyses to enable users to answer more complex questions such as which areas are moving in the right direction and which are not. More specific tasks include understanding the areas in which the most rapid progress is being made and why. Such tasks are easy to imagine, but integrating reliable data from multiple sources and supporting complex temporal geospatial and multivariate data remains a challenge.

Controlling the spread of infectious diseases or responding to biological attacks also offer opportunities for developing visual analytics solutions. Such solutions can help national or local health organizations rapidly query emergency room records to find patterns that might have been overlooked, track patients who might have been infected, or identify patients at risk who are in need of preventive treatment.

Improved syndromic surveillance includes the analysis of over-the-counter drug sales as well as the ebb and flow of social media discussion topics. Coupled with models of disease spread, visualizations can help decision makers predict the future course of an epidemic and evaluate strategies that can be applied to control the outbreak.¹¹

While temporal and geospatial data are already a strong component of health informatics, network data is becoming increasingly valuable in helping to understand disease epidemics and encourage the adoption of healthier lifestyles. In their book published in 2011, Nicholas A. Christakis and James H. Fowler launched a lively controversy about the power of social networks to spread health behaviors such as smoking versus smoking cessation or obesity versus healthy diets and exercise.¹² Their claims offer hope to those who believe that increasing use of social media could trigger the development of healthier lifestyles.

Social media is opening remarkable possibilities for health and healthcare researchers.¹³ For the first time in history, much of what we do is recorded online, and we now have the tools needed to capture, analyze, and visualize this data. As Figure 6 shows, the publicly available data from Twitter is especially interesting for public health analysts, who can use it to study how medical trends spread. Clustering algorithms can sort out the active discussion communities, and network analysis metrics such as betweenness or eigenvector centrality help to detect the key influencers for each medical topic.

TRENDS, OPPORTUNITIES, AND CHALLENGES

Over the past 10 years, directors at the National Institutes of Health have argued that to reduce costs while improving health and healthcare, medicine must move away from its Industrial Age roots in providing “one size fits all” therapies to become more predictive, preemptive, personalized, and participative over time (www.nih.gov/strategicvision.htm). Each of these attributes is an Information Age concept, and they depend on making advances in networking and information technology. Within this new 21st-century system, data will become the new currency. Understanding how to best visualize that data for each community of participants is central to improving healthcare.

Consider the case of cancer, which occurs when transcription errors from genetic code alter a cell's control mechanism in a way that spurs unregulated cellular growth. The good news is that clinicians can leverage advances in high-throughput computing, whole genome sequencing, and powerful genome browsers to identify specific transcription errors. Researchers predict that future healthcare professionals will take advantage of these same high-throughput computer technologies

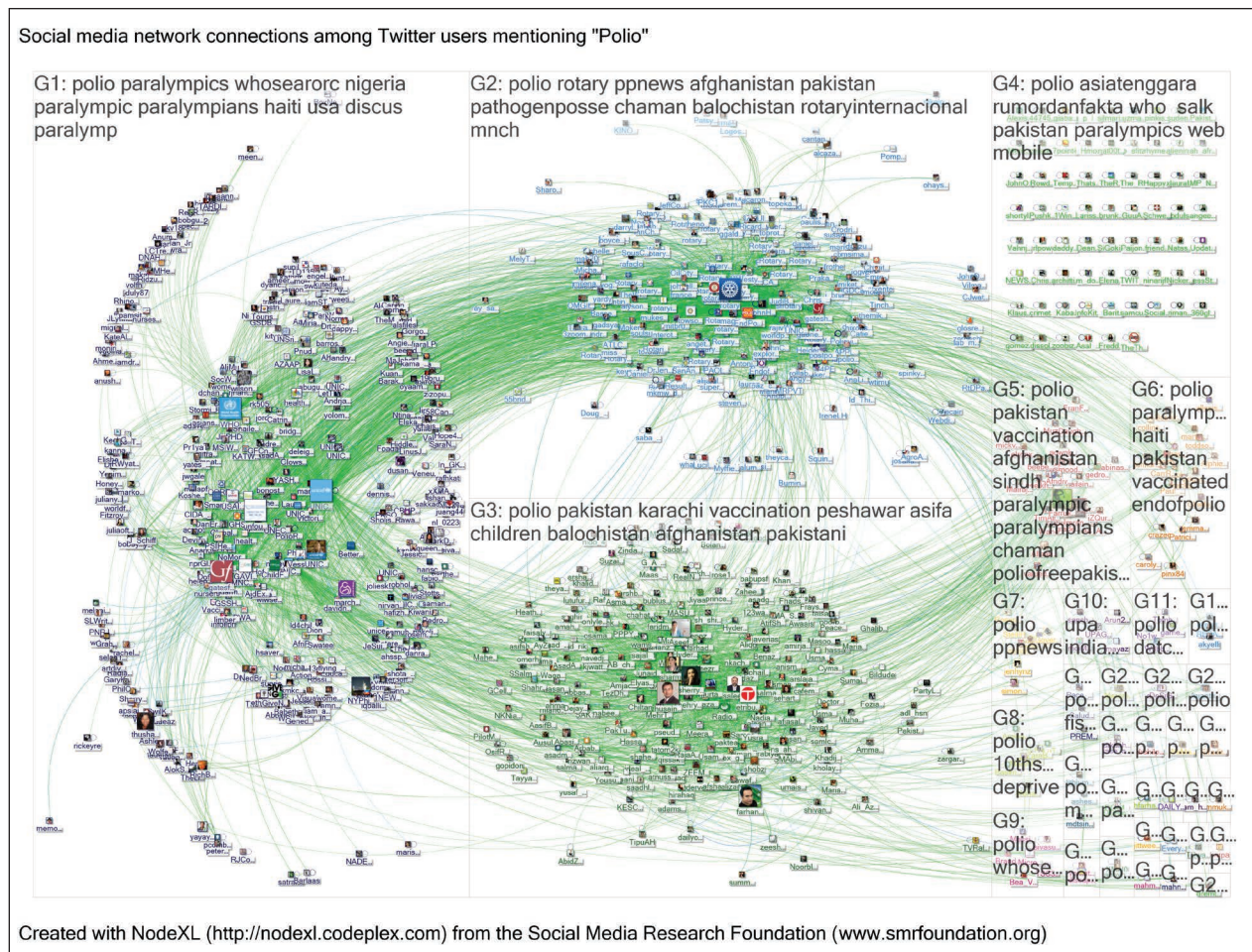


Figure 6. NodeXL (www.codeplex.com/nodexl) graph of tweets with the hashtag #polio. The links represent follower networks, which are then clustered to reveal regional interests in containing polio. Hub participants are dramatically more connected than other participants, suggesting a broadcast discussion pattern. Comparing this map to others reveals that polio lacks the pattern found in more controversial or polarizing topics, in which separate clusters have few if any interconnections. The small number of isolates shows a well-connected community. (Image courtesy of Marc Smith.)

to enhance the predictive accuracy of disease models, improve care, and accelerate basic discoveries. This is the essence of the “Learning Healthcare System” as described by the Institute of Medicine. In the IOM’s vision, health information technology will enable potent visual data analyses that can improve care, inform decision making, and accelerate discovery.

In November 2011, the American Society of Clinical Oncology described how a new visual-analytics-infused healthcare system might spur the development of a rapid learning system for cancer care. ASCO depicted an idealized system in which data collected during the healthcare process is stored and made available for the personal, clinical, and public health domains. Patients would gain access to the data to monitor their own conditions, review and implement treatment plans, gain social support, report symptoms, and communicate asynchronously with their care teams.

These challenges require research on sensors, mobile devices, social media, peak-load network performance, and privacy protection, as well as visualization. Clinicians would have access to the data as the foundation for developing their treatment plans, monitoring the progress of individual patients, meeting quality improvement goals, and ensuring that all of their patients are getting prompt, high-quality care. All of this data could then be cycled back into the public health research enterprise to improve the comparative effectiveness of therapies, enable population-wide studies, and generate new evidence. The palette of opportunities for bringing information visualization tools to the task of improving care and accelerating science in cancer and other disease areas is broad.

Based on our personal experience, we highlight seven practical challenges that should receive enhanced attention,



Challenge 1: Offering busy clinicians timely information in the right format

Summarizing large amounts of information into tailored overviews of patient histories remains a challenge. As the data is collected, visual analytics tools will be needed to help users quickly browse the general contours of health functions, look for anomalies, and then drill down to discover details and catch predictable risks early.

Visual workflow design and presentation tools can help clinicians adapt their EHR systems to their practices. For example, well-designed medical order-management displays can steer physicians' attention to late or lost results and help ensure timely follow-up even in busy environments. Improvements in data visualizations can also be critical in improving general clinical practice. Hospitals, healthcare organizations, and even individual practitioners will benefit from feedback on their own practices. Commercial systems that integrate visual dashboards of emergency room activity, staff workload, or equipment utilization will increase situational awareness, leading to more efficient use of resources.

Well-designed user interfaces with visual presentations for patients and their caregivers are improving the quality of life for patients of all ages.

Challenge 2: Moving toward an ecosystem of visual tools

As more signals are produced, the need to view the data in diverse forms will increase. The patient-centered medical home is a good example. This concept, which has been gaining popularity under the Affordable Care Act of 2010, provides patients with a primary care clinician to monitor general progress across all aspects of their care.

For the medical home to succeed, tools will be needed to help clinical professionals account for status across multiple conditions over time. Although family care doctors have traditionally provided medical care for patients at home, most estimates indicate that there will not be enough family care doctors to meet future needs. Paraprofessionals, such as physician assistants or family members, will likely take that role, but they will need easy-to-understand visual tools.

There are some indications that a new ecosystem of these visual tools is emerging as developers innovate at each point of access to the underlying medical data stream. For example, the Veterans Health Administration home care services combine personal health monitoring with telemedicine to dramatically reduce hospitalizations and recovery times (www.telehealth.va.gov). Well-designed user interfaces with visual presentations for patients

and their caregivers are improving the quality of life for patients of all ages.

Visualization might address the challenges of dealing with low-literacy populations and speakers of diverse languages. Conversion to multiple languages, use of small screens, and implementation on diverse platforms are further research challenges.

Challenge 3: Facilitating team decision making

A change triggered by the movement toward interoperable data systems is a shift from individual decision making to team decision making. While lessons learned from computer-supported cooperative work are relevant in this context, research is needed to apply those lessons to enhance situation awareness among multiple members of care teams. Such teams can include the primary care physician, specialty care physicians, nursing staff, laboratory technicians, nurse navigators, social workers, behavioral medicine specialists, the patient, and the patient's caregivers. Team-oriented medical decision making is also challenging because legal liability is involved, and all team members must signal their concurrence.

Challenge 4: Characterizing and understanding similarity

Visualization will be instrumental in helping clinicians solve difficult cases or deal with rare diseases. Further refinement in the visualization of structured and unstructured textual information will guide physicians searching for evidence to support treatment decisions in PubMed and other medical literature sources. Interfaces to query EHR databases can help find similar cases that have been encountered before. For example, clinicians might select sequences of problems and treatments they believe are most significant in a patient record, set similarity tolerances and narrow the search to a set of similar patients, and then study their treatments and outcomes or identify colleagues who treated those patients.

Challenge 5: Visualizing comparative relationships

Comparing cohorts of patients is a workhorse of health research. Visualizations will help characterize differences and facilitate comparative-effectiveness studies to enable researchers and patient safety managers to evaluate methods and treatments. In particular, the elusive goal of discovering cause-and-effect phenomena might be aided by combining appropriate statistical analysis and compact visual arrays summarizing the relationships between multiple events.

Challenge 6: Presenting risk and uncertainty

Analyzing complex data with uncertainty and incomplete entries is difficult enough for professionals,

as demonstrated in the VAST 2010 challenge on pandemic prediction (www.cs.umd.edu/hcil/vastchallenge), but presenting uncertain sources to personal health data users presents exceptional challenges. In addition, the presentation of risks of treatments, medications, or failure to act is a well-known problem in medical communications, for which interactive visualizations could be especially helpful.

Showing forecasts with uncertainty is accepted with weather data, but still novel with medical data. Research on designing persuasive visualization for patients who must decide about elective surgeries or be convinced to stop smoking would offer significant benefits. Adequate representation of uncertainty during pandemics is a related challenge for public health applications.

Challenge 7: Evaluation

Designers must validate and refine their prototypes by testing in realistic environments with troubled patients and overloaded clinicians. While errors with mobile device applications for entertainment or social engagement are easily reversed, errors in medical situations can prove deadly.

Some adventurous designers are taking on these challenges, but the medical context is especially difficult because of the life-critical nature of many decisions. Visual interface designers will need to learn a great deal more about health and healthcare. Ensuring quality treatment will require designs that provide evidence-based explanations on demand and interfaces that prevent errors.

Since poor visual designs could result in misunderstandings and ill-advised choices, simple usability testing is insufficient. Repeated testing in diverse environments and feedback mechanisms from every use can produce continuous improvement for these life-critical applications.

Medical visualizations are sometimes integrated into medical devices, thereby requiring FDA certification. Because the laws pertaining to EHR systems and personal medical monitoring are still unclear, guidelines for proper testing are still emerging.¹⁴ In addition, effective anonymization and de-identification algorithms are needed so that benchmark datasets can be made widely available for research and testing while protecting patient privacy.

Additional challenges

Health and healthcare applications also face many other general challenges, including the following:¹

- Ensuring thorough data preparation to cope with missing values, duplicated records, incorrect data entry, patient name entity resolution, and proper date-time stamps.

- Scaling visualization techniques to billions of records by filtering and dynamically forming aggregated values. This supports retrospective analyses by researchers who might seek to compare data across patients, physicians, hospitals, time periods, and geographic regions.
- Developing systematic yet flexible visual analytics processes that promote complete coverage while preserving the option of exploration in depth when novel insights are found. These reliable processes are necessary for repeating analyses as new datasets become available.
- Logging of complex sequences of visual analytics operations so users have audit trails of what they have done, allowing them to reapply these workflows to new datasets and share the workflows with clinical colleagues.
- Moving research prototypes into commercial systems—from beta to bedside. Some tools already exist but are applied unequally. Working more closely with the conservative and competitive health informatics industry will encourage more rapid adoption of innovation.

Clearly, much work remains to be done.

The rapid growth of information visualization, visual analytics, and health informatics already shows promising results, but their further integration could produce significant benefits in terms of improved personal health monitoring, clinician treatment decision making, and public health policy. These three Health 2.0 domains will inspire researchers for many decades to come, producing spinoffs that will be relevant for financial, economic, legal, and other application areas.

These research challenges are just the beginning. The remarkable wealth of possibilities for information visualization methods to substantially improve health and healthcare will trigger new conferences, journals, courses, and curricula, ultimately bringing profound changes to many professions.

Interactive visual presentations that allow drilling down to gain background information, show comparisons, and highlight anomalies will improve patients' understanding of their health and medical conditions. Developing these personal health visualizations requires considerable research and validation, especially for patients with visual impairments, but research on screen readers and sonification would respond to their needs.

Errors in clinical care remain a severe problem, but many could be avoided or detected by improved visual feedback to clinicians about patients, their medical conditions, and the treatment contexts. Improved EHRs



will apply visual techniques to reduce common errors of mistaken patient identification, mode mismatches, flawed interpretations, incorrect recall, or incomplete visibility of system states.

Public-health data analysts will benefit from more integrated systems that provide comprehensible access to diverse datasets, establish systematic yet flexible visual analytics workflows, and accepted formats for presenting results to policymakers and the general public.

The call for disciplinary excellence and public service is likely to attract many information visualization and visual analytics designers, implementers, and evaluators. These researchers face substantial challenges, but there are also grand opportunities for societal benefit. **C**

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