The Web has changed the way we live, work and socialize. The nodes in the current Web are documents and hence the current World Wide Web is a Document Web. Advances in technology and requirements of emerging applications require formation of a parallel and closely connected Web of events, the EventWeb, in which each node is an event. In this paper, we explore growth of EventWeb as a natural next step in the evolution of the Web with rich multimodal sensory information. Social networks use events extensively and have revolutionized communication among people. Mobile phones, equipped with myriads of sensors and being used by more than 75% of living humans, are bringing the next generation of social networks, not only to connect people with other people, but also to connect people with other people and essential life resources. We call these networks social life networks, and believe that this is the right time to focus efforts to discover and develop technology and infrastructure to design and build these networks and to apply them for solving some essential human problems.

1. Introduction

The Web started a major transformation in how we create, share, organize, access and use data, information and experiences. It also resulted in unprecedented growth in the volume of information in different media on the Web. Initially, the Web connected text documents. After browsers and search engines, the major revolutionary concept in Web technology was user-generated content, which further democratized creation and consumption of information by giving rise to wide sharing of personal information, opinions, photographs and videos. Popularized by online social networks, some of the most influential information-sharing systems rapidly influenced how people socialize and share their
information and experiences. Social networks connect people and increase interactions among them. By aggregating real-time information reported as micro-events and combining it with other information available on the Web, soon the next-generation networks, termed social life networks (SLNs), will evolve that will connect people to needed resources.

Not surprisingly, these systems also brought into focus many issues related to dealing with already enormous and still rapidly increasing data volumes. It became clear that techniques to associate semantics to data are essential not only to prospect and harvest large volumes of data, but also to make this data usable by unforeseen users and practitioners from disparate segments of society.

Two major reasons for the rise of social networks are their extensive sharing of live status updates (or microblogs) and their use of experiential media (such as photographs). Microblogs are micro-events reported by humans. Because time is one of the most important concepts for events, the increased use of status updates and microblogs brought real-time search to prominence. Although Twitter and Facebook have started emphasizing events in the form of tweets and status updates, they and many similar sites simply create a database of events, not a Web of events. The next major disruptive change in societal applications of the Web will be due to the creation of a Web of events, the EventWeb, which will synergistically interact with other existing and future webs.

Some reflections on current developments in the Web, both technical and social, show that this is really a natural part of human societal development. Human society is built on experimenting, gaining experiences and sharing them in creating and enhancing knowledge. What we see in the Web is really an extension of the continuing evolution of human society. In the following, first, I briefly discuss some historical perspectives, and then analyse some new developments to project where the Web may be going and how it could be steered for maximum benefit to the society.

2. Development of human communication

The ability to communicate effectively played a key role in the evolution of human civilization. Communication is essential not only for sharing experiences, but also for creating, maintaining, sustaining and propagating knowledge. Shared experiences connect people across space and time. Throughout human civilization, many influential inventions involved communicating experiences across space and time. Table 1 lists some major inventions that extended this sharing.

Before people had language, they were limited in their ability to share experiences. At first, language was just analogue sounds from vocal cords. Eventually, it became a symbolic structure based on those sounds. Languages evolved as humans standardized the sounds they could create. People soon realized that experiences were important and must be stored for sharing with others. They invented written languages as a system for representing sounds more permanently, letting them share experiences across time. Initial cumbersome techniques, such as inscribing stone tablets, gave way to more practical storage devices and writing methods. Next came the development of paper and ink, and more people began using stored experiences that others had painstakingly recorded. Experience sharing began to propagate rapidly with these innovations.

Then came one of the most influential inventions in our history—Gutenberg’s movable printing press. This invention enabled mass communication, for the first time, and revolutionized society. Our current education system, our reliance on documents (such as newspapers) as a major source of communication and the growth of libraries as public, government-supported institutions dedicated to storing knowledge all stem from that one invention that appeared more than 500 years ago. The influence of Gutenberg’s invention can be seen in all aspects of modern society.

The telegraph, which allowed instantaneous communication of symbolic information over long distances, began to bring the world closer. This invention initiated the notion of the global village. Telephones let us return to our natural communication medium—talking—while retaining all the advantages of instantaneous remote communication, even over long distances.
People could experience the emotions of the person on the other end of the connection—something symbol-based methods of writing and telegraph could only hint at.

Radio ushered in the wireless approach to sound and popularized sound as a medium for instantaneous mass communication. Television took communication another step further by appealing to our sense of sight as well as hearing. It was the first medium that let us experience with more than one of our senses, and as such, could more effectively key into our emotions. Video communication’s popularity is clearly due to its use of our two most powerful senses in harmony to communicate experiences.

Storage and distribution technologies, such as photography and magnetic tape, let people store, preserve and distribute experiences, again bringing us closer to natural experience. Video recording enhanced this experience significantly. Digital media further improved the quality of our experience.

The Internet took information availability to a new dimension, providing us with experiential accounts of an unprecedented variety. Finally, the invention of the World Wide Web (WWW) brought to us the most complete communication and sharing mechanism that human civilization has ever seen. Its impact has been immense and widespread. And it appears that what we have seen thus far is just the beginning of this new mechanism for communicating and sharing experiences that is finally challenging Gutenberg’s legacy.

### 3. Evolution of electronic computing

Electronic computing has been around for only about six decades. However, the changes in the computing landscape have been overwhelming. Just a few decades ago, a computing centre was one of the most important buildings on a university or corporate campus. Access to this building, particularly to the holy rooms in which the computer functioned, was highly restricted. A computer occupied several rooms, if not floors, of a building, needed air conditioning and required a trained staff to interact with it and run users’ programs on it. Early computers cost millions of dollars. Progress in processing, storage, networking and software technology has changed computing beyond anyone’s expectations. Now, many people carry multiple computers, each of which is more powerful and sophisticated than the computers of only a few decades ago, yet costs several thousandths of what the older version did and can be carried in a pocket, regardless of the climatic conditions. Moreover, just about anyone can operate today’s computers, using them to solve their everyday computing and communications needs. Equally important, however, is the fundamental change in the nature of computing.
Table 2. Evolutionary stages in computing.

<table>
<thead>
<tr>
<th>feature</th>
<th>stage 1: data</th>
<th>stage 2: information</th>
<th>stage 3: experiences</th>
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<tbody>
<tr>
<td>input</td>
<td>data</td>
<td>documents</td>
<td>multi-modal data</td>
</tr>
<tr>
<td>output</td>
<td>computational results</td>
<td>information and communication</td>
<td>experience sharing</td>
</tr>
<tr>
<td>processing</td>
<td>computations</td>
<td>information extraction</td>
<td>experience processing</td>
</tr>
<tr>
<td>driving devices</td>
<td>mainframe, workstations</td>
<td>personal computers, Internet</td>
<td>mobile phones</td>
</tr>
<tr>
<td>applications</td>
<td>computing</td>
<td>information and communication</td>
<td>insights and enjoyment</td>
</tr>
<tr>
<td>user level</td>
<td>trained</td>
<td>general population in the developed world</td>
<td>all humans</td>
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<td>interaction environment</td>
<td>specialized languages</td>
<td>graphical user interface</td>
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4. Disruptive innovations in computing

Computing has already gone through two major evolutionary stages. The first stage dealt with data and focused on computing; the second dealt with information and communication, using alphanumeric information in documents. Computing is now on the verge of a third stage that is based on experience sharing. Although the first two were revolutionary, the third stage will affect the most long-term fundamental changes in how computing influences human civilization.

Table 2 shows the basic features and characteristics of the three stages of this evolution. In addition to the nature of input and output, major changes are in the nature of applications and user expectations. Also, each phase builds on the advances made in the previous phase, and so subsumes and even enhances the previous phase’s functionality.

(a) Data and computation

The first major event in computing was the invention of electronic computers. These computers processed data millions of times faster than humans could. The ability to program computers opened avenues for many, previously unimaginable, applications. The focus in this initial evolutionary phase was scientific and engineering computations. Soon, the business community and other organizations realized the potential of computing with alphanumeric data. This extended computing to businesses and large organizations. Early mainframe computers and workstations represented this style of computation. The terms ‘computer’ and ‘computing’ are the legacy of this phase.

(b) Information and communication technology

The second major evolutionary stage brought personal computers, including laptops, and the Internet. In this phase, the emphasis shifted from data to information and communication technology (ICT). The rise of personal computers and what-you-see-is-what-you-get word-processing and spreadsheet programs brought computing from trained computer operators to the general population in the developed world. The Internet and WWW accelerated the ICT revolution. By networking computers to form a global pervasive network, users could connect alphanumeric data sources, including documents, and communicate data and information. The ICT revolution brought unimaginable applications and affected human life in most developed and developing parts of the world.

(c) Insights and experiences

The easy availability of multi-modal sensory data and devices that can capture, render, store and process this data is propelling the third major evolutionary stage. This phase is bringing insights
and experience to the forefront in the same way that the second phase brought information and communication. Insights refer to a human’s perception of the true nature of things made possible when he or she understands the relationships among a thing’s components. Insights support deeper analysis and problem solving. We need insights to make decisions, and information to implement these decisions. Insights are closely correlated to experiences. Merriam-Webster’s dictionary defines experience as the ‘active participation in events or activities leading to the accumulation of knowledge’ or skill or as knowledge or wisdom gained from what one has observed, encountered or undergone.

People experience events and activities, using their senses: sight, sound, touch, smell and taste. These observations constitute experience of the event resulting in insights related to the event and objects in the event. In the digital world, approaches that use sensing technology convert sight, sound and touch to electronic form and then, after processing, convert it back to sensory data for human perception. Smell and taste remain relatively difficult to capture, convert to digital form, and then convert back to the original senses for presenting to humans. It is common, however, to experience the sights and sounds of remote events, and touch is finding increasing use. People experience the world around them and create knowledge about their environment mainly through sight and sound. Thus, we can naturally extend digital experience to these dominant human senses.

This third stage is about experiencing events, saving experiences, gaining insights and knowledge from these experiences, and sharing these insights and experiences with others. It is no wonder that the last few years have seen the emergence of technologies that provide environments in which users can share experiences through photographs, videos and multimedia. Progress made in this stage could lead to revolutionary approaches for expanding access to the more than 80 per cent of the Earth’s population that has remained relatively untouched by computing.

## 5. Towards EventWeb

The Web has revolutionized many aspects of human society in just over a decade. However, in the current Web, each node is usually a document connected to other document nodes, using manually created referential links. Of course, the nature of documents has been going through many transformations, and hence on the Web today, a document might have photographs or videos embedded in it. But, the fundamental nature of the Web remains centred on a page of a document.

The Internet of things is an emerging field that is seeing strong activity [1](http://en.wikipedia.org/wiki/internet_of_things). This work is also related to creating a network of sensors. It is not uncommon for sensors to be connected to the Web, with the data from the sensors available on a website. Such efforts, however, still consider the purpose of the Web to be to make data in cyberspace available on the Web. They consider cyberspace to be different from the physical space. In other words, cyberspace is the space of digital data that is made available on the Internet. Such data are mostly created or captured by humans.

Inspired by the effectiveness of communication and sharing enabled by the Web for content in cyberspace, attention naturally focused on what is commonly called cyberphysical space [1]. Although the definition of cyberphysical space is far from universally accepted, researchers generally agree on the need to develop an interface between the cyberspace, characterized by the Internet and the Web, and the physical world.

Most events take place in the real world (i.e. the non-cyberworld). However, an event must be represented in the cyberworld to make it amenable to all the benefits that modern computing technology provides. We developed a six-faceted model [2](http://www.merriam-webster.com/dictionary/experience) to represent an event for bridging the cyber and physical worlds. To connect the physical world to the cyberspace, the first step is to use sensors to capture real-time data about the physical world. The sensors connect the cyber and physical worlds.
Each sensor is designed to capture only one particular aspect of the physical world. A sensor might be collecting data continuously about its domain, but it gets attention only when a specified event takes place. In many cases, multiple sensors must collaborate in making a decision about an event in the physical world. One of the most impressive examples of detecting physical world events using multiple sensors is human beings: we use five senses appropriately and opportunistically to detect events and act accordingly.

Another important aspect of the physical world is that in many applications, events must be detected and used as they occur. In these applications, real-time detection and use of events is essential to take action with minimal latency. The popularity of microblogs and status updates, which are a form of microblogs, has made social networking a common platform for sharing information with family members, friends and other people of interest. Most microblogs are directly related to events reported by people. In fact, all of these microblogs are creating a huge database of events.

The WWW compellingly demonstrated that a Web of documents is enormously more useful than a database of documents. Based on that experience, a Web of events will clearly provide at least as significant an advantage. In fact, the Web of events or EventWeb is more natural and effective because events are more closely related to each other than are documents. Spatio-temporal relationships among physical events result in significant propagation of their effects and hence are essential in modelling many important concepts and phenomena. Based on these ideas, my research group has been exploring the development of concepts and techniques related to EventWeb.

In EventWeb, each node (event) is represented by its basic properties (time, location and type), informational attributes (participants and characteristics of the event) and experiential attributes (text or audio reports, photographs, videos and other sensory information). In Jain [3], we discussed the structural and causal relationships among the events that create the EventWeb. Events in this Web could be as diverse as an application demands and at the desired granularity. EventWeb is fundamentally a dynamic Web structure that is linked to physical locations and uses familiar natural sensory characteristics. It uses text when needed. EventWeb will link to the current Web because the Web’s content (blogs, news sites and so on) frequently describes events and experiences. Thus, EventWeb and the Web will work synergistically.

(a) Composite events

Events can be combined in many different ways to define other (compound) events [4]. And you can again join these combinations of events with other events to define yet another set of events. These definitions are clearly determined by an application. On the other side, an event is the result of one or more past events, which were in turn results of other events, and so on. Similarly, an event might result, maybe in combination with other events, in multiple events, which in turn might result in many other events. So this process of event creation has been ongoing and will continue into the future.

All events from different input sources can be automatically classified as atomic or composite and can be indexed as such. In an event-based application, the system is active. It analyses events as they occur and aggregates them spatio-temporally using different processes and filters. It also associates events with other past and future events to continuously maintain all relationships among them based on different factors as a normal processing part of the system or on the requests from different users. Aggregation and composition of individual micro-events (atomic events) into semantically useful macro-events is an important process, resulting in an understanding of what happens in an application and how situations evolve. Such macro-events and their features can be used for trend analysis and knowledge generation, as well as decision making.

The notion of combining micro into macro is similar to many established scientific disciplines, including thermodynamics [5] and economics [6], which fundamentally study how atomic or
Figure 1. A ‘social image’ showing the interest level among users across mainland US in terms of number of tweets containing the term ‘iphone’ on 11 June 2009.

Micro-events and behaviours are aggregated into complex scientific or societal behaviours. Concepts similar to these have begun to emerge in systems such as Twitter, where, based on individual tweets, a sophisticated situation and trend analysis can be performed. Next, we briefly describe an approach towards creation and understanding of such macro-events based on the concept of social pixels.

(b) Aggregation of atomic events: microblogs and micro-events

Traditional imaging sensors use pixels that represent an aggregate of photon energies striking in the pixel area on the sensor. We define social pixels as aggregates of different user contributions coming from a particular geolocation [7]. Figure 1 is an example of a social image. For example, numerous tweets about ‘swine flu’ coming from a particular geolocation can be represented as a ‘high’ value at the corresponding pixel. The abstraction of social media content into spatial grids that make them look like images has implications on the following aspects.

— **Visualization**: this approach allows for intuitive visualization and hence aids situation awareness for human users.

— **Intuitive query and mental model**: the correspondence of the human mental model of spatio-temporal data with the query-processing model makes it easier for humans to pose queries and understand the results.

— **Common representation**: this representation allows multiple spatio-temporal data sources (e.g. maps, weather info, demographics, geocoded Twitter feeds, Flickr images) to be assimilated within the same framework. The representation is independent of the nature of the original source; it extracts information from multiple sources and collects it in one application-centric representation.

— **Data analysis**: this representation lets us exploit a rich repository of media-processing algorithms that can be used to obtain relevant situational information from the data. For example, well-developed processing techniques (filtering, convolution, background subtraction and so on) exist for obtaining relevant data characteristics in real time. Such analysis would be tedious in a text-based corpus of similar data or even as a query-based approach in traditional databases where (relatively simple) media-processing operators such as convolution and segmentation are yet to be mapped effectively.
Figure 2. Next-generation social networks will do more than let people share information and experiences; they will actively help people.

6. Social life networks

Social networks have revolutionized interaction among people, using the latest technology in the last few years. Billions of people use the Web to share information, build relationships, engage with others, buy and sell products, and fulfil their personal desires. We believe that by adding a few additional capabilities, the next generation of social networks—which we call SLNs—could become a major factor in improving human life, even in the remote parts of emerging countries by providing timely access to essential resources such as healthcare, transportation, education or even clean water.

As discussed in Jain & Sonnen [8], currently approximately two billion people, called the top of the pyramid, have access to modern information infrastructure through a variety of tools, including mobile phones. Almost equal number of humans, called the bottom of the pyramid, lack any modern means of communication. About three billion people in the middle, called the middle of the pyramid, have mobile phones but not Internet access. Given that mobile phones are rapidly becoming mobile computers equipped with many more sensors than even contemporary laptop computers have, people could easily use them as the primary mechanism for creating and accessing future Webs, including the current WWW and the EventWeb.

Figure 2 shows our vision of the next-generation networks, the SLNs. By continuously monitoring microblogs and micro-events, these systems will understand evolving situations and will help people make correct decisions and organizations to appropriately deal with situations. This is important in developed countries, but is more important in developing countries, where a lack of physical infrastructure makes dealing with the health, emergency, agriculture and transportation needs of masses very difficult. Mobile-phone-based SLNs will help people in these countries for dealing with life-critical situations easily and efficiently using the technology that they are already getting used to. A simple demonstration of such an approach was presented in Singh et al. [7] for a swine flu epidemic using microblogs. Recently, this was applied to Thai floods.
7. EventShop

Here, we present the concepts and high-level description of a system that is being implemented to develop a framework that could be used for many applications related to SLNs. EventShop is a framework [9] to recognize situations based on micro-events aggregated and filtered using massive numbers of heterogeneous data streams.

For developing SLNs, the three most fundamental requirements are:

— identify where resources are available,
— identify where resources are needed, and
— connect needs to resources with least effort and within required time bounds using the least resources.

The best way to identify resources and needs is to detect situations and convert these situations into available resources and needs by using context [9]. For detecting situations, we use all micro-events, including microblogs, and combine these from all other resources on the Web. To implement this approach, we need to combine heterogeneous real-time data streams into actionable situations. EventShop uses the spatio-temporal commonality across streams to integrate them. By using a simple unified representation (based on a space–time theme), it indexes and organizes all data into a common representation.

To represent the world and its attributes for determining needs and resources, the basic structure used is a uniformly spaced grid representing space. This could be a three-dimensional grid, or it could be simplified to a two-dimensional grid, as in maps. Because we are interested in attributes at all such points at every time instant, we represent this spatio-temporal data as E-mage (as shown in figure 1), each cell of which captures a value associated with a particular theme at a particular spatio-temporal coordinate. Grids are the fundamental data structure used by humans to understand and analyse spatial data (e.g. maps, satellite images) and many tools and techniques have been developed to analyse those. Moreover, this structure is very close to images, where many techniques are available to process them.

(a) Detecting situations

The information flow for converting heterogeneous streams to situations is shown in figure 3. In this system, data are considered at the following abstraction levels:

- level 0: diverse raw data,
- level 1: unified representation,
- level 2: aggregation, and
- level 3: situation detection and representation.

The unified space–time theme (STT) format (level 1) records the data originating from any spatio-temporal bounding box using its numeric value. Aggregating such data results in two-dimensional data grids (level 2). At each level, the data can also be characterized for analytics. The situational descriptor (level 3) is defined by the application designer as a function of different spatio-temporal characteristics.

Multiple operators are developed for analysis and characterization of temporal E-mage streams. These operators can be considered in several classes: filter, aggregation, classification, spatio-temporal characterization and spatio-temporal pattern matching.

From situations detected, mentioned earlier in the text, we need to identify the needs of users. The situations detected are combined with individual user parameters for customized actions by individuals. We use the event–condition–action (ECA) approach. The individual parameters can be spatio-temporal coordinates, as well as personal micro-events detected. The spatio-temporal coordinates are used to direct users to the nearest location satisfying certain conditions. Multiple such ECA templates can be registered to provide customized alerts to all recipients.
8. Research challenges

In the earlier-mentioned framework for SLNs, we have provided an outline of an approach to detect situations, identify personal needs and create personalized alerts. In this system, there are many research challenges of different kinds.

Computation of massive numbers of heterogeneous data streams fast enough to determine situations in a timely manner for taking appropriate action is a new challenge. Moreover, research in object recognition has demonstrated that even using just one modality, namely images, the problem of recognition is a challenging one. The problem of situation recognition using multiple data streams in real time is extremely useful, but an equally challenging task. With the volume of data available, this is not just only a nice problem to solve, but it has become an essential problem that needs to be solved.

Combining heterogeneous data streams coming at different granularity in time as well as space requires new challenges. Most data streams are captured using different types of sensors and different spatial resolution. Moreover, the sensors used have different spatial signatures, meaning their measurements are not uniform over the space that they represent. Finally, there are different sources of noise in these measurements that are time varying and that may affect the validity of data streams. Also, how does one combine data from tweets with measurements from satellite images? These are all challenging issues.

Different sources of data are also collected at different time intervals, and may be updated at irregular intervals. For example, census data may come every 10 years, whereas flood levels may be updated every few minutes during an emergency, but every few days otherwise. How do we convert these to regular data streams that must be combined to help in determining situations?

One other important challenge is created due to easy availability of data from different sources. Problems have changed in an interesting way. In trying to solve the problems in the last decade or so, one only had a source or two for solving situation recognition problem, and these sources were the only sources available. Now, the first step may be given many sources available and many types of data available, how to decide which are the best sources and how to effectively combine them for the best solution.

These are just some of the problems that we encountered while addressing some of the applications we have addressed. I am sure what we encountered is only the proverbial tip of the iceberg.
9. Future of the Web

Advances in communication, computing and their applications strongly suggest that we are at a point in history where communication and sharing of experiences is going through a major transformation. The last major transformation was brought about by Gutenberg’s press, which took the first step in democratizing creation and access to knowledge. That innovation shaped human civilization in every aspect. The new media liberate creation, storage, processing, distribution and access from being predominantly text. They make creation, distribution and access of experiences more natural for humans by bringing these operations closer to the modality of natural human senses. The media for representation and communication of experiences and knowledge have profoundly affected what could and would be communicated [10,11]. By offering the most flexible and natural medium for creation and communication, we can extend the reach of knowledge to most humans. Moreover, by liberating storage and distribution mechanisms from atoms to bits, we can do this efficiently, effectively and timely. The emerging Web will use all these for the betterment of the society.

References