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Social pervasive systems: The integration of social networks and pervasive systems

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Social Pervasive Systems: The Integration of Social Networks and Pervasive Systems

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Abstract: Sensor technology embedded in smart mobile devices branded such devices as candidates for building innovative context-aware pervasive applications. On a parallel front, the notable evolution in the shape and form of social networking and their seamless accessibility from mobile devices founded a goldmine of contextual information. Utilizing an ecosystem that combines both mobile smart devices and a big data like environment in the form of social networks allows for the creation of an elitist set of services and applications that merge the two domains. In this paper, and following the footsteps of similar research efforts that attempted to combine both domains, we describe what we label as Social Pervasive Systems that cross-pollinate a mutually influential mobile and social world with opportunities for new breeds of applications. We present herein the evolution of the merger between both worlds for a better understanding. Above and beyond what related work achieved, we present a set of new services and potential applications that emerge from this new blend, and also describe some of the expected challenges such systems will face.

1 INTRODUCTION

The recent advancement in mobile technologies and the enabling network infrastructure have paved the way for the growth of two prime domains, namely mobile-based pervasive systems and online social networks. Mobile technologies have been posed as an extremely necessary ingredient in the new rise and implementation of intelligent context-aware applications (Bellavista and Helal, 2008) (Lehsten et al., 2010) (Sambasivan et al., 2009). In parallel, the popularity of online social networks (OSNs) throughout the world is leading a tide of great social influence (Gay, 2009). With such massive social networks population - there are 1 billion active members on Facebook by Oct. 2012[1]-, OSNs possess huge amounts of social information that present a wealthy source for research. Such immense information can be a substantial source of contextual information, thus improving the intelligibility of pervasive systems (Kompatsiaris et al., 2010). Similarly, by receiving context from mobile sensors, social networks can be aware of user context enabling them to provide more intelligent social services (Quercia et al., 2010).

[1]Facebook Statistics: http://newsroom.fb.com/

While Pervasive Systems and Online Social Networks were progressing simultaneously, we show in this paper that the lack in the enabling technologies may have hindered their progress. Both domains continued to evolve at a slow pace until the end of the 90s (Satyanarayanan, 2001) and were mainly isolated worlds except for very few commercial applications such as Lovegety and Humming Bird (Eagle and Pentland, 2005) that attempted to add a flavor from both systems for better service. Since 2000, both domains witnessed rapid improvement coinciding with the advancement in sensor technology, mobile technology and network infrastructure. Initially, both the pervasive and social networking domains were aware of the power of integrating forces, yet few elementary collaborative research work accommodating both areas led to the emergence of powerful yet incomplete contributions as observed by Baldauf et al. (Baldauf et al., 2007) and Boyd et al. (Boyd and Ellison, 2008). Few attempts initiated in 2007 contributing to the merger of both domains, examining their co-influence to ultimately maximize benefits (Beach et al., 2010) (Quercia et al., 2010).

From our analysis of such merger over time, we envision a further maturity in the merger domain between the mobile and social worlds. We manifest a solid merger in the form of new systems that we call Social Pervasive Systems (SPSs). We define SPS as a system that intensively utilizes both primitive and fused context from both the mobile and social worlds. Relying on the co-influence of its ancestors, SPS will infer significant bidirectional user context and preferences between mobile and social systems, thus leading to a novel breed of wealthy services and applications. Our contribution in this paper is broken down to three main points. First, we define SPS as a new research thrust and provide illustrative analysis of the most prominent work towards its emergence. Second, we shed some light on the prominent applications in which SPS would be of striking importance followed by a discussion of the key challenges that need to be addressed by the research community. Finally, we propose pointers for addressing these challenges along with some proposed solutions.

2 CONTEXT-AWARE SYSTEMS AND SOCIAL NETWORKS

Context-Aware Systems is one of the research areas that significantly contributes to the construction of SPS. In the 90s, commercial, non-standard context-aware applications emerged, along with the challenge of building applications that use extremely heterogeneous sensors. Thus, the progress and scalability of context-aware systems was significantly hindered. In the past decade, the coinciding improvement of mobile sensor technology and high bandwidth network infrastructures revived the research and implementation of pervasive systems (Baldauf et al., 2007).

In parallel to the progress of pervasive systems, Online social networks (OSNs) transformed from being offline applications or mere contact lists into online social network sites that can be accessed off the web and through APIs (Boyd and Ellison, 2008). We spent the effort to visualize a timeline for the evolution of the merger and present it in Figures 1 and 2. The figures emphasize the milestones in the evolution of context-aware systems and OSNs.

3 SOCIAL PERVASIVE SYSTEMS

Many research attempts target either mobile context-aware systems or social systems, but few have merged both to maximize the benefits attained from each system as compared to when they are separately utilized. To support this argument, we traced some publication trends in this domain. We used Google Scholar to survey the number of publications since 1975 till 2011 that either did unique research in one of the indicated areas, or underwent combined research in both areas. The trends illustrated in Figure 3 indicate a modest activity in research that combines both mobile context aware systems and social networks. We believe that the fusion of the context extracted from sensors readily available in mobile devices, along with the wealth of information available in OSNs, can produce a new powerful generation of applications serving a wide range of domains. In this section, we briefly trace the progress in technology enabling the infrastructure motivating research towards this cross-pollination. We then navigate in time to explore early attempts of a merger between the two domains followed by more recent systematic activities, yet still unstructured. Finally, we define SPS and illustrate its fundamental features.

3.1 The Enabling Technology

Technology advancements in affordable mobile technology, including higher processing powers, larger memories, and better displays, paved the way for enabling the merger between social and mobile context-aware systems. Notable advancements also emerged in mobile networking such as the introduction of Bluetooth in 1998 until the launch of 4G technology in 2009. Both lines of advancements enabled the creation of handheld devices that, to a great extent, continue to compete in the replacement of larger non-mobile computational devices. Overall, mobile networking has become extremely ubiquitous amongst a large population of mobile users, thus fostering easier access to OSNs. Simultaneously, mobile sensor technology improved the innovation of smart phones ever since its inception in 2000. Devices continue to be equipped more and more with smaller affordable sensors, which allows devices to be more aware of ambience, and thus encouraging the creation of more intelligent applications that promote better usability and sensitivity to user needs. Such parallel improvements in sensor technology, devices, and networking infrastructure all contributed to a high coupling between social networks and mobile devices, and motivated the popularity of mobile social network applications and the smooth access to the online social network sites.

3.2 The Evolution of SPS

From our observations, there have been several shy attempts of generating premature SPSs since the late 90s. Beginning from 2007, a new era of closer fusion of both domains started as exemplified in a set of better social and context-aware contributions.

3.2.1 Early Attempts

The early attempts of implementing primitive social pervasive applications were mainly commercial products. In 1998, the first commercial product for introduction systems (Lovegety in Japan) was launched (Eagle and Pentland, 2005) where users with matching profiles were introduced as they come in proximity. However, it required special devices and manual feed to generate a primitive social profile. In 2001 Campus Aware (Gay, 2009) was an early attempt to fuse mobile sensor technology with social networks as it imposed the visitor's impressions of specific locations on top of the map of a university campus.

In 2002, mobile devices were introduced in user collocation pattern detection, and common friends were sought to introduce unacquainted persons who share common social patterns. For example, the Experience Project placed proactive displays in the UbiComp conference next to tag readers to display presenter talks that match the profiles of the users in proximity with tagged conference badges (Eagle and Pentland, 2005). User profiles, however, were stored in a local database. In 2004, Social Serendipity used Bluetooth, staged localized social profile systems, and proximity information, to achieve some kind of context-awareness (Eagle and Pentland, 2005). In 2006, Eagle et al. introduced the concept of Reality Mining by using mobile phones as behavioral sensors proving their candidacy for sensing human behavior. By analyzing the collected data, they build a system that infers relationships and senses complex social systems (Eagle and Sandy, 2006). The majority of the aforementioned research work does not include the various forms of context and does not communicate with external social networks.

3.2.2 Recent Merger

Integration of context-aware techniques, sensor technology, social networks, and mobile technology recently emerged and led to fruitful research in context

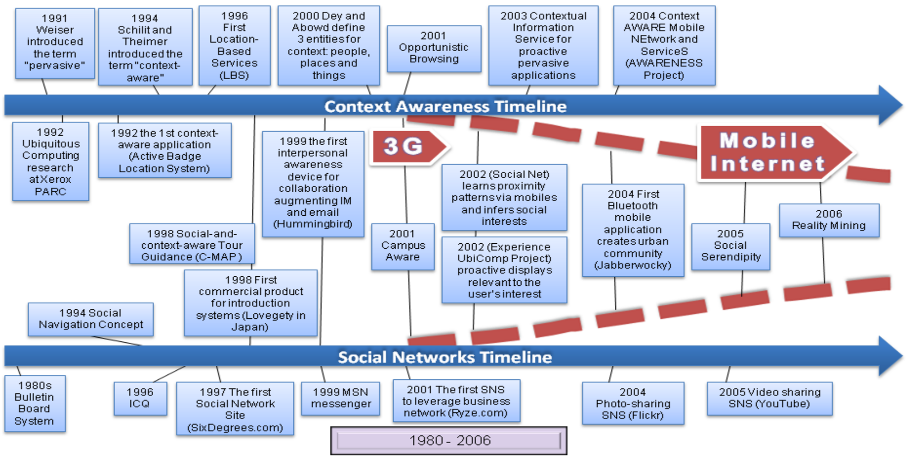

Figure 1: The evolution of both social networks and context-aware systems from the 1980s to 2006.

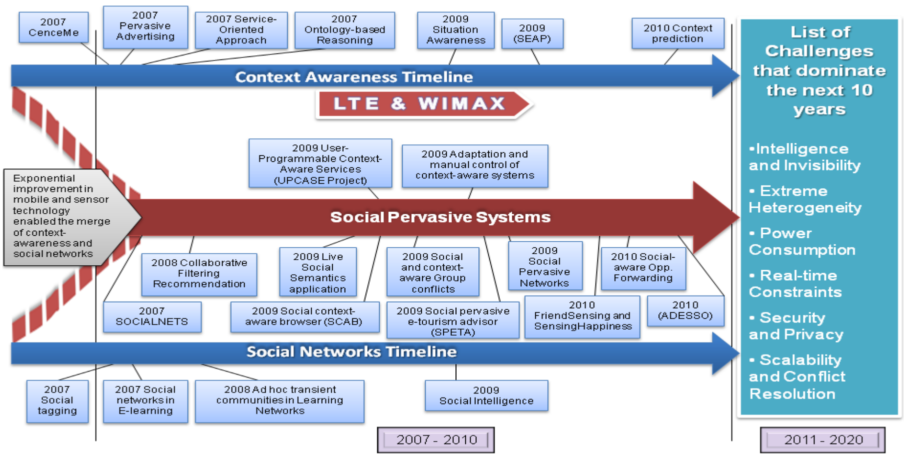

Figure 2: The merger between social networks and context-awareness since 2007.

fusion. For instance, since 2007, the SOCIALNETS project studies physical and electronic social networks to construct an opportunistic virtual and adaptive social network that provides knowledge and content management to pervasive applications (Mendes, 2008). Other studies propose local social networks as a means for privacy preservation and trust management policies in location based systems within opportunistic networks (Sapuppo and Sø rensen, 2011). More recent work incorporates social information retrieved from OSNs into context-aware systems as a new form of contextual information utilized in better service provisioning (Beach et al., 2010).

The year 2009 has witnessed many contributions including: Social context-aware browsing to improve search techniques (Vassena, 2009), applying the social approach in resolving context-aware system group conflicts (Kwon, 2009) (Beach et al., 2010), social context-aware services that feed into social networks (Santos et al., 2009), adaptation and support for manual control of context-aware systems (Beach et al., 2010) to gain users' trust and confidence, social pervasive e-tourism that infers user context and mobility profile to provide recommendation services (Garcia-Crespo et al., 2009) (Kompatsiaris et al., 2010), and integrating online user profiles with face-to-face presence (den Broeck et al., 2010). In

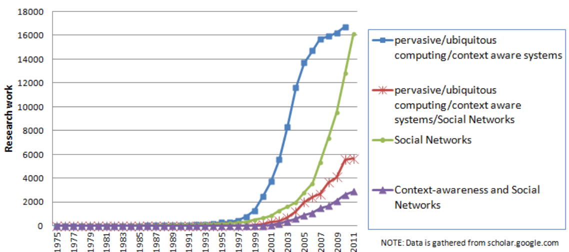

Figure 3: trend of research in social networks, pervasive computing and joint research since 1975.

2010, a closer fusion among context-awareness and online social networks, resulted in the following contributions: Context fusion to improve new forms of sensors such as the calendar (Lovett et al., 2010), logical sensor generation for individuals/group action recommendation (Beach et al., 2010), broker-based social matching service that supports opportunistic social networking in DTNs (Mokhtar et al., 2010), recommending and monitoring social relations as proposed by FriendSensing and SensingHappiness (Quercia et al., 2010), and finally integrating user experience in virtual worlds with the real world, as in SecondLife, by feeding current user actions - being extracted from the mobile sensors - into a virtual world account (Mahmud et al., 2010).

3.3 Social Pervasive Systems: Definition and Features

Social Pervasive Systems are the cross-pollination of mobile systems and social systems that intensely use mutual context. They inherit the main features of both domains, yet are depicted by a new breed of features.

Any SPS inherits from pervasive systems context-awareness, invisibility, handling data from diverse sensors, dealing with heterogeneity, context management, being proactive, adaptation, security preservation and scalability (Bellavista and Helal, 2008). On another front, SPS inherits from social systems social profile generation, social communication, interest groups generation, media sharing, posting peer comments, tagging, allowing application sharing, friendship network generation towards more social networking, and the provisioning of several levels of privacy settings (Boyd and Ellison, 2008).

However, SPSs have a unique set of prominent features - as we envision it - due to the fusion of significant attributes of both ancestors and the co-influence of both domains. In such kinds of systems, social networks will provide both low level and fused social context to mobile devices using logical social sensors. On the other side, SPSs can influence social networks by exploiting mobile-device-based sensation to improve the social networks' awareness and intelligence. To successfully exist, these systems must manage in real-time the possibly massive amounts of diverse data to avoid staleness, outdated context inference, and inappropriate SPS actions and recommendations.

We extrapolate a set of optional features for SPS performance enhancement such as: Inclusion of certainty levels with situation identification, offering optional user customization of the system at all stages to improve system flexibility, and possibly utilizing cloud technology in data storage distribution and processing. Finally, SPS may rely on opportunistic networks to widen the range of applications and to provide dynamic adaptation based on communication.

4 SPS APPLICATIONS

With this cross-pollination, a breed of new application families emerges to provide a higher level of socially influencing services. In this section, we describe five different families of applications that may emerge from such kind of merger.

- Monitoring Social Behavior: These systems monitor the cumulative behavioral profiles of the social groups within a certain population in order to categorize them into sub-populations sharing common features, economic conditions and health conditions. These systems consist of two phases; first, gathering the collective behavioral profiles from both context-aware mobile systems and social networks, and then analyzing and grouping these profiles to deduce the common sub-populations. The behavioral data gathering phase mainly relies on collaborative, large-scale sensing among people's mobile phones combined with social information collected from social systems. There are significant behavioral data gathering projects that support the data gathering phase such as Reality Mining (Eagle and Sandy, 2006) and "Big Data" (Eagle, 2010) which provide massive social/behavioral data gathered from mobile phones. The second phase requires significant research contributions in the field of high-level context inference to deduce and analyze the common social profiles among social subgroups.

Such social behavior monitoring systems are significant for a wide spectrum of applications such as population-targeting healthcare applications, economic/political applications targeting certain sub-populations, urban sensing, monitoring traffic congestion and analyzing social interactions. Furthermore, fusing social tagging with context-awareness and multimedia technology enriches Social Multimedia (Tian et al., 2010) which constitutes a wealthy source for social context-aware search engines and social studies (Kompatsiaris et al., 2010).

- Social Persuasive Applications: Effective and persuasive applications such as social pervasive advertising would use both mobile context and social context to achieve many objectives. One of the objectives could be to propagate customizable and appealing advertisements. Such applications can persuade clients to purchase certain kinds of products or services by having prior knowledge of how such products or services relate to the customers' mobility or social interests. Further information about social contacts, their preferences, the degree of their influence on the subject in question can even aid the effective persuasion process. Furthermore, persuading users to move to certain regions in commercial areas can even have more of an impact as opposed to simply purchasing the products or services, such as decongesting physical areas by routing customers to areas of lower commercial value.

Persuasive systems can also have educational applications. Amongst many, they can rely on user's social profiles, current context, and the context of friends and peers. Fusing all this data can produce information on the academic progress of users compared to their peers in an act of academic persuasion to do better. Peers with higher interaction with a user may even be more influential than others with less interaction patterns, so ranking social contacts' interaction could be very useful for applications of this kind.

- Socially Influenced Context-Aware Systems: By utilizing the history of mobility, social interactions, social and behavioral profiles, such kinds of systems can deduce their future actions and provide suitable services. Among the services provided by this family of applications is identifying mobile nodes capable of forwarding information in a way that is sensitive to their behavioral profile and their willingness to perform such actions. Social-aware ad hoc message forwarding approaches is a hot research area that can benefit from this application family; in which we propose incorporating interest, awareness of the remaining node's power, willingness to forward messages, activeness and social ranking among other context and social-aware parameters. Another example is social/context-aware search engines that can be guided by users' current context, social preferences and the history of browsing actions.

- Alerting Systems: Alerting systems monitor user behavioral patterns and gather current user context from various logical and physical sensors to infer any changes in their behavior, and to deduce whether such behavioral changes constitute alerting phenomena. In case of deduced alerting status, these systems alert users or their social contacts of the detected critical status. The alerting systems can infer the proper social contacts to alert based on the ranking of social interactions in the social graph.

Alerting systems can be utilized in applications alerting users of their peers' current activities/progress to motivate them towards better performance. We extrapolate on the benefit of alerting systems in improving nations' economic status by analyzing outcomes of the social behavior-monitoring systems to pinpoint the sub-populations on the verge of economic danger. Furthermore, governments may be alerted by these applications of the sub-populations in need of direct support to avoid approaching economic crises.

- Social Recommender Systems: They are one of the great potential applications of SPS. They provide recommendations based on situation/context inferred from the fusion of social information, user and peers' context and behavioral profiles. Situation/high-level context inference is an active research area that heavily relies on context information extracted from OSNs, mobile devices, logical and physical sensors combined with machine learning approaches.

We visualize these systems in work environments where they may recommend to managers the optimal group of employees to perform certain tasks based upon an analysis of social interactions and personalities obtained from their social profiles. These applications can also provide common services within work premises to all employees based on context. Such services can be adapted to mobile device capabilities, or the current requirements as per the task in hand.

Other types of recommender systems can include social context-aware learning management systems that can, for example, customize study material as per student level of comprehension, recommend helpful interest groups, and even persuade students to progress in their studies through alerts of colleagues' progress. Such systems can also generate study groups based on students' common study habits. On another front, the application may alert instructors of those students facing difficulty in comprehending certain lessons, and recommend suitable aiding methods, and may also refer instructors to suitable references to improve their teaching skills, all based on information co-obtained from both pervasive and social worlds.

5 SPS CHALLENGES

To realize our proposed SPS application families, we list some challenges that need to be addressed by the research community in order to realize the full potential of SPS. We believe the following to be the most prominent set of challenges:

- Intelligence and Invisibility: Given the large spectrum of contextual data an SPS can attain from both the mobile and social worlds, further challenges of intelligence and invisibility arise. Irrespective of the amount of sources of contextual information that are present in such systems, the need for user intervention in processing should be minimized as usual. Issues like the utilization of varying social networks, authenticating credentials, and diverse mobile platforms should all be invisible to users.

- Extreme Heterogeneity: Above and beyond typical heterogeneity issues in pervasive systems, SPSs are challenged by magnified heterogeneity challenges given they involve both social networks and mobile systems altogether. Challenges involving access to various social networks like Facebook, Twitter or Blackboard include amongst many, varying structures for the types of context that could be retrieved, and varying APIs for access. In addition, varying communication infrastructures, differences in interacting devices, and login credentials of the various interacting social/mobile systems still exist.

- Power Conservation: Although power and energy are typical challenges in pervasive systems, the huge information exchange that may be involved in systems combining the mobile and social worlds imposes a higher power conservation challenge. Higher communication requirements impose a larger challenge due to the amount of battery power depletion that will be incurred upon mobile devices.

- Real-time Constraints: The trade-off between real-time management of input data and processing time consumption requires close attention. The rigid time constraints expected in many SPS applications are also coupled with the need for huge storage space and large processing power in order to process large collected contextual data.

- Security and Privacy: Privacy problems still hold while exchanging and utilizing social and mobile information, especially when hosts are used in such systems whose reputation and trust is not well defined. Unsuitable privacy levels especially when social information is utilized create the risk of users refraining from trusting and using such systems.

- Scalability and Conflict Resolution: Scalability is an inevitable challenge that needs further research efforts. The majority of SPSs offer services in localized areas. Once the range of services increases, performance typically deteriorates. Furthermore, processing massive noisy real-time data, latency, inferring context from data with degrees of uncertainty are among the challenges rising from scalability (Cook and Das, 2012). On another front, the more different sources of contextual information are used from mobile and social networks, conflicting contextual information becomes a notable risk.

6 PROPOSED SOLUTIONS

In this section, we present possible solutions for addressing some of the aforementioned challenges. To achieve intelligibility , better situation inference algorithms are needed to properly react towards satisfying user needs and expectations, and to gain user confidence in the intelligibility of applications. Possible approaches for situation inference would require combining rules upon multitudes of observed activities such as recent user social interactions, response to recent communications and change in routine behavioral profiles.

To overcome the challenge of heterogeneity, standardization of context-data exchange among various systems/sensors becomes more imminent. Such standardization is achievable through a standard context markup language or a standard format/protocol for exchanged context information. Standardized login credentials are also needed. Initial contributions propose an "identity aggregator" to store these credentials and transparently map the services to the proper credentials (Beach et al., 2010). However, the "identity aggregator" idea faces its own set of challenges such as security threats, ad hoc communication, centralized versus distributed processing. Furthermore, research studies are needed to determine the best distribution of the expected collection of data for satisfying optimal processing times and storage and I/O cost.

For power conservation, some research contributions propose solutions such as balancing processing and communication among the resource-rich and resource-weak devices (Schuhmann et al., 2010). The frequency of context information update could also be set based on its frequent change and urgency (Beach et al., 2010), and trends to use renewable power sources such as solar power and wind in charging the SPSs (Cook and Das, 2012) could be used. More innovative energy harvesting techniques can be adopted such as transforming the electromagnetic waves of the surrounding objects or the negative human energy (NHE) into an electric form suitable for charging wearable/mobile devices. On another front, inclusion of NHE-detection sensors in mobile devices, coupled with the user status extracted from OSN, can guide both systems to adapt their themes/applications to the currently detected negative user mood.

Distributed processing and Cloud computing are among the promising venues that support SPS scalability and compensate for resource deficiency in resource-weak devices. Cloud computing also shows potential in resolving the stress of massive real-time processing. Besides, we believe that predicting context offline can save time and reduce the stress of the huge real-time processing.

Finally, for privacy preservation, users may set context-aware privacy settings that change per location, time, or user mood. In addition, secure zones through which SPS can safely migrate their context data could be researched.

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