Mobile social computing is the overarching theme of my research. I envision a truly decentralized computing infrastructure in which autonomous principals interact and realize social applications similar to how human societies operate. Realizing this vision requires shifting the loci of computation from conceptually centralized servers of today close to user-controlled devices such as smart phones. In the pursuit of enabling mobile social computing, my works seek to develop (1) tools for creating *personal data vaults* (PDV), user-controlled repositories of sensor data from users' mobile and wearable devices, (2) techniques for machine learning *mobile social context*, an abstraction capturing the interplay between a user's actions, interactions, and environment, from data in the user's PDV, and (3) methodologies and architectural components necessary for engineering *mobile social applications* based on the insights derived from the PDV. The objective of my research is to enable applications to deliver a personalized, privacy-preserving, and context-specific user experience [2] in domains such as healthcare, smart environments (physical or virtual), and social networks. Also, I emphasize empirical research and have conducted three developer studies and three user studies as part of my works ([4] describes two studies, [1, 3] describe a study each, papers from two are under preparation).

Platys Middleware: Exploiting Personal Data Vaults

Increasingly popular mobile and wearable devices are capable of sensing a variety of information about user's physiology, behavior, and environment. A user may not want to disclose such information to third-parties due to privacy concerns. Further, statistical analysis of data aggregated from multiple users (as it is often done today) may not provide insights objectively valuable to all users. I developed Platys [4], a framework consisting of sensors, a *middleware*, and applications. Platys middleware, the crux of the framework, (1) efficiently gathers data from multiple low-level sensors into a PDV shared across multiple user-controlled devices, (2) computes high-level concepts such as places, activities, and social circles specific to a user from low-level data in the user's PDV, and (3) exposes the learned high-level concepts to applications, respecting the user's privacy concerns.

The benefits of the Platys middleware are two fold. First, the middleware insulates application developers from dealing with both low-level sensors and user-specific idiosyncrasies. Second, the middleware provides a user a single point of access for all the data belonging to the user as well as the insights derived from the data. I empirically evaluated Platys in a study involving 46 developers, each developing a mobile application based on a user's sensor data. The finding from the study indicate that developers employing Platys, when compared to those employing the Android API, (1) develop the application faster and perceive reduced difficulty and (2) produce applications that are easier to understand (for developers) and potentially more usable and privacy preserving (for application users).

Platys Reasoner: Machine Learning Mobile Social Context

The raw sensor data in a PDV, e.g., triaxial accelerometer readings, may not provide an immediate and actionable insight to an application. Deriving useful and user-specific insights from a PDV is extremely challenging since the data in a PDV is multimodal (originating from multiple sensors), sparse (because sensing consumes battery, a limited resource), and evolving (because sensing is continual). I developed Platys Reasoner [4], a machine learning approach, to map low-level sensor data in a PDV to high-level contexts such as the user's places, ambiance, and activities. Further, a user's contexts can influence the social interactions of the user. For example, in Platys Social [1], I showed that a user's contexts can be used to predict the social relationships of the user and the strengths of those relationships.

Platys Reasoner exploits to machine learning paradigms—*active* and *semi-supervised* learning, offering distinct benefits over the traditional *supervised* (requiring user guidance) and *unsupervised* (not requiring user guidance) learning paradigms. Since Platys Reasoner yields user-specific insights, user guidance is essential for training it. Platys Reasoner's active learning approach finds the best opportunities to interrupt the user for guidance, reducing the user effort required for training, and its semi-supervised approach exploits labeled as well as raw sensor data available in a PDV, enhancing the prediction accuracy of the reasoner. I employed Platys Reasoner to learn user contexts from user-provided labels and Android phone sensor readings collected for 3–10 weeks from 10 users, finding that Platys Reasoner (1) requires fewer labels to learn a user's contexts with a desired accuracy than do two traditional supervised approaches, and (2) learns contexts with higher accuracy than two unsupervised approaches.

Xipho: Engineering Mobile Social Applications

Engineering mobile social application to deliver a user- and context-specific experience is challenging for two reasons. First, a mobile social application must capture its users' mental models of context—a high-level concern centered on meaning. Second, it must acquire the desired contextual information—a low-level concern centered on devices and infrastructure. I developed Xipho [3], an agent-oriented software engineering (AOSE) methodology for engineering mobile social applications as context-aware personal agents (CPA). Xipho treats context as a cognitive notion and understands other cognitive notions, such as goals and plans, as inherently related to context. Xipho spans all development phases, providing systematic steps for (1) capturing a CPA's contextual requirements, (2) deriving a context information model specific to a CPA, and (3) leveraging reusable components in a CPA's design and implementation.

Xipho offers three benefits: (1) introducing an explicit semantics for incorporating context in a CPA's design, (2) reducing redundancy in context information models by incorporating cognitive constructs, and (3) separating the concern of context reasoning from CPA design. I evaluated Xipho via a study in which 46 developers employed Xipho or Tropos (a traditional methodology) to engineer three mobile social applications, finding that Xipho, compared to Tropos, reduces the time and effort required to develop a CPA, and yields CPA designs that are easy for other developers to comprehend. My findings bear important implication for practical adoption of Xipho and AOSE, in general.

Relevance to Healthy Aging Technology

My current research thrusts—middleware-based framework for exploiting PDVs, active learning of mobile social context, and agent-oriented engineering of personal agents—can each play an important role in enabling technology for healthy aging. First, the increasing variety of wearable devices such as smartglasses, wrist bands, and chest patches sense data about a user's environment as well as physiology, enabling the prediction of exposure related conditions such as allergies. However, making such predictions in real time, without compromising the user's privacy, requires a framework such as Platys to aggregate data from multiple sources and to derive user-specific insights.

Second, machine learning techniques can be used to build models of a user's mobility and activities from GPS and accelerometer readings. Mobility modeling can help early detection of memory problems, e.g., by observing gradual increase in trip times of routine walks and drives. Activity recognition can help detect falls and strokes. Although mobility modeling and activity recognition problems have been addressed in current literature, Platys Reasoner adds value by relaxing unrealistic assumptions existing approaches make about the availability of frequent sensor readings or a large corpus of labeled data. I have initiated discussions with researchers in ASSIST (Advanced Self-Powered Systems of Integrated Sensors and Technology), a research center at our university, to explore how Platys Reasoner can help derive valuable insights from the sensor data they generate. Specifically, I participated in a summer institute organized by an ASSIST member, Dr. Jesse Jur, and demonstrated the recognition of activities such as walking, running, and playing Frisbee from the accelerometer readings the students of the institute collected via Platys.

Third, mobile social applications for healthy aging range from simple medication reminders to those capable of influencing lifestyle habit changes. However, tailoring these applications to meet user-specific and evolving requirements is nontrivial. Xipho simplifies the development of such applications by employing cognitive constructs such as goals, plans, and beliefs in application design. More importantly, Xipho enables these applications to deliver context-specific services, enhancing the user experience. I have contributed significantly to the development of BooST[1], a mobile social game that promotes physical and mental wellbeing by encouraging exercising and social interactions. BooST is middleware based and it exploits our intuition that positive emotions and physical exercising influence each other.

Research Plan (1–5 years)

Enabling mobile social computing on a truly decentralized infrastructure is a long-term endeavor. In this endeavor, I intend to make fundamental and inter-disciplinary contributions across artificial intelligence, software engineering, and human-computer interaction. I approach healthy aging as an application domain of mobile social computing. In the next five years, I will enhance Platys Reasoner to uncover insights specific to healthy aging. Specifically, I will build techniques for (1) modeling user mobility at multiple levels of abstraction and detecting, in particular, deviations from established routines, (2) determining best opportunities (e.g., time and place) to interrupt a user for inducing healthy habits, and (3) recommending ideal activities and support groups to patients (my experience building recommender systems [5] can be valuable here). I will conduct user studies to evaluate Platys Reasoner as well as developer studies to evaluate the Platys framework's effectiveness and efficiency for supporting applications for healthy aging. In addition, I will expand my core research program on mobile social computing to incorporate the following aspects.

Trust. Platys middleware, in its current form, strictly preserves privacy by not sharing a user's data with other users. However, controlled data sharing may benefit the user, e.g., sharing personal data can strengthen relationships. In certain circumstances, e.g., when the user is in an emergency, sharing may be inevitable. Trust between users is an important factor in controlling data sharing. I will extend Platys to compute trust and share a user's data accordingly. One of my recent work proposes a computational model of trust (paper under submission at IJCAI).

[1] `http://research.csc.ncsu.edu/mas/boost/`

Emotional Context. Platys Reasoner currently learns three contextual attributes: a user's places, activities, and social circles. I will enhance Platys Reasoner to compute additional context attributes. Specifically, I will build techniques to compute emotional context, and instrument the BooST application those techniques. I will conduct a user study of BooST to uncover the relationship between emotions and physical activities.

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