The Intel Science and Technology Center for Pervasive Computing

White Paper

Intel Labs
ISTC for Pervasive Computing

Mark's alarm went off a half hour earlier than expected. Since he and his wife installed the Family Coordination Assistant, it has taken over a number of tasks to keep the family on schedule, including setting alarms. The Assistant knows this is Mark's week to drive his daughter Megan to school, and it anticipated the heavy rush hour traffic in LA, waking Mark early to ensure he would arrive on time. Sometimes the system lets him sleep in for an extra 15 minutes; that happened two days last week, when the system sensed that Mark's eight-year-old son was packing his own lunch.

As he dropped off Megan at school, Mark began to dread his afternoon meeting with a difficult colleague in marketing. He was counting on the Mobile Health service on his smartphone to keep him calm. The service could sense when and why Mark got anxious or angry at work and would suggest ways to ease the stress. Before the meeting with Steve, the system recommended that Mark take five deep breaths each time he felt himself getting angry or tense.

Mark hoped his new smart kitchen would work its magic tonight, when his stress level was sure to be high. He was planning to try two new recipes for a dinner party with his in-laws. Mark's not a bad chef, but he normally wouldn't try any new dish (let alone a difficult French recipe) without practicing it first. But Mark's Smart Space Kitchen module has bolstered his confidence. The system talks to Mark as he prepares meals and provides video cues when needed, projected onto the kitchen counter. It watches Mark's actions and lets him know if he's slicing vegetables too thick, not stirring the sauce often enough, or over browning the meat. It even allowed Mark to demonstrate his favorite recipes for his sister in New York, who learned the nuances of preparing the meals correctly using her Smart Space Kitchen.

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The scenario above is fictitious, but the technology to support such applications will be explored by a new research center funded by Intel, to advance the field of pervasive computing.

Background

For the past 20 years, the pervasive computing community has developed technology that allows sensing, computing, and wireless communication to be embedded in everyday objects, from cell phones to running shoes, enabling a range of context-aware applications. While these apps are useful, the time has come to develop the next generation of pervasive computing systems. These future systems will support applications that have much deeper awareness of users and their activities, context, and goals. They will be able to learn and adapt continuously to user's habits, routines, and preferences. These future apps will be capable of supporting complex tasks, such as cooking a soufflé or building a complicated piece of furniture. In the process, they will deliver far richer user experiences than the technologies of today can offer.

The Intel Science and Technology Center for Pervasive Computing (ISTC-PC) will develop the fundamental technologies needed to power this next generation of pervasive computing systems. This paper highlights the key research themes and application areas that will drive the research of the new center.

Leading academic researchers

The ISTC-PC will bring together researchers from six top-tier US research universities, including leaders in pervasive computing, wireless communication and sensing, artificial intelligence and machine learning, computer vision, human-computer interaction (HCI), and security. The University of Washington will be the hub of the center, coordinating research among the five other universities involved in the collaboration, including Georgia Institute of Technology, Cornell University, the University of Rochester, UCLA, and Stanford University. The ISTC-PC will be co-led by Dieter Fox, associate professor of Computer Science & Engineering at the University of Washington, and Anthony LaMarca, a principal engineer at Intel.

An open, collaborative approach

The ISTC-PC is designed to ensure a successful collaboration through an open research model that encourages widespread sharing of information and results. While Intel is funding the work of the center, the results of the research will be made widely available through open-source software releases and technical publications. By adopting this open approach Intel hopes to encourage collaboration across the pervasive computing community and to foster the development of breakthrough innovations. The freedom to share intellectual property overcomes one of the key barriers to the success of many industry-academic research collaborations, which often stumble over IP rights.

Through the new center, researchers in a range of disciplines who rarely have the chance to collaborate will be able to share ideas and jointly develop solutions. Such cross-fertilization is designed to generate novel ideas and innovative solutions that require a multidisciplinary team to develop. The researchers also will have the opportunity to explore the large-scale scenarios that motivate their research but are difficult to pursue within a single university.

Overview of the research

Enabling the next generation of pervasive computing systems that are trustworthy, always aware, and continuously learning and adapting will require significant advances in sensing, interaction and learning. The ISTC-PC will tackle this challenge by focusing its research on the three areas highlighted below.

Low-Power Sensing and Communication

Pervasive computing systems must be continuously aware of the environment, the people nearby and the activities in which they're engaged. Because of the need for such systems to be "always on," saving power whenever possible is crucial.

The researchers will develop "perpetual power" techniques that harvest energy from ambient sources and allow simple sensing and computing systems to run indefinitely. For larger devices, they will explore how to dynamically use the most energy-efficient 802.11 and cellular modes available in the current locale, based on RF conditions and competing network traffic.

Because pervasive computing systems perform continuous sensing and inference about people, within their homes and on the go, developing privacy and trust is paramount. With that in mind, the researchers will investigate how applications, sensors and data coding techniques can be modified to improve privacy.

Finally, the ISTC-PC will investigate new sensing modalities, both for mobile devices and embedding in the

environment that can be used to infer the state of people and their surroundings.

Understanding Human State and Activities

Next-generation pervasive systems require fine-grained recognition of activities, objects, and social context. To achieve this, the researchers will deploy dense, heterogeneous sensors in mobile environments and smart spaces, including audio and depth video sensors (via novel cameras that measure 3D shapes) as well as classic pervasive computing sensors such as GPS, accelerometers, and wireless signals (802.11, cellular and RFID). The research will focus largely on developing new algorithms to extract complex context and activity information from sensor data far more accurately and robustly than the current state of the art. For instance, the algorithms might determine not just that someone's in the kitchen but that the person is slicing an onion, and that the slices are too thick for the recipe being used. To be the most useful, pervasive computing systems must be able to assess the user's context in real-time, a challenge for systems that must operate on low power. To address the challenge, researchers will explore how to divide the computational work involved (i.e., executing the algorithms) between mobile devices and the cloud.

Personalization and Adaptation

Successful pervasive computing systems must be able to learn interactively the environments, objects, schedules and preferences of their users. It should be easy for a user to teach a device to recognize activities such as a regular jogging routine, places such as a favorite grocery store, or objects such as the user's car.

The research in this area will focus on developing probabilistic techniques for handling the complex estimation and learning problems required for lifelong learning, adaptation and personalization of systems for individual users. Probabilistic graphical models that describe users and their context will continuously adapt, allowing the incorporation of new places, activities, personal objects, and social contexts over time.

In addition to personalizing what systems know, the researchers plan to build systems that personalize how they interact with users. Their goal is to enable interactions between users and systems that seamlessly blend multiple modalities (e.g., gestures and natural language), enabling users to focus on their goals rather than making the technology work.

Ensuring security and privacy

Exploring new technologies to support the next generation of pervasive computing will require dealing with significant quantities of private information. To ensure the trustworthiness and security of the systems involved and to safeguard privacy, security and privacy researchers will be involved in all of the center's research efforts. They will serve as internal consultants who will proactively surface, assess, and address potential privacy concerns related to the technologies being explored. They will also strive to develop a deeper understanding of what trust and privacy means for each problem domain, and to develop new technological solutions for achieving trustworthiness and privacy when standard best practices are not sufficient.

Concept applications

The ISTC-PC will develop three concept applications that will demonstrate the center's technologies. The applications will share many sensor and algorithmic ingredients, but each will address a unique and important human need.

The three application areas were chosen in part for the difficult requirements they present to pervasive computing systems, thus providing a driver for the center's research. They also will allow the center to demonstrate the game-changing impact that pervasive computing will have on future devices, applications, and services. As these concept applications suggest, the systems of the future will be capable of understanding much more complex scenarios and will use that knowledge to serve users in far richer ways.

Mobile Health and Wellbeing

Improving physical and emotional wellbeing is a high-value application area. The center will address this topic by exploring technologies to help users identify, manage, and reduce stress and anxiety in their daily lives. To achieve this, researchers aim to develop mobile systems that can understand the rich context of their users' lives (both at home and on the go) and learn about their routines, interactions and stressors. The researchers will combine multiple sensing modalities to measure a user's stress level and learn which factors serve as stressors in their lives.

This application area will challenge the center to develop power-optimized mobile systems, fine-grained models of everyday activities, interactions, and environments, and personalized and adaptive feedback systems to help users manage stress. Specifically, researchers aim to build a mobile, sensor-rich system with a primary focus on automatic stress detection, mapping, and mitigation.

The researchers will develop community-scale techniques for data collection and complement automatic, sensor-driven inference with user-contributed feedback. They also will develop data formats, a common infrastructure and techniques to secure user privacy, to allow sharing of results across the mobile health community.

This application scenario will leverage the center's research into the creation of perpetually-running sensor systems for use in environments such as the home. Such systems can provide data that allows deeper, more nuanced context to be inferred, compared to a mobile system. Ultimately, this rich data can also be used as further context data for the mobile system for managing stress. Capturing and interpreting this data will leverage the center's research into how sensors can understand objects, people and scenes within activities.

A stress-busting system

The ISTC-PC aims to build a system that can learn, detect, and recognize everyday activities that are related to the user's stress and wellbeing. The system will employ a smartphone as a sensing and computational platform. Other worn sensors will use the smart phone as the computational hub. Data from all of these sensors will be aggregated and analyzed automatically to infer physical and social activities and stress levels throughout the user's day.

The system will provide visualizations of activities and corresponding stress levels to make users more aware of what causes stress. It will compute an overall stress index that combines the effect of different stressors, to provide an overall view of the user's stress trends. Based on inferred activity, the system will predict impending stressors and provide timely suggestions to manage stress. Users will be able to share their activity data and models with others, enabling the models to be refined via crowd sourcing.

Task Spaces: A Smart Cooking Assistant

Computers often assist with tasks, but most of the tasks are performed in a traditional computing context. The ISTC-PC aims to demonstrate a space that is capable of helping users with physical tasks that don't involve a computer. For example, a task space could help someone assemble a piece of furniture; teach a person to cook a soufflé, or assist someone who is visually impaired in configuring a new piece of audio equipment. This highlights an important promise of future pervasive computing apps: the ability to deliver expert knowledge to novices, providing "hands" on training at home or on the go.

The center will explore task spaces that interact seamlessly with users by combining multiple cues such as a person's context, gestures, and voice, and which provide assistance through multiple output modes, such as audio and projected imagery. The task systems will infer the state of the physical environment, the objects being used, the specific step within a complex task, and the goal of the person performing the task. Task spaces will be able to learn new activities through demonstration, incorporating spoken language and manipulation of physical objects.

The ISTC-PC will integrate its sensor, learning, and interaction technologies to build a kitchen task space intended for family homes or apartments. The researchers will demonstrate cooking functionalities in this space, but the techniques developed will be general enough to be applied to other task spaces, such as workbenches, wet labs, and classrooms.

To robustly track complex multi-step activities, researchers will build a framework for integrated reasoning and modeling of uncertainty at all levels, from sensors (e.g., speech, vision, and gesture) to high-level task models (for example, cooking from a new recipe). They will enable users to interactively demonstrate new tasks to the system, which will learn automatically to translate speech and gesture input into structured representations that can be taught to other users. The researchers also will develop computer vision techniques to recognize and track objects being used during the task, such as cooking ingredients and utensils.

Chef in a countertop

Provided with a recipe, the Smart Cooking Assistant will guide the cook through the different steps of the recipe: With the help of sensors that watch the kitchen countertop and other surfaces, the system will recognize tools and implements for cooking, and their use, and will detect when ingredients are measured and added. It will track the user's progress, providing audio and visually projected cues as needed. It will also monitor time and convey to the user the scheduling and timing associated with the recipe (e.g., timing the rising of dough, marinating, and baking time).

Users will be able develop new recipes for the Smart Cooking Assistant via interactive demonstration. The system can be taught to correctly interpret gesture and speech input, and trained to recognize the ingredients, amount, order, physical manipulation of ingredients, etc. The resulting recipe will be captured by the system for later use.

Family Coordination System

Thanks to increasingly busy, mobile, over-scheduled lives, it's becoming harder for families to spend time together. The ISTC-PC will address this challenge by developing pervasive computing systems that help families coordinate their lives through monitoring, tracking and reflecting on family activities. Activities will be tracked over the entire day at a relatively coarse level both inside and outside the home, and at a far more detailed level in sensor- rich areas of the home, such as the kitchen and dining room. The system will use activity information to assist families in planning their lives. For instance, one goal might be to help a family get ready to leave on a weekday morning with a minimum of fuss, or to plan a day's strategy for picking up the kids at school if there's a change in normal daily routines.

To bootstrap learning of the models used for inferring activities, the researchers will develop techniques to motivate family members to provide data about their daily activities within and outside the home. The system will include engaging visualizations to encourage members to provide input. It will also use persuasive, unobtrusive, privacy-preserving methods of providing feedback and generating awareness.

This concept application will draw technology from nearly all of the center's research projects. For instance, to provide home-wide coverage, the application will depend on researchers' development of a sensing infrastructure that operates continuously without being connected to power. The activity detection algorithms that infer individual and group activity from this sensor data will come from research into learning and labeling family routines and recognizing people's interactions with objects.

Advancing the future

Through the ISTC-PC, Intel is helping to advance the future of pervasive computing. By creating and funding an ecosystem of leading researchers in the field, and providing a collaborative environment to accelerate their work Intel hopes to play a key role in supporting next-generation applications that have a deep understanding of users, the capability to learn and adapt to users' needs, and the ability to deliver far richer, more personalized experiences to the consumers of the future.

Coordinating busy lives

The ISTC-PC will build a smart home system that will learn, recognize and track the everyday activities of all members of the family. The system will track activities at different levels; models will infer activities such as waking up, getting dressed, walking up and down stairs, and packing lunch, as well as joint activities, such as the family breakfast or helping the kids with their morning routine. The pattern of activities (both current and historical) will be presented to members in a way that informs them and helps them to reflect on the activities and make changes if needed, to create more time together.

New activities can be taught to the inference system via demonstration and annotation on the part of the user. Annotation will be performed retroactively through interfaces that replay activities and provide ways for people to label what occurred.

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