The Intel Science and Technology Center for Embedded Computing

White Paper

Intel Labs

ISTC for Embedded Computing

Kim leaves her office carrying a briefcase full of work. As she slides into the driver's seat of her car, her updated calendar is shown on the dashboard display. No events are listed for the next three hours, so Kim plans to stop by the shopping mall along the route home.

At the entry to the mall, Kim pauses in front of a digital sign that recognizes her and changes to show products that might interest her. A virtual assistant engages Kim in a brief conversation, directs her to the store carrying the brand and size of shoe she wants, and sends a 20%-discount coupon to her smart phone—another of the many bargains she has received since allowing the mall's networked-sensor system to gather information and learn about her interests.

As she arrives home, Kim is greeted by Zia, the family's robot-maid, who begins preparing a stir-fry dinner, based on knowledge of what the family members had for lunch, what's currently in the refrigerator, and what ingredients/dinners they have enjoyed in the past. As Zia pulls ingredients from the fridge, the grocery shopping list is updated automatically. While Zia chops vegetables, Kim watches highlights of her favorite news feeds, which appeared automatically on a surround multi-panel, touch-sensitive display in the living room, after the home management system recognized her face, gait, and mood. A side panel shows an updated calendar and real-time information about the location of family members to align dinner time with their arrival.

With her husband and daughter just ten minutes away, Kim checks on the progress of dinner. Because Zia still can't cut shiitake mushrooms proficiently, Kim cuts them instead and explains the technique. Zia records multi-sensory input of Kim's actions for later analysis and learning.

After the family has retired for the night, Zia and the home management system analyze the day's activities and related data, to reinforce the family's known behavioral patterns and learn new patterns.

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The scenario above is fictitious, but a new research center, funded by Intel to advance the field of embedded computing, could one day help to transform this vision of the future into reality.

Background

Embedded computing systems touch every aspect of life. These synergistic combinations of hardware and software, designed to perform specific functions, can be found in a host of items in everyday use, from digital signs in stores to in-car GPS receivers to HVAC systems with networked thermostats. With the growing popularity of personalized, interactive, real-time technology, we expect to see a corresponding rise in demand for specialized embedded computing systems to support a broad range of new applications—including many that have not yet been envisioned.

Research concept: Embedded retail displays

With this future demand in mind, Intel is launching a new research center to advance the field of embedded computing. The Intel Science and Technology Center for Embedded Computing (ISTC-EC) will bring together top thought leaders to develop breakthrough innovations that will transform experiences in the retail, automotive and home environments of the future. Focusing on the domains where people spend much of their time and financial resources will increase the likelihood that the center's research can be transferred into high-impact applications that will be widely adopted and relevant to our everyday lives.

The ISTC-EC is one of a series of research collaborations that Intel is establishing with US universities to identify and prototype revolutionary technology opportunities. The centers are designed to encourage closer collaboration among academic thought leaders in essential technology areas

Engaging top academic researchers

The ISTC-EC will bring together university researchers who are leaders in the field of embedded computing. Carnegie Mellon University (CMU) will be the hub of the center, coordinating research among several other universities, including Cornell, the University of Illinois--Urbana-Champaign, the University of Pennsylvania, Penn State University, Georgia Tech, and the University of California, Berkeley (UCB).

The ISTC-EC will be co-led by Carnegie Mellon associate professor Priya Narasimhan and Mei Chen, a senior scientist at Intel Labs. Initially, four Intel and about 30 academic researchers will participate in the center. The researchers will collaborate locally as well as virtually and will meet occasionally at workshops, retreats and other events designed to strengthen the collaboration. Intel will work closely with the participating universities to develop an ongoing research agenda that looks beyond the horizon of today's technologies.

A unique approach to collaboration

Three unique features of the ISTC-EC are designed to increase the probability of successful collaboration: an open research model, multidisciplinary approach, and the "hands on" involvement of Intel.

Open research

While Intel is funding the research of the ISTC-EC, the results will be made widely avallable through technical publications and open-source software releases. The goal is to encourage collaboration and the development of breakthrough innovations in the area of embedded computing. 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.

Multidisciplinary approach

Researchers in a range of disciplines, from machine learning to systems architecture, will share perspectives and jointly develop embedded computing solutions. Such cross-fertilization is designed to generate novel ideas and innovative solutions that researchers could not achieve working in their individual fields.

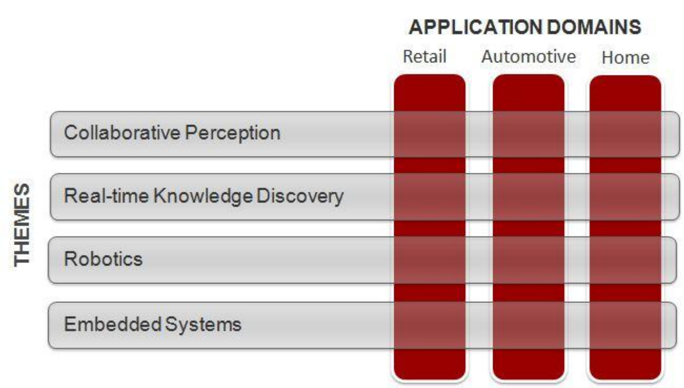
Intel's involvement

Often, companies that form research collaborations with universities limit their involvement to financial investments. Intel also is committing leading-edge equipment, and more importantly, people to the research effort. Six Intel researchers will work on site at the CMU campus; Intel researchers in Oregon, California and Arizona may participate in the center's projects as the research evolves. The involvement with Intel's Embedded and Communications Group (ECG) will increase the likelihood that research ideas emerging from the ISTC-EC have the potential to be translated into Intel products of the future.

Overview of the research

The ISTC-EC will explore new algorithms that can advance the state of embedded processors as well as innovative systems architectures and processor capabilities to support novel applications in the retail, automotive and home environments of the future. Future usage models in these domains may not be limited to single, isolated, embedded systems, but may be based on real-time, crowdsourced data, algorithms and systems derived from specific populations. For instance, one driver's experience might be improved by strategically sensing/learning from the collective experience of many drivers on the same or a similar road, presently or in the past.

The overarching goals of the center's research will be to enable real-time personalization of applications; spontaneous interaction with the environment (the automatic delivery of "right here, right now, right for me" services); and crowdsourcing (sharing, interpreting, verifying and acting upon synthesized information from diverse, distributed inputs.) With these goals in mind, the ISTC-EC will organize its research agenda around four key technology themes, outlined below.



Collaborative perception

Embedded systems interact with the physical environment and with humans through multi-modal sensing (e.g., video and audio, accelerometers, temperature sensors, and new sensors such as 3D video and modulated light). A key goal of embedded applications in the store, car and home of the future is to perceive accurately and react appropriately. For example, an intelligent home management system should not only be able to recognize who is at home to determine what entertainment content to display, but also their mood so as to determine appropriate tone of voice, volume and lighting levels. This research theme will focus on the use of computer vision to sense and understand the environment as well as human behavior and intent, to enable natural interaction.

Perception in embedded-computing applications involves unique challenges, as it must be performed online and in real time in the face of resource constraints. The ISTC-EC will investigate new ways to do this robustly, by adopting advanced sensors, synthesizing multi-modal sensor data, leveraging prior learning, incorporating contextual information, and collaborating with humans in the machine-perception process (e.g., having humans provide additional input to help embedded systems make sense of visual data). Topics to be explored might include face recognition; analysis of attention, intent and emotion; behavior modeling; and interactions between humans and the environment.

Real-time knowledge discovery

Embedded systems must be able to extract and analyze data from the host device and from external data sources in a timely, scalable and reliable manner. This research theme focuses on the use of data mining and machine learning to gather and analyze data from the physical and virtual worlds. The goal is to discover patterns in the environment and understand humans' interactions with the environment, to support more personalized, interactive applications.

The ISTC-EC will explore data mining and machine learning in real time to support future retail, automotive and home applications that require immediate responses. Specific topics to be explored might include real-time machine learning on heterogeneous (or customized) cores, discovering patterns in event streams (e.g., data generated in the home by diverse sources, from video recordings to location sensors and online calendars); anomaly mining; online learning; and learning from heterogeneous, dynamic and/or high-dimensional data.

Machine learning in embedded-computing applications presents a number of challenges, such as operating effectively in resource-constrained environments, dealing with multiple specialized sensing modalities, and managing the complex tradeoffs involved in determining when to offload computation to the cloud and when to process data locally.

Robotics

Embedded systems, particularly in the robotics space, involve technologies in unique, often autonomously mobile, multi-sensory exploration. This research theme focuses on technologies that contribute to unique new automation capabilities in the store, car and home of the future. To date, robots have primarily been successful at manipulation in simulation and tightly controlled environments such as factory automation.

The ISTC-EC will explore technologies that can contribute to new automated assistive capabilities in the store, car and home of the future. Specific topics to be investigated might include multi-modal sensing hardware; real-time interaction between robots and humans via haptic (tactile, or touch-sensitive) interfaces; fine-grained tracking of people and objects; indoor and urban navigation in a dynamic environment; motion sensing and planning; and detection and avoidance of obstacles.

Embedded systems architecture

Embedded systems pose challenges of resource constraints, such as low power, low bandwidth, limited memory, limited storage and limited computational capability. This research theme focuses on hardware and software innovations that can enable large-scale, real-time data-processing algorithms (collaborative perception, knowledge discovery), tailored to these unique resource constraints, the specific context (physical location, proximity, usage models) in which they are used, as well as domain-specific requirements posed by the store, car and home of the future.

The ISTC-EC will explore technologies to incorporate large-scale algorithms in hardware, when to offload computations to the cloud vs. performing them in silicon, and to address the architectural challenges of porting digital profiles across heterogeneous platforms in real-time (e.g., to seamlessly migrate entertainment content from the home to a car, so that a child can resume playing a game in the car while her parents run errands). Specific topics to be investigated might include power management, as energy consumption is a major issue when dealing with embedded systems and the intensive computation that will be required to support the store, car and home of the future. Other topics for potential investigation include large-scale parallel algorithms, implementing machine learning in silicon, novel platforms for crowdsourced computation and communication, and location/proximity-aware scheduling.

Potential Applications

The research of the ISTC-EC could enable a variety of innovative applications in the retail, automotive and home domains. Following are a few examples of potential future applications:

Transforming the retail landscape

Embedded computing has the power to transform the retail landscape. Digital retail technology can be used to meet shoppers' demands for efficiency, speed, improved customer service, as well as their desire to be more informed and socially connected, while simultaneously addressing the retail industry's needs for increased growth, increased basket-size ($$ of revenue per customer visit), reduced store staffing, improved back-office operations, and increased stickiness (i.e., breeding customer loyalty by differentiating themselves from other retail stores). Using sensor data to understand people's environment, behavior, and intent is crucial in the store of the future.

Retail stores have long wanted to improve and personalize customer service without having to add payroll costs through additional staff. This can be made possible through the strategic use of embedded computing at multiple points in the retail ecosystem. Networked digital signs will detect shoppers' interest and engage them in purchases. In-store localization can determine the precise in-store locations of shoppers and products while sensors track in-store traffic patterns and crowdsourced analytics (from shopping history, social networks and other stores). Mobile devices in the hands of shoppers will allow them to obtain information in real-time.

Applications informed by data about individual and collective consumer behavior could enable retailers to deliver customized information and discounts to individual shoppers at particular times. Such personalized retail applications might enhance store loyalty and increase revenue.

Applications that enable retailers to track inventory in real time may reduce or eliminate lost revenue due to misplaced or out-of-stock merchandise Real-time inventory tracking would allow retailers to target promotions dynamically, based on current inventory or sales activity, and to optimize product placement based on accurate, up-to-the-minute sales data and in-store traffic patterns. Product-location and sales data would equally empower informed shoppers, who can identify which items are in which stores now, which are top sellers, who have purchased similar items, etc.

As yet another example, in-store robots might handle tasks such as folding clothing items, stocking shelves, and helping customers to locate items and load their purchases into their cars, freeing staff to focus on providing more attentive customer service. Future retail apps might also enable shoppers to experience products virtually, e.g., through digital unboxing and virtual dressing rooms.

Transforming the automotive landscape

Embedded computing has the power to transform the automotive landscape. Embedded automotive telematics technology can be used to enhance the comfort, convenience, situational-awareness, safety, entertainment and maintenance aspects of vehicles, all while resulting in cost savings.

For example, drivers operating cars under adverse conditions such as snowstorms have always wanted more information to enable safe, fast commutes to their destinations; most drivers obtain this information through the age-old practice of manually consulting other commuters on the road. Vehicle-to-vehicle (V2V) apps that gather and analyze real-time data from many vehicles could improve the experience for all participating drivers. Algorithms and systems that analyze cross-car location, proximity and other data gathered from on-car sensors can prevent accidents and steer drivers toward the most efficient routes to their destinations.

One can visualize the strategic use of embedded computing at multiple points in the automotive ecosystem. Sensors in cars can detect roads that are plowed/passable/impassable. Computer-vision will detect the exact heights of snow banks for snowplows to clear. Crowdsourced telematics aggregate information from other cars on the same or similar roads in a timely manner, allowing automated real-time dynamic route planning to enable drivers to avoid snow-covered, impassable roads on their commutes while automated notifications to snowplow-operators expedite cleanup.

Future apps in the automotive space might leverage embedded systems to assist drivers in navigating safely through crowded urban streets, by enabling automatic detection of and reaction to pedestrians, bicyclists, or other obstacles. They also could help drivers to negotiate roadways when driving conditions are difficult. Imagine a windshield that also serves as a display, providing a clearer view of the road ahead during a heavy rainstorm.

Automotive applications of the future could increase personal productivity as well. If consumers' personal information (calendars, shopping lists, etc.) were seamlessly portable, the car of the future could learn about the owner's lifestyle and behavior to help the driver and passengers to be more productive during the day. For example, if the car were passing a store that has an item on sale which the owner buys regularly, the car could provide an alert. Or, if the driver has several errands to run, the car could plan the route dynamically, in real time, using crowd-sourced telematics to avoid construction zones and other obstacles, completing the trip in the most efficient manner.

Transforming the home landscape

Embedded computing has the power to transform the home landscape. Traditionally, embedded computing in the home has taken the form of smart appliances. However, in-home sensing networks, particularly those with video, audio, text, online, etc., have been rare. Embedded computing could make everyday living more personalized for the connected resident in the connected home, using the occupants' behavioral data, social relationships as well as in-home and "home-to-car-to-home" technology as key assets.

For example, general-purpose robots could handle many routine household tasks, such as loading and unloading the dishwasher and folding laundry. They could learn and improve on skilled tasks, such as cooking and ironing. Robots also could entertain household members, serve as companions, or simulate occupancy when the family is away to enhance security.

A smart kitchen with embedded systems could seek out and display recipes that match their owner's dietary needs and goals. They could suggest meals based on the ingredients in the refrigerator, automatically dispense the right amount of spices, and update the grocery shopping list as ingredients are used. Recipes that conform to an individual's dietary needs could be aggregated with learned personal preferences to provide desirable and healthy meal choices. Specialized embedded systems could make entertainment and information more personalized as well, adjusting automatically to the needs, moods, and preferences of each household member.

Energy-saving applications would reduce home heating and cooling bills. Future apps might automatically reduce energy usage by learning household needs and behavior patterns and shifting tasks (laundry, dishwashing, etc.) to off-peak hours when possible, without the need for the homeowner to take any action. Applications could also improve energy savings throughout a neighborhood by automatically notifying neighbors when resources can be shared.

Accelerating toward the future

With the launch of the ISTC-EC, Intel is leading the way toward the development of visionary embedded computing technologies that will transform consumers' experiences in the store, car and home of the future. By creating an ecosystem that includes the top minds in the field, and providing the funding and collaborative environment needed to accelerate their research, Intel hopes to play a key role in delivering more useful, exciting, and more personalized experiences to the connected consumers and business owners in the connected environments of the future.

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