

Restructuring software engineering education towards cross-disciplinary collaborations to create pervasive information systems and technologies

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ABSTRACT: Pervasive computing, a new generation of computing, encompasses many areas including agent technologies, intelligent systems, mobile and wireless computing, wearable and augmented reality computing, context- and location-aware computing, and sensor computing. In the article, the author discusses the critical need for cross-disciplinary collaborations to create pervasive information systems and technologies. An overview of the wide range of technical and non-technical issues that needs to be addressed by cross-disciplinary research groups is also given. The author also presents key strategies for restructuring software engineering education at the dawn of pervasive computing. These strategies include fostering cross-disciplinary research collaborations, life-long learning, partnerships with industry in research and education, understanding the technical and non-technical issues concerning pervasive computing, and a systematic updating of the contents and structure of the software engineering curriculum. The author also points out the need for the removal of the funding and institutional barriers to cross-disciplinary collaborations in research and educational activities.

INTRODUCTION

In 1991, Mark Weiser, then Chief of Technology Officer for Xerox's Palo Alto Research Centre, laid out his vision for pervasive (a.k.a. ubiquitous) computing in his seminal article, *The Computer for the 21st Century,* by stating that *the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it*. Pervasive information environments are characterised as environments that are saturated with computing and communication capability, yet are gracefully integrated with human users.

Since 1991, many technological advances have been made to bring this vision closer to reality. A series of technical and non-technical issues remain to be addressed by cross-disciplinary research groups. Table 1 shows the list of key technologies that must be revamped and integrated to implement the pervasive computing vision [1][2].

Table 1: Key technologies involved in pervasive computing.

Device technologies	• Intelligent technologies • Mobile technologies
Network technologies	• Wireless technologies
Software technologies	• Agent technologies [3-5]
User technologies	• Automation technologies • Collaboration technologies • Knowledge access technologies
Perceptual technologies	• Speech technologies • Vision technologies

Non-technical issues, such as legal, ethical, social, cultural, political, educational, economic and organisational issues, must be explored in creating pervasive information systems and technologies.

CROSS-DISCIPLINARY RESEARCH AND DEVELOPMENT IN PERVASIVE COMPUTING

An overview of the major issues in research of pervasive information systems and technologies is first presented, followed by a discussion of the need for cross-disciplinary research groups to draw on a wide range of expertise to address these issues.

Wireless, Mobile and Handheld Computing

A key challenge in wireless, mobile, and handheld computing is the loss or degradation of wireless connections. By employing mobile agents, these devices could provide a reliable technology for message transport over wireless links [6]. Developing truly intelligent and useful, wireless, mobile and handheld devices require the use of mobile agent technologies, and voice and data communication technologies. Other issues that need to be addressed include the limitations on power, size, weight and energy sources, as well as performance, reliability and vulnerability to security and privacy violations. Hence, to develop intelligent wireless, mobile and handheld devices and technologies, there is a need for cross-disciplinary research collaborations to combine device, networking, software, user and perceptual technologies.

Wearable Computing

Wearable computers provide a unique platform for creating mobile intelligent assistants [7]. They are especially valuable in situations where a mobile user is engaged in the tasks where hands-free computer operation is essential (eg vehicle maintenance, bridge inspection or aircraft inspection) or where the user is disabled. In order to advance wearable computing, there is a need for multidisciplinary research to address a variety of issues, such as mobility, portability, usability, size, weight, safety, voice, vision, ruggedness, fashion and harsh operational environments, as well as a long battery life (requiring larger and heavier batteries – conflicting with some other requirements including size and weight).

Augmented Reality Computing

Augmented reality technologies use virtual information representations (visual, aural or other) to enhance human perception. Augmented reality (AR) thus creates the illusion that the real world is visually merged with a virtual world. This opens up a host of fascinating applications. For instance, using AR combined with image recognition could pop up a *water me* reminder when a person looks at his/her thirsty houseplant. AR's potential for wearable computers is enormous. However, superimposing the image of a virtual world on the real world requires a precise correspondence between the two worlds [8].

Mobile augmented reality requires both detailed geospatial databases that describe the fixed world and location-aware computing support to match the user's location with that description. For example, if fire-fighters could look at a burning building and see (as a transparent layer superimposed over the building) a representation of the activities on each floor, it might help saving human lives. Mobile augmented reality devices are expected to have an even broader impact, particularly by providing assistance to disabled people. The mobile augmented reality devices that enhance human vision could be used by sight-impaired individuals to overcome many obstacles when they move around. Furthermore, high-resolution geospatial data could deliver key information about the immediate environment to mobile users through sounds or tactile feedback. Similar techniques could be employed to augment human hearing. Research in this area could make it possible not only for users to hear sounds outside their normal perceptual range or to mitigate hearing deficiencies, but also could provide added sensory input in situations where vision is already fully engaged [9].

To make the AR a reality, cross-disciplinary research is needed to address various research issues. Firstly, identification of how to make a trade-off between conflicting criteria, such as AR's intense computational demands and the need for small and light wearable computers, needs to be carried out. Secondly, it needs to be ascertained how to design mobile AR devices that are capable of determining those aspects of reality to augment with which information components, and helping to identify the object of interest by providing users with the necessary information from several sources, including a comprehensive 3D model of the locale, dynamic information from sensors if the object pointed to is mobile, and information derived from analysis of the image captured by the camera. Thirdly, interfaces need to be designed for mobile AR devices to help users not only specify what type of information they need but also disambiguate the target of the request [9].

Context-Aware Computing

Context-aware computing describes the special capability of an information infrastructure to recognise and react to real-world contexts. A context comprises any number of factors, such as user identity, current physical location, time of day, date or season, weather conditions and what the user is doing. The main goal of context-aware computing is to acquire and utilise information about the context of a device to provide services that are appropriate to particular people, place, time, events, etc. Context information is useful only when it can be usefully interpreted and it must also be treated with sensitivity [9].

In mission-critical context-aware applications, the interaction between users and the context-aware computing system is not through an isolated device. The user interface design needs to utilise a set of diverse points of interaction based on the application domain. Context-aware computing completely redefines the basic notions of interface and interaction. A wide range of issues in context-aware computing needs to be explored by multidisciplinary research groups.

Location Sensing

Location sensing technologies, such as cell-based location sensing, expose the user's location to the sensing infrastructure. This has raised privacy concerns among cell phone users. The more seamless and easy to use a location-aware application becomes, the fewer reminders about their location being monitored will be provided to users. On the one hand, historical location information can be analysed to obtain insights into a user's typical movements – a violation of the user's personal privacy. On the other hand, the authentication of locations is difficult, because it requires that both the user's identity and his/her current location be established [9].

Cross-disciplinary research is required to address the following needs in location sensing:

- New user interface techniques that remind users that their locations are being monitored and alert them when the trustworthiness of the entity performing that monitoring changes;
- System design techniques that are capable of providing end-to-end control of location information;
- Efficient auditing mechanisms to record the exposure of location information;
- Fine-grained access control mechanisms to allow the precise release of location information to only the right parties under the right circumstances;
- Protocols and mechanisms to authenticate and certify an individual's location at any given time;
- Techniques for rapidly calibrating an environment for specific location-sensing technologies to reduce costs.

Location-Aware Computing

Location-aware computing is a new class of computing, based on mobile computing, context-aware computing, location sensing and wireless networking. Mobile computing devices provide access to information processing and communication capabilities, but are not necessarily aware of the context in which they operate. The most critical aspects of context are location and identity. Location-aware computing systems respond to a user's location, either spontaneously (for instance, warning of a nearby hazard) or when activated by a user request (for example, is it going to rain in the next hour?). Advances in location-aware computing could have important implications not just for how geospatial data are acquired but also for how and with what quality they can be delivered and how mobile and geographically distributed systems are designed [10]. Potential applications span virtually every aspect of everyday life, including a person's ability to respond appropriately to natural and human-induced hazards.

Supporting the acquisition and use of geoinformation from the field involves interaction issues associated with database access and knowledge discovery. Both efficient rendering and efficient transmission of geospatial representations are essential [9]. There is also a number of other needs to be addressed: lightweight, portable display technologies, such as electronic paper, foldable displays, handheld projectors (which can be pointed at any convenient surface) and augmented-reality glasses. To advance location-aware computing, there is a need for further cross-disciplinary research.

Sensor Computing

Weiser's vision of ubiquitous computing refers to smart sensing as an enabling capability for collecting specific information from its physical environment for the user. Sensors that record their location and the information about their surrounding environment (eg the temperature and humidity) are already being deployed to monitor the state of roads, buildings, agricultural crops, etc. Potential applications include the use of biological and chemical sensors for water quality control [11].

Smart dust, named for its small size and disposable nature, is an immersive sensing technology; it needs to be embedded in the space that is going to be sensed. Dust sensors could be used to monitor the structural decay of bridges, highways and buildings over time due to different factors, such as the corrosion of reinforcing metal and to detect overloads of design limits to prevent catastrophic damages, etc [12]. Cross-disciplinary research is needed to address the following non-technical issues concerning smart dust: legal or social obstacles to physically embedding dust sensors in a space; cost considerations for large spaces; and environmental concerns regarding the safe disposal of smart dust.

Brilliant rocks are non-immersive sensing technology. The National Aeronautics and Space Administration (NASA) and the geophysics community refer to this style of sensing as remote sensing. Manned aircraft, unmanned drones or aerial surveillance via satellite fall into this category. Most of astronomy involves non-immersive sensing using techniques like spectroscopy. A combination of brilliant rocks and smart dust can be used as a nervous system for the physical world that has both always-on and on-demand components. This combination will also have a right balance of speed, accuracy, longevity and cost-effectiveness for some application domains [12].

Security and Privacy Issues

Security and privacy issues have been raised in pervasive computing. On the one hand, a pervasive computing environment must be highly knowledgeable about a user in order to conform to the user's needs and desires without communicating with the user before taking every step. On the other hand, a system that is truly ubiquitous will encompass numerous users, physical regions and service providers. With the current technologies, perfect trust among all parties is an unattainable ideal [13].

Security and privacy issues are crucial in some application domains more so than in others areas. For example, the development, deployment and use of pervasive information systems and technologies (eg personal digital assistants, mobile management middleware, wireless connectivity and many medical applications) have emerged as the best way to help lower the costs of health care, which has been outpacing general inflations [14]. Legal and ethical issues have also been raised. The inappropriate disclosure of medical records involves substantial liabilities. The US Health Insurance Portability Accountability Act (HIPAA of 1996) has defined felony offences and penalties ranging from fines to prison terms for disclosing individually identifiable medical records. Cross-disciplinary research collaborations are needed to address these key issues.

A research group has developed a system in which applications wishing to obtain a user's location must inform the user of their intended use and the retention and dissemination policies with respect to the information. The system then checks these policies against the user's preferences before deciding whether to release the requested information. This new approach is in parallel with the World Wide Web Consortium's Platform for Privacy Preferences (P3P) system, which is designed to protect privacy on the Web. It does not enforce or guarantee privacy, but it does provide a framework by which location-data owners and users can agree on privacy practices [15]. Further cross-disciplinary research is needed in order to address the security and privacy issues in creating pervasive information systems and technologies.

Art and Entertainment in Pervasive Environments

Cross-disciplinary research is also required to explore not only the issues concerning the improvement of efficiency in work and other tasks, but also those related to development of new technologies for improving the quality of human lives through art and entertainment in pervasive environments.

A multidisciplinary research group at Cornell University is working on the design of pervasive computing systems that are embedded *not only in physical environments but also in culture, society, and history*. The members of this multi-disciplinary research group are not all software engineers. They have different expertise and experiences in the areas within computer science, user interface design, social science, cultural studies, architecture and product design [16]. This multi-disciplinary research group is working on a new design process of ubiquitous computing technologies that are thought provoking and relevant to all researchers attempting to create artefacts that will play an important role in developing future pervasive environments. In this spirit, the research group builds technologies to change what people can do, as well as the way that they think about technology – contextualising technology in culture rather than other technology [16].

STRATEGIES FOR RESTRUCTURING SOFTWARE ENGINEERING EDUCATION

Pervasive computing, a new emerging wave of computing, requires the restructuring of software engineering education to provide students with the appropriate educational experience. The following strategies for restructuring software engineering education are presented to help software engineering program to better prepare their students for working effectively in real-world multidisciplinary team environments. The suggested strategies include fostering:

- Cross-disciplinary (applied) research projects;
- Life-long learning;
- Partnerships with industry in research and education;
- Discussions about both technical and non-technical issues concerning the technologies for pervasive computing;
- A systematic updating of the contents – and even the structure – of software engineering curricula.

It is critical that educational institutions support and promote applied research activities and projects that engage students, faculty and other professionals across different fields. These cross-disciplinary activities and projects help students learn and enhance not only their technical skills, but also their communication and teamwork skills.

Considering the need for a rapidly evolving and highly diversified world of pervasive computing, software engineers need to keep their knowledge and skills current throughout their careers. Life-long learning is a necessity, not an option. It is thus essential to provide opportunities for software engineering students to recognise the crucial need for life-long learning and to acquire the skills to actively engage in life-long learning [1][17][18].

Industry-academic partnerships in research and education significantly help bridge the gap between software engineering education and practice and provide students with exceptional learning opportunities [1][17-20]. It is critical to differentiate an industry-academic partnership in education and research from a training exercise [1][20].

It is also critical to make curricula flexible and responsive to change and require a systematic updating of the content and the structure of software engineering curricula without sacrificing the enduring principles. It is also crucially important to require software engineering programs to include both technical and non-technical issues concerning the new pervasive information technologies and systems in their curricula. The information provided earlier in this article can be used for this purpose.

FUNDING AND INSTITUTIONAL BARRIERS

Fostering cross-disciplinary collaborations across diverse professional communities requires funding and institutional support. However, the common funding and political structures in colleges, schools, departments and programmes have been major obstacles to cross-disciplinary research and educational activities. The funding and institutional support of cross-disciplinary, integrative research and educational activities require cultural changes in academia (to break down the barriers between university *stovepipes*).

CONCLUDING REMARKS

Many more cross-disciplinary research collaborations are needed to explore the technical and non-technical challenges concerning pervasive computing and to help make trade-off decisions concerning conflicting criteria for developing and evaluating pervasive information systems. In monitoring such systems, the issues are truly complicated because individual devices can collect data for different purposes at different times, and combining the data collected by these devices can reveal information that could be in violation of one's privacy. No doubt, the major issue of security and privacy in the pervasive computing environments will, most likely, keep many researchers and policy and law makers engaged in discussions and brainstorming for a long time.

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