A IIIP Issues Paper

Invisible Computing: Vision or Reality?

Bharat Rao, Ph.D.
IIIP Academic Advisor
Associate Professor of Technology Management

Bojan Angelov
Doctoral Candidate in Technology Management

Polytechnic University
Brooklyn, NY

28 February 2008

The Institute for Innovation & Information Productivity

Abstract

Invisible, ubiquitous or pervasive computing has made steady progress since it was first conceptualized almost two decades ago. While the original vision of pervasive computing itself was very radical and elegant, the reality as it has played out in the realm of everyday products and services is quite different. There are still multiple perspectives on what truly constitutes a pervasive computing environment, and the delineation between its various facets is one fraught with definitional and operational challenges. This brief paper presents the idea of an emerging value chain comprised of (1) info-structures, (2) devices, (3) interfaces, and (4) smart spaces, which together form the core elements of a pervasive information environment. We believe that a shared understanding of this framework by numerous stakeholders will accelerate the deployment of pervasive information systems in today's service-oriented organizations, and lead to increased productivity, interactivity and customer satisfaction.

What is Pervasiveness?

Being pervasive means to be "diffused throughout every part of" – a system, context, or environment. In technology, pervasiveness refers to a resource so widely available that it is almost invisible to the end user. Businesses can also be pervasive by utilizing the emerging technologies enabling them to offer ubiquitous service experience to their customers. The philosophy of "ubiquitous computing" (UC) was advanced by Mark Weiser in his work at Xerox PARC (Palo Alto Research Center). In his seminal work, Weiser refers to pervasive information systems as the 'third wave' of computing (Weiser, 1991; Weiser and Brown, 1996). The first wave was the ***mainframe age***, wherein many people were connected to the resources of one powerful computer. The second wave, now in transition, was the ***age of personal computing***. One person maintained an intimate, albeit dysfunctional and asynchronous relationship, with a single computer. The dawn of the Internet created a "transitional" phase wherein the computer was connected to a larger network, but people essentially were subject to the physical restrictions of a desktop computing model. Finally, the third wave, or the ***age of pervasive information systems***, promises to push the presence of the computer into the background by giving it an almost invisible role.

Pervasive Information Systems Value Chain

As part of our recent research, we developed the idea of a "pervasive value chain" linked to changes in enabling technologies, their interconnections, and a broad business-driven trend towards "invisible computing". Today, we believe that Weiser's vision of truly invisible computing is fast becoming reality. Mobile computing in its current manifestation can be seen as a precursor to this third wave. Many computers, or microprocessor-enabled devices, are harnessed to serve one or more end-users. These devices use the Internet as a backbone to create a massively distributed information system. In essence, this pervasiveness is powered by an infrastructure of networks, databases and servers and an outer edge of devices and sensors connected by some form of an interface (software). In this paper, we use the terms pervasive and ubiquitous computing interchangeably, though there are instances in the literature that differentiate between the two with regards to the provided level of mobility (Lyytinen and Yoo 2002).

In order to obtain a more holistic picture of the different aspects of pervasive information systems, we propose four discrete levels of abstraction (see Figure 1 below) where the notion of user interaction and connectedness within a space (be it virtual or physical) become important. We emphasize that services built on the information systems platform are the point at which customers experience pervasiveness. Thus, it is not the technology itself that is pervasive, but the access, delivery, and consumption of information services. It is not just what the iPhone or Blackberry look like, but what they can do for you.

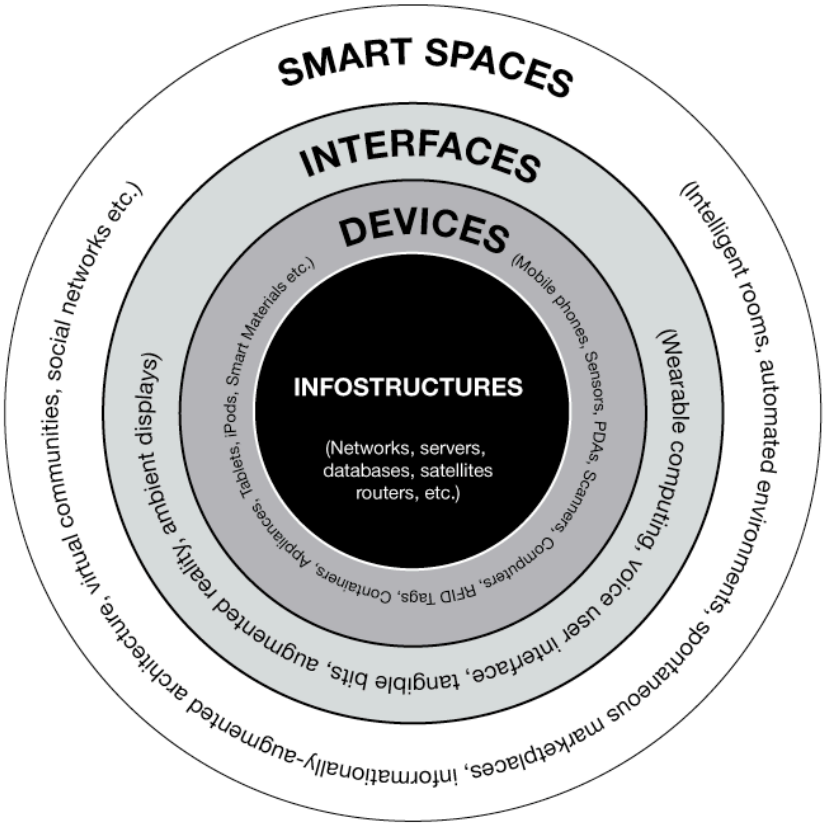

Figure 1 - The pervasive information systems value chain

We briefly describe below the key characteristics of each of these layers. Further elaboration of their impacts will be provided as part of our future research.

The **information systems architecture** (info-structures) layer represents communication channels, data and sensor networks, broadband internet access, and also the intelligent design of databases, storage, and network applications. Pervasive info-structure is all about access to information and services beyond the traditional client-server paradigm. It is the merger of computing and communications that is invisible

to the end-user (be it a human being or a machine), resting on the seamless relationship with devices and interfaces using the services of the info-structures.

A main tenet of pervasive information systems is the notion that computational power will be everywhere and that people will merely need to "tap into it" to derive its benefits. However, there has to be a way to plug into the computational environment. Since most of the power will be "out there," an entity looking to connect to it will in essence become a node on a large network. In each case, there will need to be some form of device that puts users on the grid. Inevitably, every participant in a pervasive information system will not necessarily be human or a computer in the traditional sense. We use the term **devices** to represent the clients of such a system. These devices will include mobile phones, sensors, actuators, PDAs, scanners, computers, smart cards, RFID tags, shipping containers, home appliances, medical devices, vending machines, tablets, iPods, ATMs, etc.. To date, the main way in which people have interacted with computers has been one person at one time sitting in front of one computer delivering explicit input. The vision of pervasive computing is to put many computers in the hands of the individual, or at least in very close proximity to them. Weiser and Brown (1996) also refer to this as "calm technology": putting devices at the periphery, embedded in the relationship between the environment and the end-user. As devices evolve, the increase in computational power, network access capabilities, and intelligent software play extremely important roles in the pervasive value chain.

The field of interaction design (also known as Human-Computer Interaction) has and will continue to drive the development and adoption of pervasive computing, thus leading to new and novel **interfaces**. Interaction designers are generally cross-functional teams of individuals including graphic designers, human factors engineers, psychologists, cognitive specialists, and include film and sound experts. Interaction designers measure the success of their designs through their effectiveness, efficiency, safety, utility, learnability, and memorability. The emergence of pervasive information systems will create a paradigm shift in the fundamental ways of thinking and considering how to design and build interactive products.

When a meaningful interaction takes place between a device and its environment, we take it to mean that the space in which they both exist has some intelligent attributes – we term this as a "**smart space**". For example, when a piece of building material is able to sense that it needs to be replaced and reports back this information to a monitoring database located on-site, it is tapping into a physical modality of the information system. Similarly, when we are able to provide location-based services and deliver marketing messages to consumers, we are in essence creating a new space referred to as a spontaneous marketplace (Rao and Minakakis, 2003). This is made possible by taking implicit cues both from the environment and the device, and applying them to make a product or service offering. We are practically bringing the shop to where the consumer is, rather than bringing the consumer to where the shop is (Fano and Gershman, 2002). Our notion of smart spaces refers to the provision of services built on the info-structures, accessed through the interfaces and utilized by the devices. Thus, integration, convergence, ubiquity, and omnipresence are the keywords defining the role of smart spaces not as much as a separate level in the value chain, but a unified view and glue keeping the value chain cohesive and horizontal by nature. In this perspective of smart spaces, the relationship between different actors in the environment is considered to be the focal point around which pervasiveness is experienced. The relationship can be between a service provider and a consumer, between a product and a consumer, and between devices in general. In short, smart spaces represent value creation opportunities. They go beyond ambient intelligence or some

mechanical construct, but in fact possess some of the cultural characteristics of the environment in which they operate.

Towards Pervasive Services

Research in pervasive computing has traditionally focused on engineering and design issues at the first three levels we have described (Lyytinen and Yoo, 2002; Borriello and Want, 2000). However, the emphasis has mostly been on engineering reliable devices that are power efficient and miniaturized, designing interoperable network architectures, and designing interfaces capable of harnessing the computational power with minimal effort. Our framework extends these ideas by linking the concept of pervasiveness to the emerging notion of customer experience, as enabled by technology, both hardware and software.

Parallel to the technological advances in information technology (IT), a growing interest in analyzing the social, organizational, and economic issues and challenges of pervasive computing has emerged. We argue that there is an ongoing shift in thinking about pervasive systems from a 'product' perspective to a 'service' perspective. Pervasive information systems and ubiquitous networks are the foundation for "ultimate commerce" or simply "u-commerce." U-commerce has been defined as "*the use of ubiquitous networks to support personalized and uninterrupted communications and transactions between a firm and its various stakeholders to provide a level of value over, above, and beyond traditional commerce*" (Watson, et al., 2002). Within the framework of our paper, u-commerce depicts a facet of the smart space reflecting the pervasive access and consumption of services rooted in the context, and at the very forefront of value creation.

The traditional information systems value chain has been vertically integrated, where infrastructure served as the basis for devices, interfaces, and applications to add value. It is our belief that the pervasive era of information systems brings a more horizontally integrated value chain. In fact, smart spaces are the convergence point of info-structures, devices, and interfaces. Value is created all over the entire spectrum of activities, and innovation is often concentrated at the boundaries between different levels (Fano and Gershman, 2002). It is interesting to note that information systems and technology are very often considered as the key facilitators for a service-oriented economy and society (Chesbrough and Spohrer, 2006). As applications and services based on them get more seamless with the end-user experience, they need to be created, delivered and monetized across a broad spectrum of media infrastructures and interfaces. The degree of lateral or horizontal integration can thus be expected to increase.

Implications and Future Prospects

The idea that multiple computing devices embedded in the environment will dramatically transform our lives represents a tremendous business opportunity and is one that requires an interdisciplinary approach at the outset. The use of "context-awareness," for example, will enable systems designers to create a whole new breed of software applications that utilizes information about the environment as part of the computing experience. This novel model of computing breaks the traditional desktop paradigm, and thus gives rise to new challenges in wireless protocols, spontaneous information systems and location based services, representing a key research opportunity area for *engineers and scientists*. Opportunities also abound for *businesses*, for pervasive computing represents a 'holy grail' in electronic commerce: the ability to perform transactions in real time any time and any place using any device (Fano and Gershman, 2002).

As discussed previously, innovation in the sense of the pervasive value chain often happens at the boundaries of different levels, but also at the core of supply-demand interaction. It is the coordinated relationship among various constituents in the value chain that defines and captures the real value of pervasive information systems. The pervasive information systems value chain is characterized by interdependency, horizontal integration and convergence over all levels.

This article introduced the pervasive information systems value chain as a guide to future development of a framework for analyzing the domain and industry boundaries, innovation and value creation processes, and important managerial implications related to the emerging opportunities of pervasive computing. We believe that service experience – the access and consumption of services – is the practical dimension of pervasive information systems, and as such it needs to be addressed with a framework that incorporates both the notion of pervasive computing and the dynamics of service provisioning. The third wave of ubiquitous computing is upon us, and it is time to fully reap its benefits.

References

Borriello, G. and **Want**, R. 2000. "Embedded Computation Meets the World Wide Web." *Communications of the ACM*, May 2000, Vol. 43 Issue 5, p59-66.

Chesbrough, H. and Spohrer, J. 2006. "A research manifesto for services science." *Commun. ACM* 49, 7 (Jul. 2006), 35-40.

Fano, A. and Gershman, A. 2002. "The future of business services in the age of ubiquitous computing." *Communications of the ACM* 45, 12 (Dec. 2002), 83-87.

Lyytinen, K. and **Yoo**, Y. 2002. "Issues and Challenges in Ubiquitous Computing." *Communications of the ACM*, Dec2002, Vol. 45 Issue 12, p62-65.

Rao, B. and Minakakis, L. 2003. "Evolution of mobile location-based services." *Communications of the ACM* 46, 12 (Dec. 2003), 61-65.

Watson, R. T., Pitt, L. F., Berthon, P. and Zinkhan, G.M. 2002. "U-Commerce: Extending the Universe of Marketing." *Journal of the Academy of Marketing Science,* 30(4): 329-343.

Weiser, M. 1991. "The Computer of the 21st Century." *Scientific American,* vol. 265, no. 3, Sept. 1991, pp. 66-75.

Weiser, M. and Brown, J.S. 1996. "Designing Calm Technology." *PowerGrid J.,* vol. 1.01, July 1996.

About the Authors

Bharat Rao is an Associate Professor of Technology Management at Polytechnic University in New York. He is also a Research Affiliate at the European Institute of Interdisciplinary Research in Paris.

Dr. Rao's current research focuses on the diffusion of emerging technologies, business model evolution, the integration of multiple technologies for improving business effectiveness, and global innovation strategy. His research has been published in the *Communications of the ACM*, *European Management Journal, International Journal of Electronic Commerce, Journal of Computer Mediated Communications*, *EM-Electronic Markets*, *Journal of Media Management*, *Technology in Society*, *International Business Review*, *Journal of the Academy of Marketing Science*, and in numerous conference proceedings and book chapters. He is also the author of multiple business case studies which have been published by Harvard Business School

Publishing, the Institute for Technology and Enterprise, and the European Case Clearing House. His recent research has been funded by the *National Science Foundation*, *NYSTAR (New York State Science Office of Science, Technology and Academic Research)*, and the *Othmer Institute for Interdisciplinary Studies*. Dr. Rao serves on the editorial boards of various academic journals including EM-Electronic Markets, International Journal of Business Data Communications and Networking and Electronic Commerce Research and Applications. He was recently involved in a team advisory capacity in formulating a telecommunications and economic development strategy for New York City, for the Office of Mayor Michael R. Bloomberg.

Dr. Rao earned a Ph.D. in Marketing and Strategic Management from The University of Georgia, and received a bachelor's degree in Electrical and Electronics Engineering from the National Institute of Technology in Calicut, India. Prior to joining Polytechnic, he held a post-doctoral Research Associate position at Harvard Business School in Boston.

Bojan Angelov is a doctoral candidate in Technology Management at Polytechnic University in New York. His research focuses on services innovation, management of disruptive technologies, ubiquitous technologies and services, managing emerging technologies, and global innovation strategy. His recent research has been published in the *European Management Journal*, various book chapters, and major technology management conferences.

Bojan holds a Masters Degree in Electrical Engineering and a Masters Degree in Management from Polytechnic University, New York, and a Bachelors of Science Degree from St. Cyril and Methodius" University (UKIM), Skopje, Republic of Macedonia.

About The Institute for Innovation & Information Productivity (IIIP)

The techniques for measuring performance today, from factory floors to the delivery of services to the outcomes of innovation, often fall short because they do not consider the value of new technology or provide meaningful indicators to determine tradeoffs among multiple investments. The Institute for Innovation & Information Productivity was formed in 2006 to break through outmoded, industrial-age biases and redefine knowledge economy measurements for individuals, teams, firms and nations. The IIIP develops new measurements and best practices to better understand the factors affecting business and organizational performance, studies the impact of technology, and encourages a global dialogue on improving operational results.

The IIIP is a mutual benefit, non-profit corporation. The membership and focus are global; the headquarters are located in San Francisco, California, USA. The Institute is governed by an elected board of directors, who are representatives of member companies.

Institute for Innovation & Information Productivity
Presidio of San Francisco
P.O. Box 29920 • 572 B Ruger Street
San Francisco, CA 94129-0920
USA
http://www.iii-p.org
Tel: +1.415.561.6275
Fax: +1.415.561.6120
Send inquiries to: LoBue@iii-p.org