INFORMATION EVERYWHERE

Peter Tarasewich and Merrill Warkentin

The growing capabilities of wireless technologies have created the potential for a "totally connected" society, one in which every individual and every device is (or can be) linked to all others without boundaries of place or time. The potential benefits of such an environment to individuals, workgroups, and organizations are enormous. But the implementation of such an environment will be difficult, and will require not just the ubiquity of computer technology, but also the transparent availability of data and the seamless integration of the networks that tie together data and devices. This article presents a model for a pervasive information environment that is independent of technological change, and presents reasons why such a vision is necessary for long-term organizational success.

PETER TARASEWICH *is assistant professor of MIS at the University of Massachusetts in Boston. His research interests include wireless E-commerce, Web engineering, pervasive information systems, human–computer interaction, and visualization.*
MERRILL WARKENTIN *is associate professor of MIS in the College of Business and Industry at Mississippi State University. His research is primarily in E-commerce, virtual teams, expert systems, and system security.*

Welcome to the unwired world. Communication is no longer restricted by wires or physical boundaries. People can communicate with each other anytime of the day or night. Users can access their data and systems from anywhere in the world. Devices can communicate with other devices or systems without the need for human intervention. At least in theory. The technology that currently exists, although still limited in certain regards (such as bandwidth and battery life), enables the creation of the devices and networks necessary for these wireless communications. But data is also part of the communication process for much of what we do, and is essential for communication between devices. Unfortunately, no matter how much effort is invested in creating a seamless technology network, the efforts will be in vain unless an equally seamless data structure is implemented along with it. Organizations must ensure that their information systems are structured to allow manipulation of data on or between the myriad of once and future technologies. Only then will there exist a truly pervasive environment that will benefit the dynamic information requirements of the individual, an organization, or society as a whole.

The idea of pervasive computing is not new. Discussions related to pervasive computing have been oriented toward technological factors. Proponents predict that networked computers (devices ranging from handhelds to information appliances to embedded sensors) will be diffused throughout everything we do and all systems with which we interact. Computing devices will be used to access information on anything and everything. Much attention is being paid to mobile devices and applications, but not to the information systems to which they belong. The ultimate goal should not be to make computing pervasive, but to make information available whenever and wherever it is needed, and to allow for complete flexibility.

In his article entitled "Pervasive Information Systems," Birnbaum[1] presented a vision for pervasive computing and technology, but did not address pervasive information systems in their fullest sense. There is often a

No matter how much effort is invested in creating a seamless technology network, the efforts will be in vain unless an equally seamless data structure is implemented along with it.

strong technological orientation in the way information systems are defined. But while an information system is implemented using technology, it should not be bound or driven by it. Furthermore, in addition to hardware and software considerations, an information system comprises people, procedures, and data functioning within an environment, all of which dictate important considerations for design and use.

Ubiquitous computing also plays a key role in the vision of a successful pervasive information environment. With ubiquitous computing, computers will be everywhere; they will be so prevalent that they will blend into the background. Technology will be embedded in many everyday devices, such as automobiles, home appliances, and even in building materials.[2] Sensors will be able to constantly transmit data from anywhere, while global positioning systems and proximity detection technologies will enable the tracking of devices as they move. In some instances, these embedded sensors will automatically respond to changes in their environment, a concept known as proactive computing.[3]

However, certain researchers have recognized the overemphasis on the latest gadgetry and gizmos.[4] The information appliances and other applications that we see appearing as part of pervasive computing may be nothing more than solutions in search of problems. There is a call for emphasizing data management in pervasive computing, and ensuring that information is available in the spatial or temporal context that will be most useful. Devices are simply used to accept or display data — the infrastructure that ties everything together is the most important concept. An example of this is a refrigerator that records the fact that the last can of soda was removed, and the user is reminded of that fact when passing a supermarket, or when a visit from guests is imminent. Soda is also added to the user's shopping list, which is available on his or her personal device or on the supermarket's own in-store displays.

Mark Bregman, general manager of pervasive computing at IBM, presented an insightful strategic viewpoint of pervasive information systems during a recent conference keynote address.[5] He noted that wireless technologies must be seen as an extension of E-business, but that successful companies need to implement them seamlessly, through a smarter infrastructure. Bregman emphasized that once this has occurred, "people will move quickly past the 'I have to get a device to access the information' mode of thought to the 'I have to access the information' mode of thought."

The Oxygen Project[6] advocates an information marketplace model, an environment of freely exchanged information and information services. In addition to this is the idea of "doing more by doing less," which is based on three concepts. These are (1) bringing technologies into people's lives (rather than the opposite), (2) using technologies to increase productivity and usability, and (3) ensuring that everyone benefits from these gains. Oxygen calls for general-purpose communication devices that can take the place of items such as televisions, pagers, radios, and telephones. These devices are software-configurable, and can change communication modes on demand (e.g., from a cell phone to an FM radio). Oxygen also calls for more powerful devices to be integrated into the environment (e.g., buildings, vehicles). These devices can control other kinds of devices and appliances, such as sensors, controllers, and fax machines. Oxygen links these two communication devices through a special network to allow secure collaboration and worldwide connectivity.

Other research also recognizes the current limitations and conflicting viewpoints of the current mobile computing environment. One vision for pervasive computing is based on three principles:[7]

1. A device is a portal into an application/data space and not a user-managed repository of custom software.
2. Applications should be viewed as a set of user-specified tasks, not as programs that run on certain devices.
3. The computing environment in general should be perceived as an extension of the user's surroundings, not as a virtual environment for storing and running software.

A similar vision, part of the Portolano Project, calls for a shift away from technology-driven, general-purpose devices toward ubiquitous devices that exist to meet specific user needs.[8] It calls for data-centric networks that run flexible, horizontally based services that can interface with different devices.

WHY DO WE NEED A PERVASIVE ENVIRONMENT?

A truly pervasive information environment stands to greatly benefit individuals, work-

The wireless applications that exist today — such as messaging, finding a restaurant, getting a stock quote, or checking the status of a plane flight — are all device and provider dependent.

groups, organizations, and society as a whole. The wireless applications that exist today — such as messaging, finding a restaurant, getting a stock quote, or checking the status of a plane flight — are all device and provider dependent. They are implemented on systems that are separate from other Internet or Web applications. Data is replicated from Web servers and stored separately for use with wireless applications. Ultimately, a single source of data is needed to allow for any type of situation that could arise. Data must be logically separated from tasks, applications, and technologies. What follows is a series of scenarios meant to illustrate different types of situations that require flexible access to data resources to be effective.

Workgroup Meeting

A competitor's introduction of a new product hits a company by surprise, and the company hastily calls a meeting to brainstorm a retaliatory product. Representatives from several of the company's key suppliers are able to join a cross-functional team at company headquarters. Several other suppliers are participating virtually in the meeting from offices, hotels, and other locations. The company's marketing executive is currently on a cruise ship in the Mediterranean, but under the circumstances agrees to spend some of her vacation time participating in the meeting from her cabin. Devices used by the participants during the meeting range from PCs to laptops to handhelds, all attached to the Internet, some by wires and some not.

Manufacturing calls attention to specifications, electronic drawings, and materials analyses taken from a reverse-engineering session conducted on the competitor's product. Finance runs an estimate of the materials and labor costs of the product. A supplier says that, based on an analysis he just performed, the performance of such a product could be increased tenfold with very little additional cost. Another supplier adds that some of the other materials could also be substituted with lower-cost alternatives. A new product specification is worked out and approved by the group. Based on current inventories of all the suppliers, production capacity of the company, and estimates of initial demand, a product introduction date is set. The executive notifies her global marketing staff to prepare for the new product launch.

Emergency

Sensors embedded in the paint of a house detect a rapid increase in temperature and notify Emergency Services that a fire has developed. Firefighting and medical crews are immediately dispatched to the scene. As the vehicles travel, the drivers are shown when and where to turn, by voice and by a visual guidance system. Other people in the fire truck receive information on wireless display tablets concerning the construction of the house. A map of the neighborhood and a blueprint of the burning house are also shown. The fire captain begins to develop a strategy on how to attack the fire, still minutes before arriving on the scene. Based on information received about the occupants of the house, he plans a search and rescue. The strategy details appear on the tablets of the other crew members. When arriving on the scene, a final assessment of the situation is conducted, and the fire is attacked.

Ninety seconds later, someone is brought out of the burning house — unconscious, but still breathing. Monitoring devices are placed on the patient. The emergency crew, along with a nearby hospital, begin to diagnose the patient's condition. The identification of the person, who was already thought to be living in the house, has been confirmed through a fingerprint scan. Past medical history on the patient, fed through a decision-support system, aids the process of determining a treatment. Doctors at the hospital confirm the course of action and request that the patient be transported to the hospital.

Business Traveler

A businesswoman is traveling from New York City to Moscow to close a business deal with a large multinational organization. On the way to the airport, her handheld device gives her updated gate information and departure times for her flight. A few minutes after her plane reaches cruising altitude, the phone at her seat rings. It is one of the marketing directors at her organization's Boston office. He asks her to review some updates that he has made to the proposal that she will be presenting tomorrow afternoon. The proposal appears on the screen embedded in the seat in front of her. She pulls a keyboard out of an armrest and makes modifications to two paragraphs. The director sees the changes as she makes them, and says he agrees with them. He also mentions that he received a call from Moscow five minutes ago, and that he agreed to push the meeting time back an hour. She checks the calendar of her handheld device and notices that it has already been updated to reflect the new time. Her device is also displaying a map showing an alternative route to the meeting, which is being recommended because of problems detected by the traffic sensor network in the city streets.

Logistics Management

The flexible manufacturing system in a Seattle plant automatically orders components for next month's production from the Asian supplier. The containers report their position to the shipper and to the plant at regular intervals as the containerized cargo is loaded onto ships by cranes at the cargo terminal, as they cross the ocean, and as they are offloaded onto flatbed rail cars or trucks. Because tens of thousands of containers on thousands of ships report their location to the global logistics network linking all supply-chain partners, the entire system is continually rationalized to reduce waste and delays. New timeslots are automatically calculated for scheduling ground transportation and for activities pursuant to anticipated delivery times.

Overall Pervasive Environment

The underlying activities and problems addressed in each of these scenarios are not uncommon. But what is unique *is* the use of a pervasive information environment that allows for efficient real-time solutions to each problem. The technology in each situation is independent of the task and can utilize any required data sets. This requires a model that divorces data management from the applications that use data and the devices that interface with the applications. The following section describes such a model.

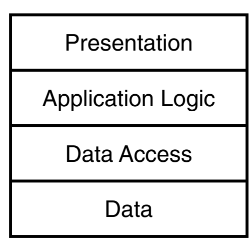
MODELING THE PERVASIVE INFORMATION ENVIRONMENT

Organizations must maintain a focus on IT as an *enabler* for information systems. Technology will provide the ability to communicate over the Internet anytime from anywhere. The *form* of input and output is determined (and limited) by the I/O device used (e.g., cell phone, PDA, embedded sensor, robot, laptop, personal computer). Wireless and mobile devices may always have limitations in terms of screen size, interactivity, and communication speed relative to physically connected devices.[9] Well-designed processes are a necessity and will ensure that information systems function well, no matter what technology is used to access them or what the user needs from them. System flexibility is required to support users in this new, fast-paced dynamic global environment. The user should never have to concentrate on the task of using technology or applications, but only the task at hand. Access to data and systems should be straightforward and intuitive, without regard to configuring devices, reformatting output, selecting protocols, or switching to alternate data sets.

Well-designed processes are a necessity and will ensure that information systems function well, no matter what technology is used to access them or what the user needs from them.

The governing principle for establishing a pervasive information environment is "access to one set of information anytime from anywhere through any device." To accomplish this goal, information systems should be structured according to the four-layer model presented in Exhibit 1. This model is an extension of similar multi-layer models that have been used for database and network systems. The user interacts only with the highest layer: the *presentation layer*. In this layer, the devices utilized to access, send, and receive information must be selected and implemented. Bandwidth limitations will affect the use of most of these devices, especially wireless ones, for the foreseeable future. The *application logic layer* comprises the applications that process and manipulate data and information for use on devices. Application logic can reside on a device itself or elsewhere within the information system. Applications may also provide context for converting raw data into organizational knowledge. *Data access* concerns the actual retrieval of stored data or information, and the execution of basic processing, if required. Database queries fall into this level. At the data access level, the use of various wireless and other protocols facilitates the smooth transfer of data from the disparate sources of data.

EXHIBIT 1 Pervasive Information Systems Architecture



For the sake of application independence and data integrity, data representation format must be independent of the presentation format.

The lowest layer is the *data storage layer*, which forms the foundation for all information networks. Its focus is *how* and *where* to store data in an unambiguous secure form. Data integrity is critical, so the underlying data structures (whether object oriented, relational, or otherwise) must be carefully conceived and implemented. One crucial issue is data format; incompatible data formats can prevent flexibility in the applications that access the data. We must maintain an environment in which data from heterogeneous and distributed sources, including embedded technologies, can be readily combined and delivered. This may require the use of middleware to achieve compatibility between the data sources.

In addition to issues affecting individual layers, there are some that concern the interaction between layers. Seamless transfer between presentation environments will be necessary when moving from location to location and from device to device. Security issues will affect all four layers. Organizations must also ensure that their network communications are not intercepted in this "anytime, anywhere" environment, and that data privacy requirements are met. These challenges will continue to shape the process of designing and implementing truly useful pervasive systems in the future.

CREATING THE PERVASIVE INFORMATION ENVIRONMENT

To accomplish the goal of a flexible, pervasive information environment, one set of data must be maintained. Yet this data must be available to any application and any device, now or in the future. This information vision will become an imperative for all organizations as they struggle to compete in a rapidly changing information environment. There may be many different ways to implement the model described in this article, and these paths may be difficult to execute. The remainder of this article, while not proposing or advocating a specific implementation design, describes research that might support a solution. Also presented are general concerns that must be addressed to achieve this environment.

The Oxygen Project described above may offer the best implementation design to allow for the vision of pervasive information environment articulated in this article. Although it appears to allow a great amount of flexibility, it is still very device dependent. Access and collaboration revolves around specific devices, although they seem to be multipurpose and can communicate with other devices. Furthermore, Oxygen does not address the concerns of the data infrastructure necessary to support such a pervasive information environment.

Evolving technologies may provide the foundation for implementing the individual layers of the pervasive information model. The presentation layer may benefit from several of these technologies.[7] One is the concept of a distinct user-interface management system, which clearly separates the user interface from application logic. Web technologies such as Java applets, which are device-independent programs, may also be useful. The relatively newer service technologies (also known as E-services), which allow applications to dynamically request needed software services from outside sources, are also promising.

One solution for the application layer and its interface with the presentation layer has already been proposed, using an application model based on a vision for pervasive computing described previously in this article.[7] The model is currently being implemented as part of continuing research, based on the assumptions of a services-based architecture wherein users will interact with applications through devices that are most readily available at the time. The Portolano Project also supports this application model, with research focused on practical applications such as a pervasive calendar system and infrastructure issues such as service discovery.

The most difficult layers to address are the data and data access layers. For the sake of application independence and data integrity, data representation format must be independent of the presentation format. Yet raw data is rarely useful without the lens of organizational and environmental context. Although raw data itself is not useful for most purposes, and must be converted into information to provide meaning and value to decision makers and processes, the data representation format is critical. Logical data storage designs must be based on sound principles of data integrity. And the metadata or context must also be stored and communicated to the applications or devices that use it. Further complications arise if the context changes, or if the data can be used in multiple contexts. Data and metadata models must be carefully designed to ensure that all systems and individuals using the data will be presented with meaningful and accurate data within the context of its use. Raw data must always be available and metadata must be maintained independently to ensure that they can be altered as the environment and context change. Thus, metadata really forms a sub-layer on top of the lowest layer, converting the data into information as it is acquired by higher layers.

In terms of inter-layer issues, there are several technologies that might play a part in creating a secure, seamless environment. Agents could be used to follow a user from place to place and from task to task. Research conducted with software agents shows that they can be used to facilitate the movement of users from one device to another.[10] Data must also be protected as it travels to where it is needed. Risks of unauthorized data interception can be reduced through frequency hopping and encryption, and biometric technologies can be used to verify the identity of people who are accessing data through different devices.

This ubiquitous network means that we will not only have access to our data and information from everywhere, but that it will reside on the network, where it will be secure and accessible from multiple locations and with multiple devices.

CONCLUSION

One corporate mantra from the early 1990s was "the network *IS* the computer." The concept of pervasive computing depends on pervasive access to *all* data. If we migrate toward a pervasive computing environment, we also need ubiquitous, secure access to all data from any device, wired or wireless. This ubiquitous network means that we will not only have access to our data and information from everywhere, but that it will reside on the network, where it will be secure and accessible from multiple locations and with multiple devices. This valuable corporate asset should be *accessible* from anywhere, and transparent data availability needs to be maintained. However, data should not be *stored* everywhere and anywhere. By following the multi-layer approach described above, organizations can ensure that data will be available to users and automated systems whenever and wherever they are in a secure manner with embedded contextual metadata.

The days of individuals "going to the data" (walking to computers tethered to the network) instead of having the data come to the individual are numbered. The world is quickly becoming a place of full-time and ubiquitous connectivity. Technology is marching forward, but these advances often precede the development of corporate and public policies and procedures for integrating and managing them.

Decisions concerning system architectures necessary for maximum leverage must be carefully evaluated and executed. It is also necessary to evaluate the extent of the benefits that this connectivity will have on individuals and organizations. With the current technology-driven model, the benefits of wireless technology will be limited. A more comprehensive perspective must drive the process, one that enables seamless integration of networks. The pervasive information model presented in this article can foster a flexible environment that can meet all users' long-term dynamic needs and ensure that the real potential of the technologies can be achieved. ▲

References

1. Birnbaum, J., "Pervasive Information Systems," *Communications of the ACM,* 40(2), 40-41, February 1997.
2. Estrin, D., Govindan, R., and Heidemann, J., "Embedding the Internet," *Communications of the ACM,* 43(5), 38-41, May 2000.
3. Tennenhouse, D., "Proactive Computing," *Communications of the ACM,* 43(5), 43-50, May 2000.
4. Huang, A.C. et al., "Pervasive Computing: What is it Good for?," *Proceedings of the ACM International Workshop on Data Engineering for Wireless and Mobile Access,* 1999, 84-91.
5. O'Hanton, C., "IBM: Wireless E-Commerce Next Revolution," *Computer Reseller News,* June 13, 2000, http://crn.com/dailies/digest/dailyarchives.asp?ArticleID=17468.
6. Dertouzos, M., "The Oxygen Project: The Future of Computing," *Scientific American,* 281(2), 52-55, August 1999.
7. Banavar, G. et al., "Challenges: An Application Model for Pervasive Computing," *Proceedings of the Sixth Annual ACM/IEEE International Conference on Mobile Computing and Networking,* 2000, 266-274.
8. Esler, M. et al., "Next Century Challenges: Data-Centric Networking for Invisible Computing. The Portolano Project at the University of Washington," *Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking,* 1999, 256-262.
9. Tarasewich, P. and Warkentin, M., "Issues in Wireless E-Commerce," *ACM SIGecom Exchanges,* 1(1), 19-23, Summer 2000.
10. Kotz, D. et al., "AGENT TCL: Targeting the Needs of Mobile Computers," *IEEE Internet Computing,* 1(4), 58-67, July 1997.