Manuele Kirsch Pinheiro
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The Evolution of Pervasive Information Systems

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Preface

The purpose of this book is to combine "state-of-the-art" solutions of various research communities (such as Information Systems Engineering, Cloud Computing, Fog/Edge Computing, Pervasive systems, Distributed systems, Middleware systems) related to the Pervasive Information Systems emergence as a common point of view. Pervasive Information Systems (PIS, for short) are deeply multidisciplinary systems, demanding a holistic view in which multiple domains are invited to contribute.

Indeed, new IT trends have an important impact on IT infrastructures, which become more and more heterogeneous, flexible, and dynamic. For example, IT infrastructures now are supposed to:

- Push the business by supporting alternative pervasive business processes
- Capture data from IoT devices, which can be used to improve business layers

PIS should be aware of the evolution of its real environment and its own execution environment, helping to adapt its behavior at each layer according to the situation at hand.

Therefore, Kirsch Pinheiro et al. introduce in chapter "What is a "Pervasive Information System" (PIS)?" the definition of PIS and present a transversal view of a PIS, its interactions, and the multiple research domain that contribute to this view. This chapter also describes the implications of its adoption on both technical and organizational aspects, identifying a set of requirements for the construction of a PIS and its operation.

In chapter "Design and Modeling in Pervasive Information Systems", Souveyet and Deneckere propose a systematic literature review to analyze how researchers handle the design of PIS. This literature review demonstrates that the requirements identified in chapter "What is a "Pervasive Information System" (PIS)?" remain an open issue for PIS at the design level.

In chapter "The Context Awareness Challenges for PIS", Kirsch Pinheiro discusses the challenges related to context awareness support on PIS. Multiple insights are highlighted from the literature, including the need for an efficient middleware for context awareness support, but also the opportunities that arise with

Edge Computing and Edge Learning technics that are respectively the subject of chapters "Middleware Supporting PIS: Requirements, Solutions, and Challenges" and "Edge Computing and Learning".

In chapter "Middleware Supporting PIS: Requirements, Solutions, and Challenges", Taconet et al. examine challenges related to middleware supporting PIS activities. Several requirements and state of the art of available solutions are discussed, with a particular interest in energy concerns.

In chapter "Edge Computing and Learning", Lalanda expands the vision of PIS toward IoT, Edge Computing, and Edge Learning (Edge AI). By analyzing usages and similarities among these research domains, this chapter tackles the opportunities and challenges for the deployment of PIS.

Looking closer to implementation aspects, Le Moël and Carrilo produce in chapter "IS: IoT & Industry 4.0 Challenges" a detailed panorama of environments, protocols, and standards that enable the implementation of PIS over IoT and Industry 4.0 environments. By observing how context information is handled in these environments, the authors invite a reflection on how to conciliate customer and industry goals with the help of PIS.

Finally, going further on the deployment of PIS aspects, Fernandes et al. produce in chapter "PIS: Interoperability and Decision-Making Process – A Review" a detailed survey on requirements and strategies to ensure the interoperability of PIS. This is indeed a key aspect for the integration of services and the adoption of PIS.

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Correction to: PIS: Interoperability and Decision-Making Process—A Review C1

What Is a “Pervasive Information System” (PIS)?

Manuele Kirsch Pinheiro, Philippe Roose, Luiz Angelo Steffenel, and Carine Souveyet

1 Introduction

The integration of new technologies such as IoT, Big Data, Cloud and Edge Computing, as well as new practices, such as agile and DevOps makes organizations rapidly evolving. Through these technologies and practices, organizations are mainly looking for more flexibility in order to better react to a dynamic business context.

The Information Technologie (IT) domain is gradually embedded in the physical environment and can accommodate the user’s requirements and desires when necessary. This evolution significantly changes the way Information Systems handle its infrastructure. The traditional approach in Information Systems Engineering is silo-based, in which the IT business services layer and the IT infrastructure layer are always managed separately, whereas this evolution implies considering Information Systems beyond the organization’s physical environment to integrate new technologies in a transparent manner, leading to a pervasive environment whose behavior should be more and more reactive & proactive. It corresponds to an important change for Information Systems Engineering and for IS themselves, which are becoming what we call here Pervasive Information Systems.

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Pervasive Information Systems (PIS) can be defined as a new class of Information Systems. It can be characterized by an IT that is gradually embedded in the physical environment and can accommodate the user's requirements and desires when necessary. In contrast to traditional Information System, Pervasive Information Systems should be aware of the evolution of its real environment and its own execution environment, requiring a holistic view of them at the design time but also at the execution time. Thanks to these multiple influences that characterize this new generation of Information System, Pervasive Information Systems are deeply multidisciplinary systems, demanding a holistic view in which multiple domains are invited to contribute.

The purpose of this book is to combine "state-of-the-art" from various research communities related to the PIS emergence (such as Information Systems Engineering, Cloud Computing, Fog/Edge Computing, Pervasive systems, Distributed systems, Middleware systems), in order to build such a holistic view. But, before analyzing the different aspects contributing to this view, it is necessary to define what is a Pervasive Information System and what can be its outstanding characteristics. In this first chapter, we tackle this question, abording different definitions found in the literature and proposing a set of requirements and characteristics for those systems.

The remaining of this chapter is organized as follows: Section 2 remind the definitions of traditional Information Systems; Section 3 tries to understand the evolutions leading to emergence of PIS, while Sect. 4 proposes a definition for PIS. Section 5 identifies relevant requirements and additional characteristics for these systems, before concluding on Sect. 6.

2 What Is an Information System (IS)?

Before considering Pervasive Information Systems (PIS), it would be important to consider the notion of Information System (IS) itself.

Several definitions for IS can be found in the literature. For instance, Laudon and Laudon (2013) consider as IS as an interconnected set of resources which are able to gather, to handle, to store and to disseminate information in order to contribute to decision making, coordination, control and management in an organization. Rolland et al. (1988) have defined IS as set formed by: data; rules that define the informational functional; procedures to collect, store, transform, retrieve and communicate information; human resources and technical means that cooperate and contribute to system function and to achieve its purposes.

Carvalho (2000) has underlined that there is more than one possible meaning for the term "Information System". This author has studied multiple definitions, emphasizing common aspects characterizing these definitions (and by extension the IS themselves): all definitions deal with information; they are all related to organizations or to the work carried out in organizations; and they all are related to information technology, either because they can benefit from its use or because they are made with computers and computer-based devices. Most of the definitions cited by Carvalho (2000) mention information that are necessary to and handled by the organizations, as well as the presence of both IT elements and human/manual elements, reveling a complex ecosystem of resources. According to Carvalho (2000), we may see an IS as: (i) an object that deals with/process information, that collects, store, transmit, code/decode, calculate and create information; and/or (ii) an object whose purpose is to inform, to contribute to someone's acquisition of knowledge, which is necessary for executing some action in some context. Through these definitions, it becomes clear that we are facing a complex ecosystem composed of different aspects related to information (production, management and dissemination) in an organization, and of resources (human and IT) necessary to handle it, acting together on the behalf of organization's interest.

In the last decades, Information Systems have become an important aspect for every organization, contributing to its overall performance. This impact can be observed through the last decades of researches on management of IS, as underlined by Desq et al. (2016). However, we could observe in the last years the growing importance of IT aspects on IS. On many organizations, IS is mostly considered as a set of IT resources necessary for the organization's process and global running. In this sense, IS is often perceived as a set of IT resources controlled by the IT department, who masters all its components and whose existence is bounded by the limits of the organization. In this IT-driven perception, an IS is perceived as a complex construct with technologies, information, processes and practices necessary for satisfying stakeholders' needs and reaching organization's goals. The business aspects represent then the guiding line for the management of this construct, which remains stable: every single component is decided and managed according organization's needs. It is precisely this stability and this fined-tuned control that new technologies and practices are bringing into question.

3 Information System Evolution: Towards a Pervasive Information System

The last decades have witnessed several technological evolutions and new uses that have strongly impacted IS. Among the new trends that have emerged in recent years, we may cite BYOD, IoT, Big Data, Cloud Computing and Edge/Fog Computing, and the democratization of Machine Learning.

The introduction of these trends brings profound changes in organizations and in their Information Systems (IS), as they are now facing a pervasive environment. These systems and their users are confronted with a growing heterogeneity that must be managed and understood. In order to better understanding the upheaval motivated by the introduction of those new trends, it is necessary to get a closer look on these trends, which can be organized on four categories: the usage evolution, the barrier with the physical world, the data revolution and the IT infrastructure.

Usage Evolution

The development of mobile technologies, including 4G, has contributed to the democratization of the Internet access with a reasonable bandwidth almost everywhere, which has also contributed to the adoption of the BYOD (Bring Your Own Device) practice. BYOD consists in using one's own personal computer at work. According to this practice, employees use their own personal terminals to work, navigating seamlessly between their private and work spaces, instead of accumulating multiple terminals according to circumstances, location or professional needs (Chang et al. 2014). This mix of personal and professional hardware represents a significant change for organizations IT departments, which traditionally govern, deploy and control all technologies used by employees/collaborators for their professional activities (Earley et al. 2014). Today, it becomes common (or usual) to use your own personal devices (which are no longer limited to laptops) to access your company's information system, wherever you are. A ubiquitous access "Anytime, anywhere" from any kind of terminal has become a reality. According to Andriole and Bojanova (2014), the use of new devices such as Microsoft HoloLens, Apple Watch, and other Bluetooth devices, creates new opportunities for businesses as these new devices are changing the way we browse, search, shop, and even live. It is therefore natural to think that the arrival of these new personal devices into organizations may also change the way we work.

Breaking the Barrier with the Physical World

The introduction of Internet if Things (IoT) technologies on companies offers new opportunities of interacting with the physical environment, and through these new interactions, it brings new business perspectives. According to Sundmaeker et al. (2010), it is expected that IoT objects will become more and more active, participating in different aspects of society, through business, information and social process. The informational aspect remains probably the most prominent one within today's organizations. Thanks to the IoT, it is possible to easily (and even continuously) collect information from the physical environment, but also to act upon this environment through sensors and actuators often connected to networked nano computers with some computing power. The physical environment can then become an integral part of business processes and, consequently, part of the Information System itself, as shown by the recent development of Industry 4.0, which heavily relies on the IoT and on the data coming from it, as observed by Lu (2017). Data can be new collected almost everywhere directly from the physical environment. As a consequence, the Information System is not anymore bounded to a world of virtual/digital objects, it extends its action into the real/physical world.

Data Revolution

The data collected from IoT objects enriches an already large set of available data within organizations. Big Data platforms allow to better control this impressive data volume and to exploit it properly. The recent success of Data Lakes (O'Leary 2014), often built on the top of platforms such as HDFS, is an excellent illustration of the definitive adoption of Big Data into organizations. This massive volume of data is now available to data scientists, who can extract an added value from it, thanks to multiple data analysis techniques, including those derived from Machine Learning, whose success often depends on the availability of such a large volume of data. The growing interest of companies on Machine Learning techniques illustrates the interest of those on exploring this data and on the potential added value it may offer. Nonetheless, the possibility of performing such analysis depends on the availability of an appropriate infrastructure allowing this kind of exploitation, demanding an appropriate infrastructure and (human resource) skills for doing so. The availability of these new sets of IoT data imposes also considering its management, and particularly handling privacy, security and data quality issues, whose impact grows together with volume.

IT Infrastructure Flexibilization

Last but not least, IT infrastructure has significantly changed with the popularization of Cloud Computing platforms. Indeed, the rise of Cloud Computing has enabled many organizations to rationalize their IT infrastructure. Cloud Computing can be seen as the ability to access a pool of resources owned and maintained by a third party via the Internet. It is not a new technology by itself, but a new way of consuming computing resources (Ferguson-Boucher 2011). In the cloud model, the resources no longer belong to the organization, but they are most often "leased" from one or more providers according to the organization's needs. Cloud resources are thus perceived as having a low maintenance cost, switching to an on-demand model in which organizations may adapt their consumption according to their needs and only pay for the resources they actually consume. However, the adoption of the Cloud model is often accompanied by some fears related to the outsourcing of data and data processing. These fears concern in particularly security, confidentiality and network latency issues. The choice between deploying a certain service in an internal organizational resource or outsourcing it into a public Cloud resource becomes now as strategic as technical. Consequently, resources are more and more visible and must now be managed from more than just a technical perspective.

Edge/Fog Computing have reinforced this aspect. Fog computing is an architecture that extends services that the cloud provides to the Edge devices. It can be seen as a new paradigm for disseminating computing, storage and service management closer to the end user, all along the continuum between the cloud, and objects (IoT) and end devices (Atta-ur-Rahman et al. 2021). Cisco was first introducing the term Edge Computing in 2012 as it works at the edge of the network, but it is also called Fog as we use close to the ground services. Thus, thanks to Edge/Fog Computing platforms, it is possible to consider the use of proximity resources for the execution of certain services. This makes it possible to consider the use of resources other than those located in data centers or in Cloud platforms to run services, offering new perspectives for further rationalizing the use of available resources.

Moreover, the current trend towards increased use of micro-services in organizations, which advocate for a finer breakdown of functionalities, is enabling applications to be deployed more easily over differ kind of infrastructures. It is now possible, with the help of micro-services, to envisage an opportunistic use of available resources, as supported by (Mulfari et al. 2015; Villari et al. 2016). All the conditions are thus in place to enable the dynamic deployment of IS services over resources as varied as cloud resources (private or public), traditional data center resources, network devices, IoT, or mobile terminals, in a transparent way. All these developments have transformed the nature of the resources available in Information Systems. These resources have become more distributed, heterogeneous, and organized in an infrastructure that has itself become more dynamic. The placement of services on these resources, which before stated for a "simple" technical problem, becomes a non-trivial problem, with a strategic dimension.

All these new technologies and trends are gradually entering into the composition of Information Systems, leading to their evolution. Today, we are observing the emergence of a new generation of IS that could be called pervasive, both by their distribution beyond the organization's boundaries, and by the pervasive nature of the environment they integrate. Thanks to these new technologies and practices, Information System can extend well beyond the physical limits of the organization. They are now accessible everywhere, they include resources both inside and outside the organization, and they can even integrate the physical environment itself. As pointed out by Castro-Leon (2014), the notions of what is inside or outside an organization have become blurred with processes that use resources other than those within the organization's traditional perimeter. The environment has become more and more heterogeneous, integrating very different devices, which can moreover be mobile, adding dynamism to the heterogeneity. Thus, we have Information Systems and IS users that are increasingly confronted with a heterogeneous and dynamic environment, in terms of resources, services and data. We may expect from these systems more flexibility and a certain "smartness" in order to better carry out the organization's activities and better satisfy user's and organization needs. This expected "smartness" is one of the main points leading to the rise of Pervasive Information System, whose definition is discussed on the next section.

4 Defining Pervasive Information System

In this section, we will try to define what is a Pervasive Information System, based on the literature and on the expectation, one may have about these systems.

Several visions of the term "Pervasive Information Systems" exist. A first trend is summed up by the fact that the keyword "pervasive" is associated with ubiquitous information that is captured anywhere, thanks to sensors scattered around the physical environment. The system, in this case, is designed as a sensor-oriented system to capture information anywhere and anytime. This trend is represented in particular by systems derived from IoT (Xiao et al. 2017; Brahem et al. 2021; Lippi et al. 2021; Kim and Lee 2021). However, even if the data represents an important concern on these systems, notably thanks to IoT and Big Data related technologies, this evolution cannot be reduced to the availability of data everywhere. It is not only a matter of data, it is about a whole Information Systems that can be deployed everywhere, available all the time. In short, it is about the Weiser's (1991) vision of Ubiquitous Computing becoming reality over current Information Systems.

Another trend consists in assimilating these systems to ubiquitous environments, autonomously providing comfort to one or more users. These pervasive systems are often limited to an application, a location and/or a set of intelligent technological devices. However, they are rarely connected to the trades or traditional Information Systems of an organization. We then speak of pervasive systems or rather applications, of which we can cite (Maass and Varshney 2012; Cheraghi et al. 2021; Lalanda et al. 2021; Raychoudhury et al. 2013; Romero et al. 2010). This trend lacks of a business view, which characterizes traditional Information Systems. Besides, as we could observe on Sect. 2, Information Systems cannot be reduced to a simple set of applications, which will be the case if we consider Pervasive Information System only through pervasive systems lens.

Finally, the trend that we consider in this chapter is indeed that of an Information System that is becoming pervasive. It must consider events in physical environments and offer adapted services as close as possible to users. In this trend, we can cite (Kourouthanassis et al. 2010; Najar et al. 2014; Hauser et al. 2017).

For Kourouthanassis and Giaglis (2006), a Pervasive IS can be seen as an emerging class of IS in which IT is gradually embedded in the physical environment, capable of accommodating users' needs and desires when necessary. The term "Pervasive Information Systems" was introduced by Joel Birnbaum (1997). In this article, Birnbaum (1997) considers a technology that becomes pervasive, and thus invisible to the human eyes: "Today's schoolchildren don't think of TVs and telephones as technology-they can't imagine life without them. Tomorrow's children will feel the same way about computers, the networks connecting them, and the services they perform". This corresponds to the "cognitive invisibility" reported by Bell and Dourish (2007). These authors mention a technology that is invisible to us, since we use it continuously without necessarily perceiving it as computers. Birnbaum (1997) talks about an information technology that should become intuitively affordable for everyone and that should bring enough added value to justify the necessary investments. Considering the aforementioned evolutions and trends, as well as the opportunities they offer to the organizations, we may say that this point has been reached. And the consequences for IS are not insignificant. Birnbaum (1997) emphasizes in particular the expectations with regard to the services offered. For this author, in the same way that people expected (in 1997) to have a dial tone when they picked up a telephone handset, people will (nowadays) wait for useful information to be available and ready for use. To sum up, even if Birnbaum (1997) does not precisely define the notion of PIS as Kourouthanassis and Giaglis (2006) do, the elements that he enumerates in his article, *i.e.* the technology that becomes "invisible", the importance of services and the added value of information, the paradigm shift with people paying by use, modifying what was before a capital investment in service, etc., characterize quite well what today's information systems are becoming.

Again, according Kourouthanassis and Giaglis (2006), unlike traditional IS, PIS encompass a more complex and dynamic environment, composed of a multitude of artefacts (and no longer just desktop computers), capable of perceiving the users' context and of managing the mobility of these users. In the literature, the term "mobile" IS (Krogstie et al. 2004) is also employed, with the notion of mobility used in a broad sense: spatial, temporal, but also contextual. Krogstie et al. (2004) refer to systems characterized by their dynamism, by frequent changes of context (spatio-temporal, environmental context, but also relative to users, their tasks and even available information), and thus requiring an important capacity of adaptation from the system to the users. Even if (Krogstie et al. 2004) mention in particular the adaptation of interfaces for a better interactivity with users, whatever the terminals they use, it is easy to imagine that this adaptation should be extended to the proposed services and their implementation.

Therefore, we are confronted with the emergence of Information Systems that extend beyond the physical (and logical) boundaries of the organization, that integrate new technologies and an environment that has itself become pervasive (in a technologically charged sense) in a more or less transparent way, and from which we expect more intelligent behavior, both reactive and proactive.

Pervasive Information Systems are more then never characterized by its complexity, whose management should change when compared to traditional IS. Indeed, traditionally, Information Systems engineering has mastered the complexity of the system by a layered and "silo" view. This traditional compartmentalized view limits interactions between the different levels and does not promote the flow of information between them. However, the introduction of new technologies and new practices has turned this organization upside down. For example, the strategic nature of the choice between an "on-premise" or Cloud deployment, or the migration of systems to a micro-services architecture are all illustrations of these upheavals. The complexity of managing IT infrastructure is no longer just a technical issue but becomes constrained by policies that the business can drive. Likewise, the ubiquitous IT infrastructure in an organization's physical environment enables information to be captured that can influence the business processes supported by the information system and the organization. Nevertheless, when one considers an Information System that becomes pervasive, the synergy between the business layers of the Information System and the distributed, dynamic and heterogeneous IT infrastructure then becomes an essential factor of PISs.

Therefore, this synergy forces us to question the stratum of partitioned layers in which IS engineering was built and to think of the pervasive information system according to its vertical dimension (verticality) from the business to the IT infrastructure in an integrated manner (see Fig. 1).

In order to promote such verticality, several aspects ought to be considered. In the next section, we consider relevant requirements and characteristics that, for us, should designate Pervasive Information Systems.

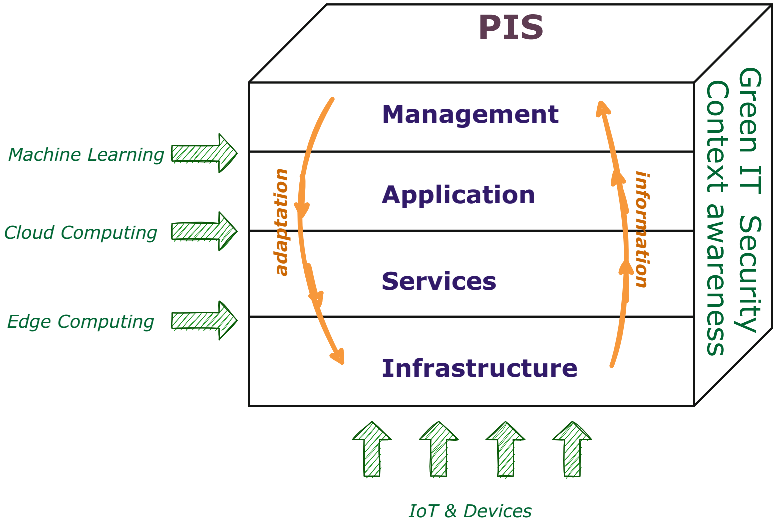

Fig. 1 Schematic view of a Pervasive Information System

5 PIS Requirements and Characteristics

As stated before, Pervasive Information Systems should be aware of the evolution of its real environment and its own execution environment. This will help to adapt the behavior of each system layer according to the situation at hand. This synergy between the layers is materialized in Fig. 1 by the adaptation link coming from the upper layer to the lower layers. Figure 1 illustrates these multiple layers and the influence of several trends mentioned in Sect. 3 on the overall system, ***together with transversal concerns such as context-awareness, security, and Green IT.***

Each layer of PIS mentioned in Fig. 1 can be summarized as follows:

- ***The “infrastructure” layer*** is increasingly complex as it integrates technologies such as Cloud/Edge/Fog computing, and IoT.
- ***The “services” layer*** represents the application services (or components) deployed and executed on the IT architecture and supporting the user and/or the business. Service orientation is well known in Information Systems and applications. The adoption of a micro-service architecture brings service-oriented architectures back to the fore, not in the sense of technologies like REST and SOAP, but in relation to the principles and qualities expected by these architectures, as pointed out (Shadija et al. 2017).
- ***The “application” layer*** corresponds to all the applications constituting the Information System. Each application is made up of services interconnected by application rules, which are supposed to translate business needs concerning organization’s activities. The siloed operation that IS enjoyed for many years has contributed to the design of applications that are today considered monolithic