Data-Centric Systems and Applications

Francesco Colace · Massimo De Santo
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Data Management in Pervasive Systems

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Preface

1 Introduction

The adjective *pervasive* comes from the Latin verb *pervadere*, which literally means *to go through*. However, looking at modern dictionaries, we find wider definitions such as *to permeate* [5] or *to diffuse in order to modify and characterize the atmosphere or the physiognomy of a certain ambient* [3]. The last definition well characterizes modern pervasive information systems, which had a remarkable growth in recent years. Indeed, as shown in Fig. 1, we can find applications of pervasive systems in the most disparate domains, such as health care, archaeology, museums, pollution control, and others: domains which only a few years ago used computers only for administrative purposes and were alien to involve computers directly in their functionality. On the other hand, pervasive systems rest on, and integrate, many different technologies as far as sensing devices, transmission modalities, and networking techniques are concerned.

Back in 1991, Mark Weiser [6] set the essence of modern pervasive systems, stating that they must allow the computer to vanish in the background in the same way as happened with other facilities such as the electric grid or the telephone switching network: as a matter of fact, a typical car has more than a dozen computers and electric motors, but almost no driver is aware of that. This has a fundamental psychological effect, since only when we do not have to concentrate on the individual features of such utilities any more, and they become part of the infrastructure, is our mind free to focus on our goals.

The creation of intelligent pervasive spaces is one of the most interesting opportunities offered by pervasive systems: social and physical ambients can be created with the aid of information and communications technologies (ICT), providing enhanced capabilities for humans to interact with the surrounding environment [4]. These features are useful at home—for instance, for providing services for security, energy management, and water and pollution control or to create assisted-living ambients for impaired or elderly people—but also as proactive and intelligent supports to visiting museums and historical sites.

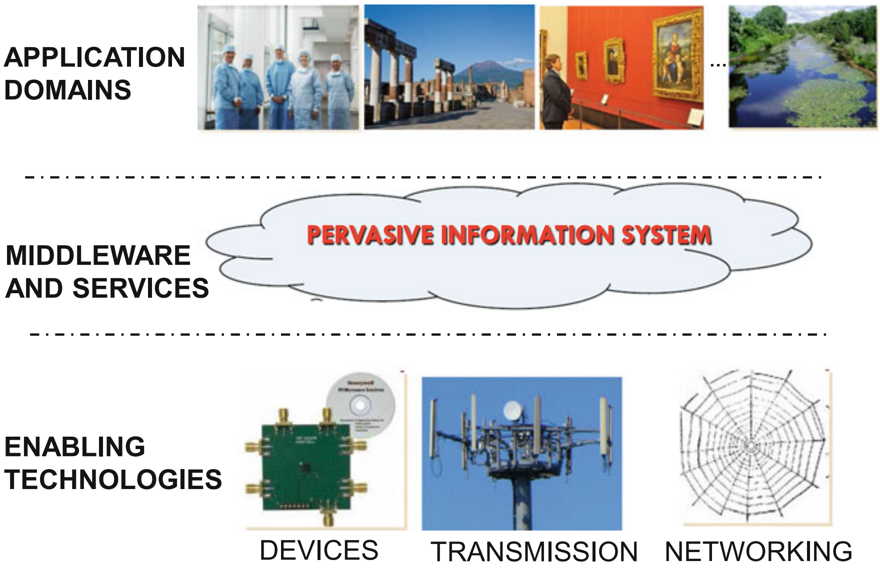

Fig. 1 The components of a pervasive system

Many of these solutions are made possible thanks to the adaptivity and context awareness of pervasive systems; by sensing the environmental conditions, the system dynamically recognizes the situation and context into which it currently operates and behaves accordingly. Adaptivity and context awareness are strictly related to each other and in many real situations are considered as interchangeable; however, while context awareness actually refers to the ability of the system to recognize the current context and to provide, at any time, the necessary contextual information and services [1], adaptivity refers to the execution of behavioral variations in response to changes of context or other parameters that can affect the behavior of the system, even the internal software itself [2]. Therefore, adaptivity and context awareness are complementary in building pervasive applications.

In Fig. 1, the pervasive information system is shown as a layer of middleware and services between the technological level and the application domains.

2 A Guide to Readers

The goal of this book is to provide a systematic description of the plethora of research issues related to the management of information in pervasive systems, illustrating the state of the art in this area. It can be used for a self-contained graduate

(PhD or master) course or for a series of seminars included in other courses on data management or distributed systems.

The book is divided into six parts with a final case study covered in the last part. Part I (Chaps. 1–3) covers very briefly the basic ideas underlying the economical, technological, social, and legal aspects of pervasive systems; Part II (Chaps. 4–7) describes several aspects of sensor networks and data stream processing; Part III (Chaps. 8–10) covers the main aspects of social networks with a special emphasis on cultural heritage applications; Part IV (Chaps. 11–13) describes the personalization and context awareness issues in pervasive environments; Part V (Chaps. 14–16) covers the multimedia aspects, again with a particular attention to the cultural heritage realm. Finally, a real case study is presented in Part VI (Chap. 17) with the description of an application within the DATABENC[1] project of the Campania region in Italy. Each part has its own foreword, guiding the reader through its chapters.

Readers of two different categories can take advantage from reading this book: on one hand, humanities and cultural heritage experts and enthusiasts can be introduced to the enabling technologies that are so promising for their application domain; on the other hand, ICT researchers and professionals can familiarize themselves with the issues of the cultural heritage realm while gaining new knowledge on the advances of pervasive technologies.

As shown in Fig. 2, we suggest the following path to cultural heritage experts. Chapter 1 analyzes and illustrates how new technologies have radically changed cultural and economic models, while Chap. 2 explains the essential technological aspects involved in the implementation and deployment of pervasive information systems. Chapter 3 surveys the main issues related to privacy in emerging pervasive scenarios and discusses some approaches toward their solution. In order to avoid overwhelming non-ICT readers with too many technicalities, we propose to skip some details and sometimes whole chapters: from Chaps. 4, 5, and 7, we recommend to extract only the first two sections. Chapters 8, 10, 11, 12, 13, and 14 are more descriptive and thus can be profitably read by a nontechnologist, while we advise the reader to jump from here directly to Chap. 17, which contains an overall description of the pervasive technologies applied to DATABENC.

The reading path for ICT experts is depicted in Fig. 3. Chapters 1 and 3 provide the readers with the economical, social, and legal aspects raised by the introduction of pervasive technologies, especially in the cultural heritage domain. From here, the readers can probe deeper into one or more technological aspects covering their interests: Part II (sensors, data stream, and storage), Part III (social networks), Part IV (context awareness and personalization), and Part V (multimedia information management). Also the technologists will be interested in the application of all the discussed technologies to the real case of the DATABENC project described in Chap. 17.

[1] High Technology District for Cultural Heritage.

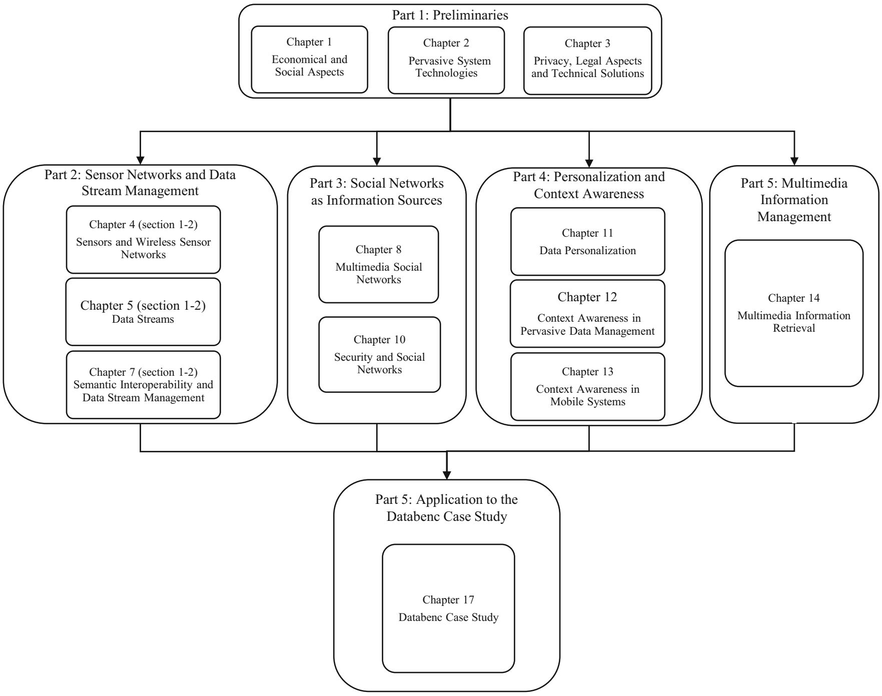

Fig. 2 Reading path for humanities and cultural heritage experts

3 Presentation of the Case Study

The DATABENC project is a high-technology district for the management of cultural heritage, recently funded by the Campania region in Italy. Campania boasts one of the largest and most precious cultural heritages in the world: valorizing and promoting such a patrimony, by the adoption of information and communications technologies, is nowadays of paramount importance also at the international level, with a large variety of potential applications.

In particular, DATABENC aims at designing and developing a general framework that provides each cultural site (indoor museums, archaeological sites, historical archives, old town centers, etc.) with several context-aware services for seamlessly assisting users (e.g., visitors or staff personnel) in the exploration and management of the related environment. As in a typical smart-city scenario characterized by the use of Internet-of-Things technologies, the physical sites as well as the users are equipped with all sorts of smart devices and appliances against which the topics of sensor data management, user-originated data operation and reasoning, multimedia and social data management, data analytics and reasoning for event detection and decision making, context modeling and control, automatic data, and service tailoring for personalization and recommendation have to be challenged.

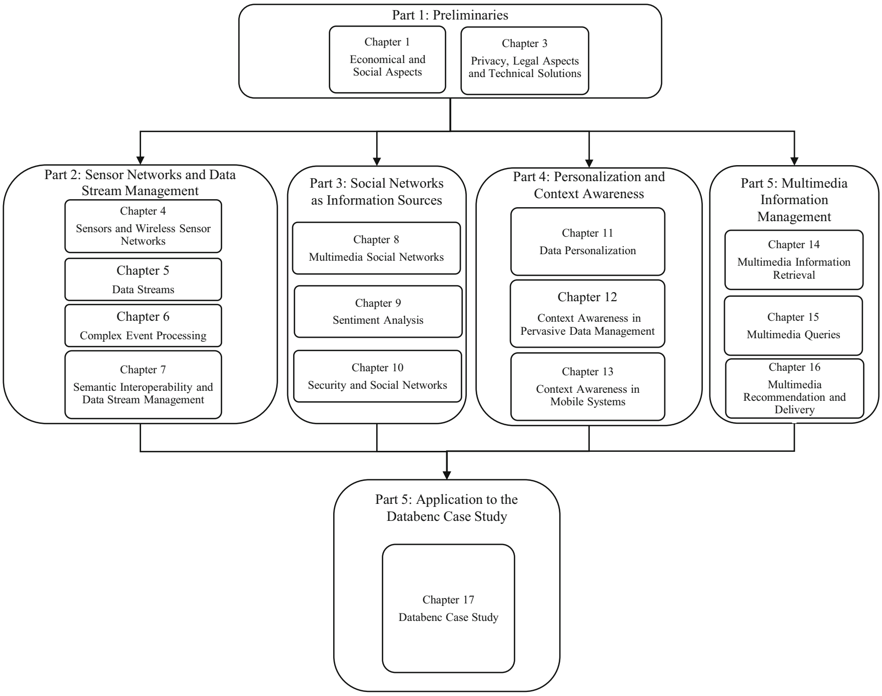

Fig. 3 Reading path for ICT experts

As a first motivating example, we can consider tourists who, during their vacation, want to visit a special exhibition of paintings and sculptures offered by a given indoor museum (e.g., the national museum of Capodimonte in Naples). To be considered *smart*, the museum environment should provide users with a set of functionalities for:

- Booking a visit for a specific date and time and buying the related ticket, managing, and user accounting/registration
- During the exhibition visit, accessing appropriate guides which describe the artworks by means of information coming from multiple and heterogeneous multimedia repositories (e.g., Flickr, Panoramio)
- Enabling the objects of the exhibition to “talk,” when a user is sufficiently close to them, automatically telling their story by means of multimedia facilities, again according to user preferences and needs
- Analyzing feedbacks, reviews, and comments of other users or experts coming from the most common social networks (Twitter, Facebook, etc.) to have a more detailed vision or an opinion about artworks
- Monitoring the environmental condition of each room by means of sensor networks (e.g., a Wireless Sensor Network (WSN)), for example, detecting some danger and showing the exit in the case of an emergency

- Saving the users' visit experiences in a digital format for future memory, which also allows them to post their comments on social network web sites

As a second example, we can imagine tourists visiting an archaeological outdoor site (e.g., Paestum or Pompeii ruins), endowed with an app which guides and supports them in their visit. In this case, to be considered smart, the environment should provide a set of functionalities for:

- Suggesting useful data and services tailored according to the current user context (user location, user preferences and needs, cultural level, environmental conditions, etc.); as an example, the information can be tailored differently according to the different levels of detail required by an archaeologist or by a nonexpert user
- Dynamically recommending visit paths, using the multimedia description of the cultural attractions or other support information, possibly enabling the publication of comments about user experience on social networks
- Allowing the 3D reconstruction of objects and the interaction between physical and virtual space by means of Virtual Reality technologies
- Monitoring environmental conditions, buildings' state, and users' behavior for security aims

Summarizing, the aim of the DATABENC project is the design and implementation of a Cultural Heritage Pervasive Information System based on the adoption of the future Internet architectural models and technological standards, capable of managing, in an integrated way, sensor-originated data and user-generated content in a pervasive context. Therefore, according to the most recent methodological and technological research on pervasive data management, the system should have the following features:

- It must manage the communication with any kind of sensor that can be deployed in the cultural site of interest (WSN, Radio Frequency Identification (RFID), video cameras, etc.).
- It must provide a set of primitives for the access, retrieval, integration, and analysis of information coming from the different data sources (multimedia repositories, social networks, sensors' database, etc.), managing the correlation with spatial information.
- While supporting data management, it must implement the transformation of the captured data into usable knowledge.
- It must be able to discover and track users within a site using heterogeneous technologies (GPS, Bluetooth, WiFi positioning, etc.).
- It must provide intelligent and personalized access to the knowledge base on the user profile, context state, and applications using context-aware and recommendation facilities.
- It must provide basic primitives for data analytics and reasoning, with the aim of supporting dynamic, on-the-fly personalization and social network analysis applications.

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Part I
Preliminaries and Relevant Related Topics

The first part of the book mainly focuses on the foundations of pervasive systems with the related characteristics and research challenges, especially for the cultural heritage management problem.

The new capacities of pervasive and ubiquitous computing are defining new horizons for human creativity and connectivity. This is also because pervasive and ubiquitous computing is very often linked with other emerging technologies, such as semantic knowledge portals, objects in 3D, 2.0 and the semantic web, cloud computing, and open-source software. At the same time, there has been a rapid development in 3G and 4G networks as well as in the use of feature-rich smartphones. This means that everyone can be connected at anytime and anywhere. In the near future, the development of specific hardware as well as software will enable everyone to be in touch with everything and everywhere, thus closing the "circle of pervasiveness." The Internet of the future promises to connect our mobile devices with everything (from the fridge in our homes to special sensors in our cars or even in our bodies), whenever and wherever we are. The Internet of the future, furthermore, will simultaneously generate and make available for everyone huge amounts of data. Scientific and technological research is proceeding so fast nowadays that often a semantic definition (e.g., pervasive and ubiquitous computing) has no time to become established by scholars before some other innovative device emerges in the market. Meanwhile sociocultural styles change and the cost of data management and acquisition is on the decrease. Cloud computing, for example, allows small firms to transfer the cost of hardware and data management to third parties (such as Google, Microsoft, etc.), which makes it possible even for them to have easy access to large amounts of information at low cost. The same is promised with the Internet of Things.

Chapter 1 analyzes and systematizes the abovementioned aspects, and, by means of some examples from the realm of cultural heritage, it shows how new technologies have radically changed cultural and economic models.

Chapter 2 introduces the main architectural issues concerning pervasive systems with the essential technological aspects involved in their implementation and deployment. The authors focus on some typical advanced data management topics that are useful prerequisites for the subsequent chapters such as relational and Not Only SQL (NoSQL) data management, real-time and main memory database management systems, big data, and data analytics.

The globally interconnected society we live in entails an increased exposure of possibly sensitive information and new risks of privacy vulnerabilities. Chapter 3 surveys the main issues related to privacy emerging in pervasive scenarios and discusses some approaches toward their solution.

Chapter 1
The Internet of Things and Value Co-creation in a Service-Dominant Logic Perspective

Aurelio Tommasetti, Massimiliano Vesci, and Orlando Troisi

1.1 Introduction

The new capacities of pervasive and ubiquitous computing are defining new horizons for human creativity and connectivity. This is also because pervasive and ubiquitous computing is very often linked with other emerging technologies, such as the semantic Web, cloud computing, and affective computing. At the same time, there has been a rapid development in 3G and 4G networks as well as in the use of feature-rich smartphones. This means that everyone can be connected at anytime and anywhere. In the near future, the development of specific hardware as well as software will enable everyone to be in touch with everything and everywhere, thus closing the "circle of pervasiveness." The Internet of the future promises to connect our mobile devices with everything (from the fridge in our homes to special sensors in our cars or even in our bodies), whenever and wherever we are. The Internet of the future, furthermore, will simultaneously generate and make available for everyone huge amounts of data. Scientific and technological research is proceeding so fast nowadays that often a semantic definition (e.g., pervasive and ubiquitous computing) has no time to become established by scholars before some other innovative devices flood the market. Meanwhile, sociocultural styles change and the cost of data management and acquisition is on the decrease. Cloud computing, for example, allows small firms to transfer the cost of hardware and data management to third parties (such as Google, Microsoft, etc.), which makes it possible even for them to have easy access to large amounts of information at low cost. The same is promised with the Internet of Things (IoT). The chapter intends to analyze and systematize the abovementioned aspects and, by means of some examples from the realm of

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cultural heritage, to illustrate how new technologies have radically changed cultural and economic models. In particular, this chapter aims to point out the impact of IoT on value co-creation, based on a service-dominant logic (S-D logic) perspective.

1.2 Service-Dominant Logic: A Conceptual Framework of Analysis

Service-dominant logic (S-D logic) is a theory that has emerged in the early twenty-first century. It derives from the critical analysis of Vargo and Lusch [46] about the impact of recent nonmanufacturing development on global economies. The contribution of Vargo and Lusch to S-D logic development [47–49] has had a great impact on marketing theory, shifting the root of the economic system from goods to services. Consequently, "the traditional economic worldview, i.e., the goods-dominant logic (G-D logic)" [30], rooted in the general concept of tangible goods or products, has been gradually replaced by a new logic or perspective according to which service is the main driver of current economic development. S-D logic is grounded on ten main foundational premises (FP), which have been developed, modified, and extended by Vargo and Lush between 2004 and 2006. These premises contribute to a better understanding of the pivotal role of service in value exchange, a process open to concrete customer contribution (co-creation), while goods still remain a means for value distribution. These emergent phenomena are summarized in some of the ten premises and, in particular, in FP1 "service is the fundamental basis of exchange," in FP3 "goods are a distribution mechanism for service provision," and in FP6 "the customer is always a co-creator of value." Furthermore, "the terms 'co-creation', 'coproduction', and 'prosumption' refer to situations in which consumers collaborate with firms or with other consumers to produce things of value" [24]. Since the emergence of the S-D logic paradigm, the debate on its specifics, evolution, and relationship with G-D logic has been subject to lively discussion and analysis among scholars. Moreover, this debate has contributed to better define and differentiate the S-D logic theoretical framework, compared to the traditional G-D paradigms.[1] In this respect, the main differences between G-D logic and S-D logic, which are fundamental for this discussion, can be summed up as follows [44, 45, 47]:

- Driver of value
- Resources used
- Customer role

[1]Service-dominant logic "represents a shift in logics of exchange, not just a shift in type of product that is under investigation" [28, 29] leading to a new approach to resources, value (co-)creation, and competition. According to Vargo and Lush, this shift is still in progress, being strictly related to and influenced by the evolution of "information technology (e.g., service-oriented, architecture), human resources (e.g., organizations as learning systems), marketing (e.g., service and relationship marketing, network theory), the theory of the firm (e.g., resource-based theories)" [30].

The first main difference between G-D logic and S-D logic relates to value exchange. In line with the first perspective, it refers to value in exchange, while for the second, it is related to value in use or value in context. “There is no value until an offering is used - experience and perception are essential to value determination.” Another important difference between the two perspectives relates to the resources used. According to G-D logic, the most important resources are the operand ones, and with the emergence of S-D logic on the contrary, operant resources became fundamental in value creation process. Thus, operand resources (e.g., natural resources) are tangible and static and in most cases require action to create value. On the other hand, operant resources (e.g., human skills and knowledge) are intangible and dynamic and capable of acting on operand and other operant resources in order to contribute to value creation [12, 14]. The third fundamental difference between the two perspectives relates to the role that customers play in value creation. G-D logic considers the customer as a mere user or even a destroyer of corporate value, while according to S-D logic, customers participate in value co-creation through the integration of corporate resources and additional ones provided by other subjects, such as public or private companies and even other clients. Thus, co-creation can be considered “the process by which products, services, and experiences are developed jointly by firms and their stakeholders, opening up a whole new world of value. Firms must stop thinking of individuals as mere passive recipients of value, to whom they have traditionally delivered goods, services, and experiences. Instead, firms must seek to engage people as active co-creators of value everywhere in the system” [34].

1.3 The Relevance of the Internet of Things: A Review of Definitions and Main Concepts

The pervasive nature of today’s computing has directly influenced the Internet of Things (IoT) development, making it critical for the future progress of the Internet and the Web 2.0 in terms of people, digital devices, and even common objects’ interconnection and interoperation [13, 18, 41]. From the literature, it emerges that the term “Internet of Things” was used for the very first time in the late 1990s to better define ubiquitous and pervasive computing that “has the potential to change the world, just as the Internet did. Maybe even more so” and that “refers to uniquely identifiable objects (things) and their virtual representations in an Internet-like structure” [5]. It was in 2005 that the International Telecommunication Union (ITU) formally introduced its definition of IoT, according to which it represents “the future of computing and communication, and its development depends on dynamic technical innovation in a number of important fields, from wireless sensors to nanotechnology” [25]. Moreover, “the basic idea of the IoT is that virtually every physical thing in this world can also become a computer that is connected to the Internet”; consequently the spread of these technologies can be considered a radical revolution that led "from anytime and anyplace connectivity for anyone" to a "connectivity for anything." Later, starting from 2008, several studies have pointed out the emergent relationship between IoT and the interoperable communication protocol, even if this relationship and its influence on the whole research field has only been investigated in depth in recent years [8, 10, 17, 22, 27, 35, 50]. Moreover, the European Commission has analyzed the semantic origin of the term which "is composed of two words and concepts: Internet and Things, where Internet can be defined as the world-wide network of interconnected computer networks, based on a standard communication protocol, the Internet suite (TCP/IP), while the term Things refers to objects not specifically identifiable. Therefore, semantically, IoT means a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" [50]. In the first decade of the twenty-first century, definitions of IoT were mostly based on their logical and operational relationship with "physical objects and beings, as well as virtual data and environments" [40]. In recent years, the IoT has also been considered a "metaphor for the universality of communication processes, for the integration of any kind of digital data and content, for the unique identification of real or virtual objects and for architectures that provide the communicative glue among these components" [35]. According to other perspectives, this concept is related to those things that have "identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts" [11, 50] and to "a world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these smart objects over the Internet, query their state and any information associated with them, taking into account security and privacy issues" [22]. Moreover, the Cluster of European Research Projects on the Internet of Things (CERP-IoT)[2] considers IoT as an "integrated part of future Internet and could be defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network." According to this definition, smart devices and interfaces contribute to outline real and virtual objects' identities, attributes, and personalities, in order to render them capable of interacting and cooperating in a broadband global network in an effective, practical, and inexpensive way. Consequently, "The IoT allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service" [19], and also because "the basic idea of IoT is the pervasive presence of a variety of things or objects - such as radio-frequency

[2]The Cluster of European Research Projects on the Internet of Things (CERP-IoT) consists of about 30 research initiatives, platforms, and networks dedicated to the identification technologies (e.g., RFID) and to the investigation of the forthcoming Internet-connected and interconnected world of objects.

identification (RFID) tags, sensors, actuators, mobile phones, etc. - which, through unique addressing schemes, interact with each other and cooperate with their neighbors to reach common goals" [17]. Several authors have also investigated the main goal of this emerging paradigm with particular reference to "the ability of smart objects to communicate with each other and build networks of things" [16]. According to Lu and Neng, IoT contributes to the development of things that "have identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environment, and user contexts."

Currently, the IoT depends on a vast set of properties, related not only to people and objects' active participation, and devices' or smart interfaces accessibility, but also to the interconnection of physical and virtual worlds. The IoT has led to a "virtual world of information technology integrated seamlessly with the real world of things" [43] and "encompasses a variety of technologies and research areas that aim to extend the existing Internet to real world objects" [27]. Currently, debate on IoT is very lively among scholars and practitioners as an increasing number of studies and definitions demonstrate. In order to respond to the lack of standard definitions, the ITU Telecommunication Standardization Sector (ITU-T) has defined IoT "as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based in both existing and evolving interoperable ICTs" [25]. However, the IoT evolution has also been defined in terms of improved network connectivity that goes from "the very simplest electronic devices - to the point where almost anything can connect to the Internet" [21]. In this emerging and advanced world, "connected devices ('temperature sensor') can interact with physical entities ('flowers') by its on device software resources ('sensing software component on sensor device') that can be accessed through standardized services ('Web Service Interface')" [31]. Consequently, "The IoT refers to the emerging trend of augmenting physical objects and devices with sensing, computing, and communication capabilities, connecting them to form a network and making use of the collective effect of the networked objects" [21]. This definition led to an emerging feature of IoT: its pervasiveness. This concept is closely linked to "several technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. Technologies like RFID, short-range wireless communications, real-time localization, and sensor networks are becoming increasingly pervasive, making IoT a reality" [42]. Moreover, this paradigm is related to the possibilities of brand new objects to "become active participants of everyday activities," while "people interact with the technological ecosystem based on smart objects through complex processes. The interactions of these four IoT components, person, intelligent object, technological ecosystem, and process, highlight a systemic and cognitive dimension within security of the IoT" [36]. In conclusion, "IoT does not revolutionize our lives or the field of computing. It is another step in the evolution of the Internet we already have" [32]. In Table 1.1, a classification of the main definitions of IoT has been furnished. The critical analysis