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A framework for human interaction with mobiquitous services in a smart environment

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ABSTRACT

Mobiquitous is a term recently introduced in literature to stress the strategic convergence of mobile and ubiquitous technologies. Mobiquitous services in a smart environment rely on the capability of smart objects to sense, compute, communicate and take some adaptive actions according to their goals in situated contexts, even without the human intervention. These complexity oriented issues make the human interaction with mobiquitous services more crucial and more challenging as compared with the classical human–computer interaction. In this paper, we propose a general framework as a conceptual tool for modeling such an interaction, once specific technologies are selected and employed. We view a single interaction occurring in a smart environment as a sequence of actions that involve users, mobiquitous services, interaction resources, environmental context items, and information exchanges between the user and the mobiquitous service. We specify these concepts and we discuss their interrelationships. The rationale is to provide a conceptual aide for designing, analyzing and operationalizing human interaction with mobiquitous services and applications in smart environments.

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1. Introduction and backgrounds

Nowadays, we are living in a new technological era where we continuously interact with smart objects in order to run a variety of context-aware applications and services that can make our everyday life simpler, safer and faster. At any time and place, these objects can let us know more about what we want to know about the environment surrounding us (weather conditions, up-to-date traffic, ...), organizational systems (current product prices, local events, flight status, ...) and people (phone numbers, birthdays, meetings, ...) we are interested to have relations with. Moreover, they allow us to select and control devices (printer, home appliance, ...) and applications for getting a service, to pass information assets (buying preferences, medical data, ...) to an organizational system, and to share personal information (notes, bookmarks, photos, ...) with other people, minimizing the cognitive load needed to interact with our environment.

Smart objects are defined as everyday physical things that are enhanced by a small electronic device to provide them with local intelligence and connectivity to the cyberspace established by the Internet (Kopetz, 2011). In this definition, "local intelligence" is understood as the capability of smart objects to sense/log/interpret what's occurring within themselves and the world, to act on their own, to intercommunicate with each other, and to exchange information with people (Kortuem, Kawsar, Fitton, & Sundramoorthy, 2010). For instance, a smart object might know about itself (where and how it was made, what it is for, who owns it, how it is used, what other objects in the world are like it) and about its environment (Johnson, Levine, & Smith, 2009).

Such objects are building blocks for a "smart environment", i.e. a small world that is able to acquire and apply knowledge about itself and its inhabitants in order to improve the experience of its inhabitants (Poslad, 2009). Smart environments link together computers and other devices to everyday settings and commonplace tasks (tracking people, physical objects or data, navigating through an unfamiliar space, providing reminders for activities, changing position of a physical object, controlling resource consumption, ...) by running context-aware applications or services. In a broader perspective, smart environments are a fundamental dimension of smart cities. Their development needs an improved regional knowledge management that can enable processes involved in the creation and operation of knowledge cities to be much more fully interactive, participatory and truly knowledge-based (Chatzkel & Dueckert, 2011; Zhao & Ordóñez de Pablos, 2011).

Smart objects and smart environments are fundamental components of the Internet of Things (IoT), i.e. a global infrastructure of networked of smart objects and other physical/virtual objects (electronic devices, sensors, data, ...) objects uniquely addressable,

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based on standard communication protocols. IoT is also widely recognized as a promising paradigm for a novel generation of context-aware applications and services. Although this vision is compelling, several important research questions about how to realize IoT have yet to be examined sufficiently, especially in terms of human involvement (Stankovic, 2014).

More specifically, in a smart environment many users use multiple services via many smart objects, and this leads to the need of a model of human interaction with services that is more complex than the classical human–computer interaction based on the WIMP (window, icon, menu, pointing device) style. This complexity derives from many aspects of a smart environment, but two of them are of special relevance. First, the human interaction may be explicit, implicit or a mixing of them. Explicit interaction occurs when a user interacts directly with a smart object user-interface that involves a command-based paradigm and relies on explicit input and output. Implicit interactions occurs when a smart object implicitly senses a user's action, without requiring an explicit input, and the service infers and executes an appropriate action whose output is not necessarily immediately perceived by the user (Ju & Leifer, 2008). Second, human interaction with services is mediated by an ubiquitous computing system and every smart object in the environment can potentially give either an input to the system or an output to the user. Unlike the classical human–computer interaction requiring the user to be in front of the computer, now the interaction is not centralized in a single device, but it involves a person, a potentially huge set of smart objects distributed in the real world, and many services running on the system. Far beyond the WIMP, another style that comprises many different interaction techniques (touching, pointing, scanning, user-mediated object selection, indirect remote controls (Rukzio et al., 2006), should be conceived in order to permit interaction with services everywhere.

In this paper, we propose a general framework for modeling human interaction with mobiquitous services in a smart environment. A single interaction occurring in a smart environment is viewed as a sequence of actions (called interaction pattern) that involve users, mobiquitous services, interaction resources, environmental context items, and information exchanges between the user and the mobiquitous service. We specify these concepts and we discuss their inter-relationships under an interdisciplinary perspective.

This framework provides definitions and distinctions that constitute a primary benefit at a general level of communication among all mobiquitous ecosystem stakeholders. Many services that are currently available in different business sectors exhibit the same interaction patterns and make use of mobiquitous applications with considerably overlapping interface requirements. Another motivation of our work is to provide a conceptual aide for interaction design, analysis and operationalization, as specific technologies are employed.

2. Mobiquitous services

As we described before, a smart object can be simply viewed as a physical object which has been enhanced or augmented with local intelligence through sensing, storing and networking technologies (attached/embedded/blended computers and/or other devices such as sensors, actuators, e-tags and so on). In general, the augmentation can be visual, auditory or radio frequency-based. Of course smart objects can exhibit different levels of intelligence from low to high.

A smart environment is a small world where networked smart objects interact continuously and collaboratively to make lives of occupants more comfortable. It is populated by a collection of context-aware applications or services in order to enhance the abilities of its occupants in executing tasks (e.g. navigating through an unfamiliar space, providing reminders for activities, moving heavy objects, etc.). These services are likely to be based on context knowledge that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object. Generally, they are supported by a mobiquitous system (i.e. a computing infrastructure that comprises sensors, embedded subsystems, portable devices owned by mobile users, as well as remote or local servers) making use of knowledge structures (e.g. predefined ontology and rule based reasoning) and information on physical user-environment interaction, relationship between people and between people and objects in the environment, as well as features of the physical environment (e.g. spatial layout and temperature, identity and location of people and objects in the environment).

"Mobiquitous" is a term recently introduced in literature to stress the strategic convergence of mobile and ubiquitous technologies. Mobiquitous services are services that respond effectively to end user's needs and actions by adapting to:

1. the mobility of people and physical/virtual objects in the environment;
2. the ubiquity of accessible computing devices, embedded in the environment and connected to a network structure;
3. the change of environmental context (particularly in terms of people, objects. time and place) of their use.

The satisfaction of the first condition makes service interaction independent of spatial and temporal constraints, as people and objects move across the environment. By considering only this kind of adaptation, information and communication devices (e.g. mobile phones and PDAs connected to a central computing resource) are used in a way largely irrespective of location and time. They are not aware of the context within which they operate and do not transmit location/time-specific information that could be very relevant for a better quality of service the user requires. In few words, the quality of mobile computing services is not affected by changes in location and time when interacting with them, unless the user is consciously and explicitly involved in service demand and configuration. On the contrary, service interaction dimensions, such as who (i.e., user profile), where (i.e. location and interaction devices), when (i.e., time), and what (i.e., user's goals, expectations and optional requirements) play a crucial role in providing high quality mobiquitous services. These dimensions have been taken into account by many researchers in conceiving services with the basic purpose of satisfying the second and third conditions listed above, (Ishkina, 2011; Miranda & Pastorelly, 2011). The ultimate goal is to create services that, by and large, exhibit pervasiveness (i.e., capability to be accessed and provided over a multitude of different devices in the environment) and context-awareness (i.e., ability to understand enough of a user's current situation in order to effectively meet users' needs by performing actions and offering information relevant to the particular context).

Mobiquitous services may be delivered to members of an organization owning the environment, as well as to other people visiting the environment; they may be grouped in *information provisioning* (delivering personalized, context-dependent content), *physical environment awareness and control* (providing access to information collected from sensors and control of the physical environment), *remote work support* (providing access to personal data stores and services for users in the environment), *collaborative work support* (sharing information among users and service components present in the environment) and *sharing or leasing of networked devices and appliances*, (Cortese, 2005).

3. Human interaction with mobiquitous services

In contrast to passive environment that is unaware of its inhabitants and unable to assist or engage them in a meaningful way, smart environment is active since it can sense the surrounding context of the physical space and human activity and respond appropriately to the people and activities taking place within it. The human is not a mere operator of the environment anymore, but he continuously interact with the environment in which he acts in order to get mobiquitous services (shortly, m-services).

Moreover, these services not only change the notion of mediation through particular interactions at certain locations and at certain times, but, more importantly, require to dynamically reconfigure activities of people that act in a smart environment. As a matter of fact, smart objects are able to react to contextual circumstances and can request the user to execute certain actions in response. This leads to study the role of tools, including mobiquitous technologies, and explicit and implicit rules that affect people activities and their outcomes in a smart environment (Kietzmann, 2008).

3.1. The framework

An interaction is generally understood as the effect two or more entities will have upon their counterparts as they perform actions on each other. In this respect, the human interaction with m-services is an interaction between people (users) and m-services mediated by the mobiquitous system (shortly, m-system) in their surrounding smart environment: a user action affects the states of items in the user's context, and may trigger a service action that, in turn, changes the state of items in the service's context; conversely, a service action affects the states of items in the service's context, and may trigger a user action that, in turn, changes the state of items in the user's context. Thus, the human interaction with m-services mediated by a m-system is based on sequences of actions (called interaction patterns) that involve users, m-services, interaction resources, and information exchanges in a smart environment context. Let us define and discuss such elements and their inter-relationships:

- *User* is a person that has entered into the real spatial environment (e.g. a room, laboratory, home, office, school, shop, road, bridge, car, park, etc.); he/she gets information provided by a m-service action through an interaction resource in his context (including smart objects carried by the person himself/herself); on the other hand, the information generated by a user action is directly detected and communicated by an interaction resource to the m-service (interaction with other users is indirectly detected as the user is interacting with an interaction resource).
- *Interaction Resource (IR)* is any smart object that directly interacts with the user and with the m-service. In an action execution, an *IR* may be either controlled by the user or by the m-service that exchanges information with the IR by using any wired or wireless data bearer, such as Bluetooth, Wi-Fi, WLAN, WiMAX, GSM, CDMA, GPRS, and Zigbee. An *IR* can act as either an output device, providing feedback to the user and behaving as an actuator in the smart environment, or an input device. A *user oriented interaction resource* (*UOIR*) allows the user to explicitly enter data into the system, while an *environment oriented interaction resource (EOIR)* provides implicit input detected by sensing and perceptual technologies attached/embedded/blended into the smart object, such as location sensors, mobile sensors, and environmental sensors, (Taysheng, 2009).
- *M-service* is, generally speaking, a set of software functionalities and policies that control its usage. The service runs on a server that could be distributed over the m-system, i.e. multiple computing resources work together to handle a request for service, or located on a single computing resource that is remote or even an element of an IR (e.g. a public interactive display with a built-in computing device). Requests for service could come from a UOIR or an EOIR.
- *Contexts*. The *smart environment context* is generally understood as a set of entities with their relevant properties (called *items*) used to characterize a situation that might occur in an interaction between a person (i.e., a user) and a m-service in the smart environment. Considering a certain user, the *user's context* is the set of the items, in the smart environment context, that may directly affect or be affected by the user's behavior; it may regard user's physical aspects as well as mental properties of the user (i.e. beliefs, desires and needs), relationship between the user and IRs, relationship between the user and other entities in the smart environment (including other people), temporal aspects, and identity, location of the user. Considering a certain m-service. the *service's context* is the set of the items, in the smart environment context (inside or outside the m-system), that may affect or be affected by the m-service, through an IR or an inner part of the m-system; it may regard features of the physical environment surrounding IRs, such as spatial layout, temperature and temporal aspects, physical relationship between an IR and the user, as well as identity, location, and physical/logical properties of an IR or an inner part of the m-system. Given a certain user and a certain m-service, the *interface context* is a set of items that belong to both the user's context and the service's context. The *state* of an item is a value associated to the item; the *status* of the interface context is determined by the states of its items. Interface context items may fall in five broad classes:

(1) **Identity**: The identity refers to items whose states identify the current user, m-service function, and IRs involved in the interaction. Namely, these states allow a user (respectively m-service) to univocally determine the m-service function (respectively, the user) and the IRs that is interacting with; the identification of these entities may specify other attributes relevant for the interaction.

(2) **Distance**: These items refer to the measurable distance between the positions of the user and the IR or between two IRs involved in the interaction. Their state may be determined by a continuous or discrete measure, given as absolute positions or as relative distances between entities. For instance, a discrete measure of what zone an entity is in with respect to another entity could be taken into account (Vogel & Balakrishnan, 2004). In the simplest cases, this is just a binary or ternary measure, just as in NFC interaction where the communication between two NFC-enabled devices is carried out with a mere touch or proximity wave of two devices near each other (usually, a short range from 4 to 10 centimeters).

(3) **Orientation**: These items refer to the facing direction of an interaction entity (user or IR) relative to another IR (relative orientation) or a fixed point in the environment (absolute orientation). Their states may be determined by a continuous measure (e.g. an estimation of Euler angles or Tait-Bryan angles) or a discrete measure (e.g., facing toward, somewhat toward, or away from the other object).

(4) **Movement**: These items refer to the changes of distance and orientation of an interaction entity (user or IR) with respect to time. Their state may be represented by a sequence of parameter values that describe the entity moving through space, and even its velocity.

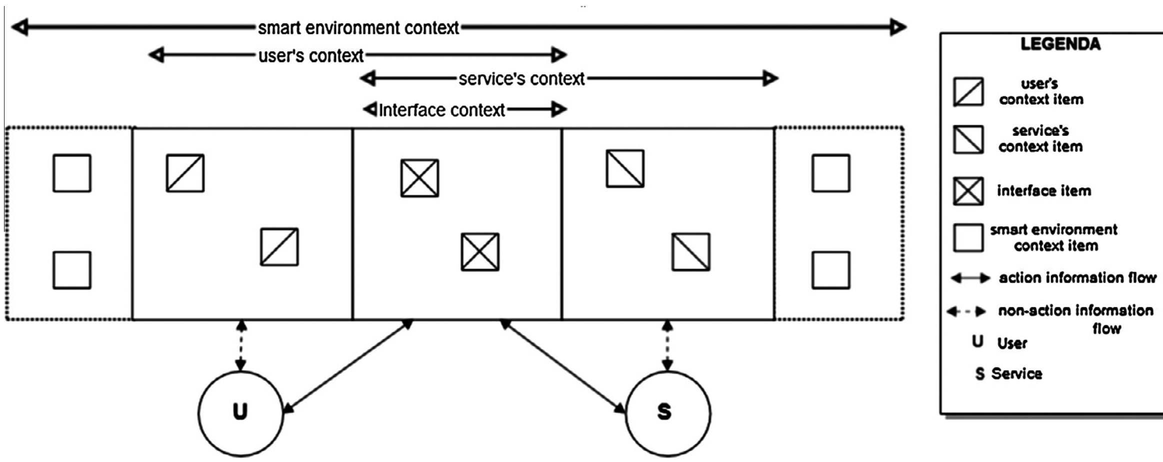

Fig. 1. Contexts and human-service interaction.

(5) **Location**: These items refer to the position of entities (user or IRs) involved in the interaction. Their states may be determined by using a *geometric model* in order to identify the absolute position (e.g. exact degrees of longitude and latitude, like the GPS) or a position relative to a fixed point in the environment (e.g. a position in a grid, like in mobile interaction with dynamic NFC-displays (Broll, Reithmeier, Holleis, & Wagner, 2011)).

(6) **Time**: These items refer to time-related properties of the interaction between user and IRs. Their states may be determined by a set of parameter values, such as date and time, i.e., when entities start to interact, and duration, i.e., how long they are involved in the interaction.

(7) **Environment**: These items refer to physical conditions of the environment surrounding interaction entities. Their state may be represented by a set of parameter values that measure or determine some physical properties like light, humidity, temperature, and spatial layout.

(8) Items in some of the above classes (namely, identity, distance, orientation, movement and location) are often taken into account in designing proxemics interface for human interaction with m-services (Marquardt & Greenberg, 2012).

- *Action.* Keeping apart from philosophical investigation about the meaning of "action"[1], here we intend an action a as an act that is triggered by a status change of the smart environment context and that, in turn, changes the status of the interface context; the action a transforms an interface context status in another, letting an interaction entity (user or service) exchange information about the respective context with the counterpart. More specifically, a *user action* is an act performed by the user that changes the interface context status in order to let the m-service get information about the status change of the user's context through an interaction resource (thus, changing some inner item state of the m-system). Conversely, a *m-service action* is intended as the execution of a software program that changes the interface context status in order to let the user to get information about the status change of the service's context through an interaction resource (thus, changing some inner item state of the user). Therefore, any act performed by the user or the m-service that does not change the interface context status (and thus not communicating any information to the counterpart) is not considered an action (let us say that is a *non-action*). The *action information flow* is the information exchanged in an action between the two interaction entities. An action a is *externally triggered* if it can only be triggered by an environment status change that leaves the interface context status unaltered; it is *internal* if it is triggered by an environment status change that determines an interface context status change.
- *Interaction pattern.* Generally speaking, an interaction pattern is the structure of chained actions that is common to all interactions occurring in similar situations (Volpentesta, Frega, & Filice, 2013). We need to introduce some definitions before formally modeling interaction patterns. Let I be a non-empty set of interface context items; let S be the set of all possible interface context statuses and let A be a non-empty set of user or m-service actions that can be applied on S; we denote by s_i the state of item $i \in I$ in the status $s \in S$. We assume that any action $a \in A$ is:
  1. univocally determined a pair $(x(a),y(a))$, where $x(a), y(a) \in S$ and $x(a) \neq y(a)$, representing the interface context status change from $x(a)$ into $y(a)$ when a is executed;
  2. either externally triggered or triggered by the execution of another action in A that brings the interface context status into $x(a)$.

An interface context item $i \in I$ is *changeless* when $x_i(a) = y_i(a)$, for any $a \in A$, i.e. it does not change its state when a user or m-service action is performed, whatever its state and user or m-service action may be. However, a changeless item state can be changed by an action performed by an external entity different from the user and the m-service. An interface context item $i \in I$ is *changeful* when $\exists\, a \in A\ x_i(a) \neq y_i(a)$, i.e. one of its states can be altered by a user or service action. A changeful item state can affect and be affected by the user or m-service behavior, while a changeless item state can

Table 1
Interface context items and their class, type and states.

Interface context item	Class	Type	States
Distance between user's finger and remote control **open button**	Distance	Changeful	Null/ Positive
Distance between user's finger and remote control **close button**	Distance	Changeful	Null/ Positive
Gate spatial layout	Environment	Changeful	Open/ Closed
Malfunction **indicator light**	Environment	Changeful	Off/On
Gate open duration time	Time	Changeless	Expired/ Not expired

[1] It is only worth to recall that the standard action theory views actions as "a complex mixture of beliefs, desires and the execution of actions, and explains the latter as causing by rationalising through a 'primary' reason (primary in relation to possible other reasons), itself being a compound of belief and desire" (Leist, 2007).

only affect the user or m-service behavior (for instance, its change can trigger an action). Let F be the subset of changeful items in I. The pair (S,A) univocally identifies the interaction graph $G(N(S), E(A))$, where $N(S) = \{s_F = (s_i)_{i \in F} | s \in S\}$ is the set of nodes, and $E(A) = \{(x_F(a), y_F(a)) | a \in A\}$ is the set of arcs. A node $n \in N(S)$ is a *terminal node* if $\forall\, s \in S$ such that $s_F = n$ we have that s can be changed only by an externally triggered action. An *interaction pattern* is either an elementary path where the first and last node are the only terminal nodes or an elementary circuit where there is only one terminal node.[2] Interaction patterns are the building blocks of interaction structures, in the sense that any interaction structure comes out from a combination of some interaction patterns.

Fig. 1 illustrates main framework elements and their interrelationships.

3.2. Example scenario

Let us consider a very simple scenario: an automatic gate can be opened (respectively, closed) by touching the "open" (respectively, "close") button on a remote control that is owned by a single user; moreover, the gate remains open until a preset auto-close time; the gate is also equipped with a light sign indicating that the gate does not function when the light is on; for sake of simplicity, we can imagine that the gate is normally closed and that it instantaneously and completely opens and closes off. We do not consider any safety precautions. The user (end-user) is near by the automatic gate (we assume that the person is not a gate system operator). In this scenario we have:

3.2.1. User's context

Mental property of the user (does he want to travel in/out the yard? Is he in a habitual place? Is he accustomed to interact with the automatic gate? ...), spatial layout of the gate (is the gate open/closed?), malfunction indicator brightness (is the light on/off?), distance between the user's finger and the remote control open (or close) button (has it been touched?), gate open duration time (is it expired?).

3.2.2. Service's context

Spatial layout of the gate, malfunction indicator light, distance between the user's finger and the remote control open (or close) button, gate open duration time, service availability (is the gate system functioning?), gate open duration time.

Table 1 summarizes interface context items and their class, type and states in the example scenario.

Table 2 specifies interface context statuses in the example scenario.

Table 3 specifies the nodes of the interaction graph related to the example scenario.

Table 4 specifies the arcs of the interaction graph and the associated arcs and triggers,

Lastly, Fig. 2 shows the interaction graph for the example scenario; we observe that $n1$, $n5$, $n6$ are the **terminal nodes**, and ($n1$, $n5$), ($n1$, $n2$, $n3$, $n6$), ($n1$, $n2$, $n3$, $n1$), ($n1$, $n2$, $n3$, $n4$, $n1$) are the i**nteraction patterns**.

4. Interaction dimensions

In this section, we introduce some dimensions that we believe are most relevant to designing, analyzing, and operationalizing human interaction with m-services. They describe properties and relationships between the framework elements that should be considered in modeling interface and action information flow (i.e., the information exchanged in an action between two interaction entities) in mobiquitous applications.

Let P be an interaction pattern in an interaction graph. The list below describes each dimension.

Table 2
Interface context statuses.

Status	Item				
	Open button distance	Close button distance	Gate spatial layout	Indicator light	Gate open duration time
s1	Positive	Positive	Closed	Off	Not expired
s2	Null	Positive	Closed	Off	Not expired
s3	Positive	Positive	Open	Off	Not expired
s3bis	Positive	Positive	Open	Off	Expired
s4	Positive	Null	Open	Off	Not expired
s5	Positive	Positive	Closed	On	Not expired
s6	Positive	Positive	Open	On	Not expired

Table 3
Nodes of the interaction graph.

Node	Changeful item			
	Open button distance	Close button distance	Gate spatial layout	Indicator light
$n1$	Positive	Positive	Closed	Off
$n2$	Null	Positive	Closed	Off
$n3$	Positive	Positive	Open	Off
$n4$	Positive	Null	Open	Off
$n5$	Positive	Positive	Closed	On
$n6$	Positive	Positive	Open	On

4.1. Role

The role specifies the behavior of the user, the m-service, and the IRs when an action $a \in A$ is executed. Formally, it is univocally determined by the binary variable APE(a), the **action performer entity**, that is defined as follows:

- APE(a) = *user*, when the user performs action a, passing information about the user's context to the m-service through an IR. The user plays an active role while the m-service (called also the counterpart of the user) plays a passive role as it gets information about the user's context through some IRs that play a mediator role;
- APE(a) = *m-service*, when the m-service performs a, passing information about the m-service's context to the user. The m-service plays an active role while the user (called also the counterpart of the m-service) plays a passive role as he gets information about the m-service's context through some IRs that play a mediator role.

4.2. Trigger

It is a description of the event that triggers an action $a \in A$. This can range from a detailed measure, including many event attributes, to a less detailed measure, such as an event's type. However, a useful variable needed to be considered is given by a binary variable ATD(a), the **action trigger dependency,** that indicates if action a is triggered (or not) by the execution of another action in A . It is defined as follows:

- ATD (a) = *dependent*, when a is triggered by the execution change of an item state in the interface context status resulting from the execution of another action in A that brings the

[2] A path $(n_1,n_2,\ldots,n_k)$ in a graph is called *elementary* if $n_i = n_j$ for $i = j$; a circuit $(n_1,n_2,\ldots,n_k,n_1)$ in a graph is called *elementary* if $n_i = n_j$ for $i = j$.

Table 4
Arcs in the interaction graph and associated actions with their triggers.

Arc	Action description	Trigger	Trigger type
(*n*1, *n*2)	*a*1: pressing the "open" button	User's desire to open the gate	External
(*n*2, *n*3)	*a*2: gate opening	Open button has been touched	Internal
(*n*3, *n*4)	*a*3: pressing the "close" button	User's desire to close the gate	External
(*n*4, *n*1)	*a*4: closing the gate	Close button has been touched	Internal
(*n*3, *n*1)	*a*5: gate auto-closing by timeout	Pre-set time is passed since the gate is open	Internal
(*n*1, *n*5)	*a*6: turning the sign on at gate closed	Gate system troubleshooting	External
(*n*3, *n*6)	*a*7: turning the sign on at gate open	Gate system troubleshooting	External

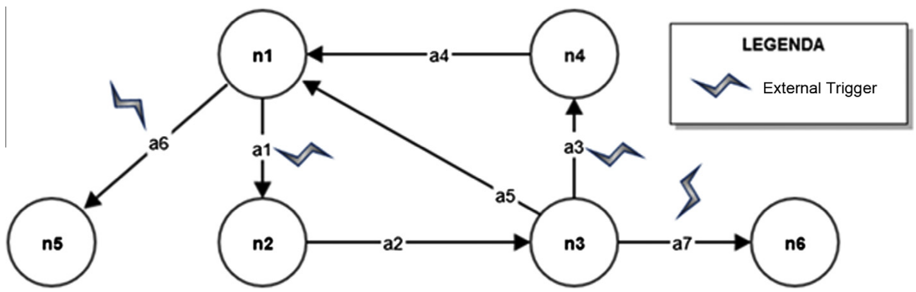

Fig. 2. The interaction graph.

interface context status into $x(a)$; we say also that APE (a) initiates and executes a in response to another action or simply that a is a response;

- ATD (a) = *independent*, when a is externally triggered or it is triggered by an interface context status change that is not due to the execution of any action in A (i.e., a is triggered by the change of some changeless item states). We say also a is auto-initiated when APE(a) = *m-service* and a is spontaneously initiated when APE(a) = *user*.

Table 5 better clarifies the two introduced dimension variable for an action a in an interaction pattern P:

Table 5
Mapping an action a into the APE-ATD space.

ATD(a)	APE(a)	
	User	M-service
Independent	a is **spontaneously initiated** and executed by the **user**; the role of the user is active as he spontaneously executes a with the deliberate purpose of communicating information (or launching a command) to the m-service that plays a passive role	a is **auto-initiated** and executed by the **m-service**; the role of the m-service is active as it executes a with the aim of passing information to the user that plays a passive role
Dependent	a is **initiated** and executed by the **user** and it is a **response**; the role of the user is active as he elaborates information obtained from a previous action of P and communicates other information to the m-service that plays a passive role	a is **initiated** and executed by the **m-service** and it is a **response**; the role of the m-service is active as it elaborates information obtained from a previous action of P and communicates other information to the user that plays a passive role

4.3. User's attention

Generally, it describes the attention paid by the user in attending an action in an interaction pattern. It is worth to recall that the introduction of m-services changes the conditions of pervasive activities of people in their environment. In the interaction, different levels of user participation may arise, as the user uses some IRs as mediators. In any smart environment, many sensory inputs coming from the user's context (such as the mere physical presence of people or IRs in the visual scene, and voices or sounds in the auditory array) impact the user's perceptual system that does not have the capacity to process all of them. However, some user's or service's context information could be relevant, whereas some other information could be irrelevant for the user interaction, when considering the current user behavior.

According to the cognitive psychology approach to human information processing (Styles, 2006), user's attention is the selective mechanism that, at a given moment, picks out some context information (called, *foreground of user's attention*, or simply, *foreground attention*) which is relevant for the user and leaves out the irrelevant information (called, *background of user's attention*, or simply, *background attention*).[3] There is evidence to support that items in the foreground of user's attention are perceptually, consciously, and mnemonically available (De Brigard & Prinz, 2010; Lamme, 2004).

This leads us to introduce the dimension variable AAD(a), the **action attentional demand,** that is the degree of cognitive or perceptual focalization, concentration, and consciousness of the user on the interface context, as he is playing an active or passive role in attending the action a in the interaction pattern P. Under a human information processing perspective, one may say that AAD(a) is a measure of the amount of the information that is associated to the interface context status by the user, as he is attending the action a. For sake of simplicity, we consider a binary measure and define the variable as follows:

AAD(a) = *high*, when most items of the interface context are in the foreground of user's attention, the human consciousness-intentional realm. We may also say that a is a *foreground action*,

AAD(a) = *low*, when most items of the interface context are in the background of user's attention, the human realm of unconsciousness and inattention (or split attention). This may happen

[3] The study of attention has a long and checkered history in cognitive psychology and neuroscience. See (Posner, 2012) for a deeper understanding of the nature and functions of attention and its relationship to broader cognitive processes.

when most (or all) items completely escape user's observation, and in this case, it is considered a *background action.*

In traditional HCI, foreground actions occur in the so-called "command-based interactions" and "explicit interactions". Background actions are comprised in interactions called in literature as "noncommand interaction" (Nielsen, 1993), "incidental interaction" (Dix, Finlay, Abowd, & Beale, 2003), and "implicit interaction" (Ju & Leifer, 2008).

The variable AAD(a) plays an important role in designing human interaction with m-service, especially in designing *attentive user interfaces* (AUIs) to "support users' attentional capacities" (Vertegaal & Shell, 2008). The value of AAD(a) may be determined by using orientation items states in the interface context (e.g. an IR recognizes when a person is looking at it) and may triggers a m-service action.

The distinction between foreground and background actions should not to be seen as a strict dichotomy, but indeed the threshold between them lies in a continuum. Moreover, since such a threshold depends on the four basic elements (namely, user, m-service, interaction resource, and contexts) previously discussed, it may change with time, as at least one basic element changes:

4.4. From background to foreground action

A context change may alter conditions underlying an interaction pattern, requiring users to undergo a learning curve before it is fully accepted. In an interaction pattern, some user actions that had previously been routinized may have to be relearned. Interface context items that used to be in background of user's attention become the clear focus of the user's attention.

4.5. From foreground to background action

Some user actions may, over time, become routine actions and the user's context becomes a habitual context. Such actions no longer require interface context items to stay into the foreground of the user's attention. Some IRs can become accepted and frequently used for everyday operations, and thereby interface context items move into the background of the user's attention, as the user is interacting with them in habitual contexts; through practice, the mental effort required to the user diminishes and user actions can become subliminal, automatic, and routinized. The balance of foreground action versus background action may change in favor of the latter.

In Tables 6 and 7, we give some criteria for mapping an action in a three dimensional space according to the three variables APE,ATD, and AAD.

Table 6
Mapping a foreground action a into the plane AAD(a) = *high* in the APE-ATD-AAD space.

ATD(a)	APE(a)	
	User	M-service
Independent	Some interface context items are the clear focus of the user's attention, as the **user spontaneously initiates** and conducts a with the conscious-intentional purpose of communicating information about his context to the m-service through an IR; interface context item state changes are in the **foreground attention**	Some interface context items capture and hold the user's attention, for a certain period of time, as the **m-service auto-initiates** and executes a communicating information about its context to the user through an IR; interface context item state changes are in the **foreground attention**
Dependent	Some interface context items are the clear focus of the user's attention, as the **user** consciously –intentionally **initiates** and conducts a that is **response**, i.e. elaborating information previously obtained and communicating other information about his context to the m-service through an IR; interface context item state changes are in the **foreground attention**	Some IR properties captures and holds the user's attention, for a certain period of time, as the **m-service initiates** and executes a that is a **response**, i.e. elaborating information previously obtained and communicating other information about its context to the user through an IR; interface context item state changes are in the **foreground attention**

4.6. Information flow

This dimension relies on a domain model (generally, an ontology) of the information exchanged in any action a, for each a in the interaction graph, between the user and the m-service through some IRs. The model takes into account the relative nature (rather than absolute) of concepts of interface context items (identity, distance, ...) as they are merely constructs of the human mind. The instantiation of the model for an action a is denoted as AIF(a), the **action information flow**. This information makes the

Table 7
Mapping a background action a into the plane AAD(a) = low in the APE-ATD-AAD space.

ATD(a)	APE(a)	
	User	M-service
Independent	The **user spontaneously initiates** and executes the action a with low or without attention to any interface context items (the primary reason why the user performs a is not to communicate data or launch an activity of the m- service); although no interface context item is the clear focus of the user's attention, some IRs senses a and passes information to the m-service in order to infer or anticipate user needs; interface context item state changes are in the **background attention**	The **m-service auto-initiates** and executes a without the explicit behest and awareness of the user, as it unobtrusively communicates info about its context to the user through an IR, i.e. without interrupting what the user is doing; interface context item state changes are in the **background attention**; these items do not capture the user's attention during the execution of an interaction pattern, but their states might persist until the user explicitly notices them (thus, possibly triggering another interaction pattern)
Dependent	The action a is a **response** and it is initiated and executed by the **user** with low or without attention to any interface context items (the primary reason why the user performs a is not to communicate data or launch an activity of the m- service). Although the user is not primarily aimed to consciously–intentionally communicate with the m-service, some IRs senses a and passes information to the m-service; interface context item state changes are in the **background attention**	The action a is a **response** and it is initiated and executed by the **m-service** without the explicit behest and awareness of the user; the m-service unobtrusively communicates info about its context to the user through an IR, i.e. without interrupting what the user is doing; interface context item state changes are in the **background attention;** these items do not capture the user's attention during the execution of an interaction pattern, but their states might persist until the user explicitly notices them (thus, possibly triggering another interaction pattern)

counterpart of APE (a) aware of some item states in the APE (a) context, as inferred, or associated with the interface context status change resulting from the execution of a. Main components of AIF(a) can be grouped in:

4.7. Identity

It is enriched information about the entities (user, m-service function, and IRs) that are identified by the identity items states of the interface context when executing a. This component describes the:

- **user**: *personal profile* (name, physical characteristics, such as age and sex, languages spoken, preferences, disabilities, ...), *social profile* (friends, community role, ...), *activity profile* (current activity, work schedule, meetings, ...), as well as inferred *mental properties* (mood, belief, desire, need, ...);
- **IR**: *semantic structure and data extension* (object type, manufacture, ownership history, physical location, obsolescence, business data, ...), *trust&security description* (digital rights, access control data, ...), *functional specification* (settings, network address, state and capabilities, such as sensing, processing and connecting, ...);
- **m-service function**: *provisioning entities specification* (application server, smart objects, such as sensors, appliances, and personal user devices, ..), *organization specification* (service provider, policy, ...), *function type*, such as application-oriented or device oriented, *access control type*;
- **relationships**. It is information about the relationships between the action entities that are identified through the interface context identity state when executing a. This component describes the relationship between *user and IR* (ownership, physical access type, authentication,...), *user and m-service function* (access rights type, session characteristics and state of the m-service instance including user preferences and choices, e.g. pattern history,...), *m-service function and IR* (protocol between server and IR, protocol between two IRs, method and IR device specific commands for the communication...).

4.8. Distance

It is enriched information associated to the distances between entities position as they are identified by the distance items states of the interface context when executing a. This information is an instance of the distance-dependent semantic component of the domain model, and it may reveal what action zone an entity is in with respect to another entity, even determining the amount of information that is exchanged between them. For instance, in a RFID based interaction, the amount of information transmitted between the tag and the reader may depend on the distance between them: the closer the tag is to the reader, the more information is revealed, (Vogel & Balakrishnan, 2004).

4.9. Location and orientation

Location is spatial information associated with the interaction entities (user or IRs) positions that are determined by the location items states of the interface context when executing a. This information may let user or m-service know qualitative aspects of the physical context where the interaction takes place, e.g. a particular room and its characteristics, and social practices and context of use of that place. Orientation is information associated with the directions which interaction entities (user or IRs) are facing, as they are determined by the orientation items states of the interface context when executing a. In combination with location, it may let the m-service know where the user is looking at (e.g., facing toward, somewhat toward, or away from the IR interacting with him), thus inferring an estimation of the user's attention, as he is attending the action a.

4.10. Time

It is enriched temporal information associated with time-related properties of the interaction as they are identified by the time items states of the interface context when executing a. Generally, such information is extracted from a time ontology that describes the interaction temporal domain through temporal concepts and their relationships, e.g. season (spring, summer, ...), activity time (breakfast, work, lunch, ...), day time (morning, afternoon, night, ...), event time (anniversaries, meetings, ...).

4.11. Environment

It is environmental information inferred from the environment items states of the interface context when executing a. For instance, it may be inferred if environmental conditions (brightness, humidity, temperature, spatial layout, wind velocity, ...) are suitable/unsuitable for user's activities or m-service delivery in the environment, or whether the interaction is currently occurring in an outdoor or an indoor environment.

In order to better clarify the introduced dimension variables APE, ATD, AAD, and AIF, we consider again the example scenario depicted in Section 3.2.

Table 8 shows the values of variables when the interaction pattern $P = (n_1, n_5)$ is considered.

Table 9 shows the values of variables when the interaction pattern $P = (n_1, n_2, n_3, n_6)$ is considered.

Table 10 shows the values of variables when the interaction pattern $P = (n_1, n_2, n_3, n_1)$ is considered.

Table 11 shows the values of variables when the interaction pattern $P = (n_1, n_2, n_3, n_4, n_1)$ is considered.

Table 8
Dimension variables values for the interaction pattern $P = (n_1, n_5)$.

Action	Dimension			
	APE	ATD	AAD	AIF
a_6: turning the sign on at gate closed	M-service	Independent	High	Gate system not working

Table 9
Dimension variables values for the interaction pattern $P = (n_1, n_2, n_3, n_6)$.

Action	Dimension			
	APE	ATD	AAD	AIF
a_1: pressing the "open" button	User	Independent	High	User intention to open the gate
a_2: gate opening	M-service	Dependent	High (unless the user changes his intention to travel in/out the yard)	M-service correctly responds to the open command
a_7: turning the sign on at gate open	M-service	Independent	Low	Gate system not working

Table 10
Dimension variables values for the interaction pattern $P = (n_1, n_2, n_3, n_1)$.

Action	Dimension			
	APE	ATD	AAD	AIF
a_1: pressing the "open" button	User	Independent	High	User intention to open the gate
a_2: gate opening	M-service	Dependent	High (unless the user changes his intention to travel in/out the yard)	M-service correctly responds to the open command
a_5: gate auto-closing by timeout	M-service	Independent	Low	User cannot launch the close command

Table 11
Dimension variables values for the interaction pattern $P = (n_1, n_2, n_3, n_4, n_1)$.

Action	Dimension			
	APE	ATD	AAD	AIF
a_1: pressing the "open" button	User	INDEPENDENT	High	User intention to open the gate
a_2: gate opening	M-service	Dependent	High (unless the user changes his intention to travel in/out the yard)	M-service correctly responds to the open command
a_3: pressing the "close" button	User	Dependent	High	User intention to close the gate
a_4: closing the gate	M-service	Dependent	High	M-service correctly responds to the close command

5. Conclusions

Despite progress in mobiquitous computing, potentialities and problems of human interaction with smart environment remain largely unexplored and unresolved. Only recently, we are observing a growing interest in novel interaction styles and techniques. However, most research studies just focuses on a single interaction style and their usage within different mobiquitous applications and services.

In this paper, we introduced basic concepts for modeling human interaction with mobiquitous services. These concepts are structured and presented in a general framework that abstracts from specific techniques and technologies (e.g. Bluetooth, RFID, NFC, Laser pointer, visual marker, etc.). The framework can be regarded as a conceptual tool that can assist in designing, analyzing and operationalizing human interaction with mobiquitous services in smart environments where different communication technologies are employed. It has been applied in developing a project which has required the design of NFC-based interactions with simple services for managing municipal parking areas in the city of Cosenza (Italy). Its practical usefulness has been confirmed as it has been an important element in supporting either a better communication among project stakeholders and an appropriate interface design of NFC apps for interaction with mobiquitous services. (Volpentesta & Frega, 2015).

Moreover, we believe that the presented framework may be used as a reference framework for educational activities (practical courses, master theses and project theses) oriented to students with irrelevant or missing background knowledge of developing human interactions with mobiquitous services and applications.

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