An Overview of Human-Computer Interaction Patterns in Pervasive Systems

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Abstract— **Despite a growing interest in design patterns by the Human-Computer Interaction (HCI) community, an interaction pattern collection that is universally accepted is yet to be found. Such a collection would aid the design of pervasive computing systems, in which interactions occur in both the material and logical worlds. This paper first seeks to define interaction patterns by adopting a model that captures such duality and then considers the challenges and opportunities that non-traditional interaction brings. Some patterns are then reviewed, with examples relating to motion-aware systems. We conclude that the creation of a widely accepted interaction pattern collection is unlikely in the near future.**

Keywords- Pervasive systems; interaction; HCI; interaction design; patterns; inspirational patterns.

I. Introduction

The Human-Computer Interaction field emerged 25 years ago with the aim of improving the interaction between people and computers. However, with the computer "becoming liberated from the desktop" [1], such interaction presents other challenges and opportunities. Computer systems have become ubiquitous in every aspect of our lives while becoming less visible as separate and distinct artefacts. This paper reviews the current literature in pervasive systems in order to identify some patterns of interaction, considering non-traditional modalities of interaction, like interaction with mobile devices, intelligent environments, and other users that are equipped with mobile devices. In order to limit the scope of this overview, we are particularly interested in those that are relevant to motion-aware systems.

This paper is organised as follows: In section 2 we offer a definition of interaction, followed by a review of how traditional human-computer interaction (HCI) came into being, and then a discussion of the challenges that ubiquitous computing brings to HCI. Section 3 is about the pattern approach, and the evolution of IT community's interest in this, since it was first formulated in architecture, up to Jonas Löwgren's "inspirational" patterns. In section 4, we turn our interest towards interaction patterns, most especially those emerging while designing pervasive systems. Here we offer examples in motion aware systems in which some of these patterns can be used. Finally, in section 5 we present some conclusions to be drawn from this review.

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II. Human-Computer Interaction

This section concerns the field of Human-Computer Interaction and its evolution over the years leading up to the design of pervasive systems, which is our concern. Firstly, we need to define interaction in a way that it is not only accurate, but flexible enough to be used in the context of HCI in pervasive systems.

A. Interaction

The term interaction, as with many concepts that are used in everyday language, has many working definitions. In particular, Dix, Finlay, Abowd and Beale define it as "any communication between a user and a computer" [2], where computer means any technology, process or system, which in turn could have non-computerized parts including other users. Furthermore users could be people or other systems. From this definition we can establish that any interaction is a form of communication between given entities.

Nonetheless, it is imperative to consider a more specific definition that includes the necessary conditions under which an interaction can take place. From the definition above it is apparent that there need to be at least two communicating entities and, for such communication to be effective there must be a medium for the communication as well as a shared protocol of exchange. Here the word "exchange" suggests a two-way communication, therefore only interactive communication is considered under this definition (i. e. a one-way communication does not constitute an interaction, as the broadcast of a message does not require an explicit response from any receivers). Therefore, all interactions are a form of communication, but not all communications are interactive.

Arguably, there are forms of interactions for which there is no explicit exchange of information, for example in physical or chemical interactions, where instead, an exchange of energy causing an effect in both interacting entities is observable. In this case, we could be contemplating general interactions which are not communications in the traditional sense [3]. However, when we consider information in its broadest sense, as an influence which leads to a transformation, it is clear that all interactions (even the purely physical ones) can be conceived as a certain form of communication.

Conceiving communication in this way is particularly convenient when studying ontological [1] systems, that is, systems composed of entities where the focus of interest is the relationships between the entities.

One model that clearly represents these considerations about interaction, is one developed in Neuchâtel by Eric Schwarz. Under his model [3], it becomes clear that even interactions that occur solely at a physical level (such as movement and gestures), can and do have logical implications: the exchange of energy, occurring in the "physical world" of objects, might alter the relationships between the entities representing such objects. In Fig. 1 (adapted from [3]) it is shown that physical and logical interactions affect the whole system.

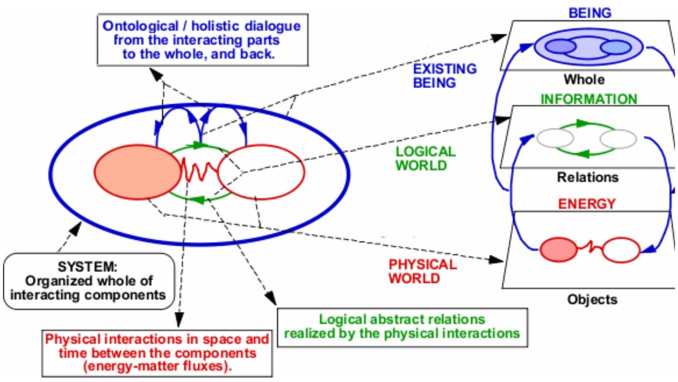

Figure 1. Interacting entities form a communicating whole.

Schwarz's model does not only allow the representation of interactional relations, as seen before, but also spatial-temporal relations. For example, information about the location (and/or the change of location) of a given entity might affect its relationships with other entities, and the meaning of the same interaction at a physical level can be completely different depending on the time when it occurs, implying a different interaction at a logical level. These considerations are of special relevance in motion-aware systems.

Now we have established that all types of interaction can be seen as some sort of communication, we can explore the challenges of designing interactive systems, as well as some design considerations for such systems in order to identify some patterns of interactions. The problem of designing interactive systems is the area of concern for HCI, discussed in the next section.

[1] Ontology is a concept borrowed from philosophy used in informatics to define "the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary" [4].

B. From Human-Computer Interaction to Interaction Design

The term human-computer interaction (HCI) has been in use since the early 1980s, when the field emerged as a discipline in its own right, with the primary objective being to allow the user to achieve particular goals in some application domain [2].

However, as Dix, Finlay, Abowd, and Beale have pointed out [2], it has its roots in previously established disciplines in which systematic study of human activity was performed. Rapid technological change and the pressures of war meant that people in the first half of the 20th century had to interact with machinery as never before. The focus of research remained the effectiveness of the technology or machinery itself. However this focus shifted over the years towards the factors that affect user performance, such as physical characteristics and cognitive issues, giving birth to the fields of Ergonomics (as it was called in Europe) and Human Factors (in America). As computers became more commonly used, research increasingly focused on the interaction between humans and machines, analyzing physical, psychological and theoretical aspects, resulting in the emergence of the field of man-machine interaction (today HCI).

The goal of HCI is to understand and improve the interactions between human beings and computers, "often with an eye toward improving the technology's design" [5]. Furthermore, authors such as Sharp, Rogers and Preece insist that as the focus of HCI is broadening, the discipline ought to be referred to as interaction design (ID), as it is now concerned with "the theory, research and practice of designing user experiences for all manner of technologies, systems and focus" [6]. Others, like Löwgren [7], believe that this is not sufficient from the epistemological point of view, as HCI is distinct from ID in the same way that engineering is distinct from design. According to Löwgren, ID is far beyond HCI, and authors should be careful in using that term to name the movement in HCI towards design.

Design is a mixture of applied art and engineering, and is innovative and multifaceted, that is, it has many aspects, often conflicting, such as aesthetics and usability (see discussions in [8] and [9]). For this reason, it makes sense to try to support the design process with aids, such as by the application of patterns, as explored in section 3.

The HCI field is, and has always been, multidisciplinary, particularly because of the intrinsically disparate nature of the two interacting elements. Sharp, Rogers and Preece name as many as fifteen disciplines which are concerned with ID [6]. The underlying idea, though, remains to be "designing interactive products to support the way people communicate and interact in their everyday and working lives" [6]. This is a great challenge, and it is a challenge that is here to stay. As Beaudouin-Lafon claims, "interaction is the future of computing" [10]. As computing becomes ubiquitous, increasingly more users are interacting through these systems, and this shift is considered in the next subsection.

C. Interaction in Pervasive Systems

In the 1980s, the prevailing paradigm in HCI was for the design of user-centered applications for the desktop computer.

Questions about what and how to design were framed in terms of specifying requirements for a single user interacting with a screen-based interface [6]. The premise of ubiquitous computing (*ubicomp*), or pervasive computing, is that computing systems can be everywhere the user needs them to be, "weaving themselves into the fabric of everyday life until they are indistinguishable from it" (paraphrasing Weiser, [1]). In other words, ubicomp has the potential to simplify people's lives through digital environments that sense, adapt, and respond to people's needs. A device can be a portal into an application-data space, not just a repository of software a user must manage. An application can be a means by which a user performs a task, not just software written to exploit a device's capabilities. And a computing environment can be an information-enhanced physical space, not just a virtual environment that exists to store and run software [11]. This phenomenon is encapsulated under the term embodiment [12], and it is the embodiment of digital artifacts into physical ones that is key to unlocking the power of affordances (for Norman, affordances are the perceived and actual properties of a tool which determine how it could be used [8]). In terms of interactive computation, it means that the environment becomes symbiotic with the computer system [13]. This suggests a different interaction model, one that allows for both *traditional interaction*, which is purposeful and explicit, as well as what Dix calls *incidental interaction* [14]. From a spectrum of interactions with varying purpose, traditional interactions would be at one end, and incidental interactions at the other. Here interactions emerge almost as a collateral effect. Dix illustrates this with shopping websites that keep track of customers' purchases, which can "incidentally" infer users' tastes in order to suggest additional purchases [14].

Incidental interaction goes against most of what is "proved and tested" in traditional HCI, where the interaction model is some form of intentional cycle such as the Norman execution-evaluation loop [8]. In traditional HCI, the intentional cycle is seen as starting with the user (who initiates the interactions), while in more contextual accounts of interaction the focus shifts to a cycle of activity starting with the state of the world and system 'responses' to the user actions. When the interaction is incidental, the user might not even have any awareness of the interaction taking place, and many of the traditional HCI design principles (most notably: feedback, visibility and consistency [6]) need to be scrapped or at least redefined. A truly pervasive system fades into the background: it is only visible when something requires the user's attention and therefore feedback is kept to the minimum. As a result, the interfaces have become more natural in terms of the affordances they provide to the user. Furthermore, computing devices tend to support the user by executing the task in hand in such way that there often occurs a transfer of control (even if unconsciously, such as in Norman's example of the driver reliant on the correct operation of the cruise control feature in his car [15]).

As ubicomp is fast becoming a reality for wider audiences, in no small part due to the recent advances in miniaturisation of computing devices and affordability of these by a wider community, HCI research now falls in either of the two following general approaches: either to focus on "creating powerful yet not always totally reliable interfaces, such as speech or gesture input", or on "creating less complex, more reliable input techniques" [16].

Chris Harrison, talking to Kroeker [16], predicts that eventually computers will be able to recognize nuanced human communication and interpret a complex range of gestures, eye movement, touch, and other cues. He states "if we ever hope for human-computer interaction to achieve the fluidity and expressiveness of human communication, we need to be equally diverse in how we approach interface design". One valid approach to face such diversity is the same that designers and architects have been using long before the emergence of HCI: the pattern approach.

III. Patterns

As just hinted, the field of architecture was the origin of the pattern movement. In the seventies, Christopher Alexander wrote a series of books, *A Pattern Language* being one of the first and most cited in the subject. There he characterizes a pattern as follows: *"Each pattern describes a problem which occurs over and over again in our environment and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over without ever doing it the same way twice"* [17].

A set of patterns which can be combined to create a variety of solutions is referred to by Alexander as a pattern language. The quotation above suggests that, rather than being rigid templates, patterns give designers an idea of how to solve a given problem allowing freedom to introduce as many variations as desired, increasing user participation [18]. The notion of patterns entered the IT community through the field of software engineering. Inspired by Alexander's works, software developers strived for the definition and usage of patterns in which, besides its name, the description of the problem and the context of usage, a template of the solution would be clearly specified, for example in the influential book by Gamma, Helm, Johnson and Vlissides [19], and others, such as [20], [21], [22].

The Gang of Four (GoF), as Gamma, Helm, Johnson and Vlissides are colloquially known, were the first to use Alexander's pattern language as model to create a form of documentation in software design. In the fifteen years since the first publication of their influential book, the patterns defined in it have been used and reused by developers as templates of the solution for their design problems, thanks to the immense detail of their specification[2]. This level of detail clearly indicates a purpose different from Alexander's, and as opposed to facilitate diversity, it aimed to articulate and disseminate knowledge among programmers. Furthermore, Crist *et al.* [23], who created patterns for cognitive modelling of business systems and processes, state that "each pattern is reflected by a problem-solving template", subscribing to the idea of patterns

[2] The GoF book [19] devotes 266 pages to their pattern catalogue, each pattern with the attributes: Pattern name and classification, intent, a.k.a, motivation, applicability, structure, participants, collaboration, consequences, implementation, sample code, known uses, related patterns.

needing to be well specified to be useful. Derntl agrees with this notion and highlights that a problem is dependent on its context (what Alexander referred to as "environment"), and that the solution of such a problem can be a configuration of the discipline's design options in the form of a template that can be applied in solving similar problems [21]. Alexander's works have also influenced researchers in the field of HCI (for example Norman admits so in [8]), and nowadays the community is increasingly interested in patterns. Some authors return to Alexander's original intentions, like Jan Borchers [24], who formalised a pattern language for interactive music exhibitions. Also Landay, van Duyne and Hong [25], who offer a pattern collection for web development, and Martijn van Welie [26] who maintains another one for interaction design. What all of these have in common is the idea that a pattern represents "a proven and successful design solution" (as said in [18]).

Other pattern literature suggests that it is acceptable for the solutions offered in patterns to be less fully specified and, instead, a verbose outline of the user expectations is offered, such as in [27], and [28]. That is why distinctions between patterns, universal patterns, pattern catalogue and pattern language are used to indicate the degree of detail in the solution specified, and whether the collection of patterns is interrelated in a meaningful way. From the extensive literature Jenifer Tidwell's "behavioural patterns" [28] are notable since, instead of presenting such patterns in the way of a template (such as the rest of the patterns in her book, no doubt inspired by the GoF), she presents them as "small essays", describing human behaviours rather than interface elements. Tidwell describes these behaviours in terms of needs, which are to be catered for if a good interface design is intended[3]. Jonas Löwgren's inspirational patterns, or *i-patterns*, are similar to Tidwell's in that they are abstract and only described in sentences and verbose examples. For Löwgren, it is a collection of "successful" patterns, where his notion of success differs from the traditional HCI view where success is measured in terms of user acceptance and performance. His nine patterns aim towards the innovative and inspirational: into "new parts of the design space of embodied interaction" [18]. They are as follows:

1. Virtual information is tied to positions in the material world;
2. Virtual bookmarks are tokens of positions in the material world;
3. Material objects are tokens of virtual information;
4. Virtual information "has" material properties;
5. Virtual information forms objects in the material world;
6. Material objects' qualities influence interaction qualities;
7. Heterogeneous virtual information fuses into a few sensory parameters;
8. Interactive and broadcast media combine to form a positive spiral of participation; and
9. Virtual information and functions are limited at certain times.

Such patterns capture the relationship between the logical world of information and the physical world of objects described in section II.A, and we will show in the next section how some of them are applied.

IV. Interaction Patterns in Ubicomp

According to Michel Beaudouin-Lafon [13] there are three interaction paradigms: first-person interfaces, in which users interact in a dedicated manner with a computer, as within traditional HCI research, and can follow the rules of direct manipulation; then second-person interfaces, in which users delegate some tasks to the system, who is seen as a "partner" assisting in reaching the user's goal as in the cruise control example of section II.C; and finally, third-person interfaces, where the system mediates the interaction among various users, such as in the case of computer-supported cooperative work and social networks.

Non-traditional modalities of interactions, like those considered in the design of pervasive systems, fall into all three paradigms, and we will comment on some patterns of each kind: interaction with mobile systems (first person interface), intelligent environments (second person interface), and other users that are equipped with such devices and intend to do some collaborative work (third person interface).

A. Interactions with mobile systems

Let us consider the following problem: mobile devices used in a variety of locations and situations might interrupt or distract the user from performing a primary task or disturb a nearby group of people. This corresponds with Löwgren's inspirational pattern "virtual information and functions are limited at certain times".

Landay and Borriello [29] apply the design-pattern concept to this problem proposing that "input and output modalities should adapt to the user's current context". For example, relying on speech or audio output is not a good idea when the user is participating in a meeting, attending a lecture, or in a movie theatre. A context-sensitive mobile phone should know when its owner is in a meeting and switch automatically to a vibration alert rather than require the owner to turn off the audible ringer. In addition, speech might be desired over direct manipulation input to a handheld device when the user is driving a car. Likewise, when the driver places or receives a call, the car stereo volume should lower automatically.

[3] For example: humans interacting with devices need to be allowed to explore safely, knowing that no dire consequences will arise as a consequence of trying out unfamiliar features. They also have a need for instant gratification, i.e. a positive result should arise within a few seconds of the interaction. Users need to be offered "good enough" as well as "best" if the latter involves extra cost. Humans need to be allowed to change their minds during an interaction and perhaps to return later without having to restart the whole process.

Erik Nilsson [30] developed a pattern collection [4] for interacting with mobile applications, aiming to solve over 60 specific problems (which he groups in problem areas, and these further into three main problem areas), all aiming to improve the quality of the user interaction with handheld devices. Notable examples of these problems are those arising from interaction mechanisms (such as use/lack of a stylus, multimodal input, etc), and utilizing screen space (such as horizontal scrolling, switching from portrait to landscape, etc).

In their book "The design of sites" [25], Landay, van Duyne and Hong, propose three patterns for "the mobile web" in a manner not dissimilar to Nilsson: mobile screen sizing (pattern M1), mobile input control (pattern M2) and location-based services (pattern M3). However, they also present the relationships to other patterns in their vast collection. As an example, consider pattern M3, *Location-based services*. They are a class of applications that allows the creation of *Personalized content* (pattern D4) based on a visitor's current physical location. Pattern M3 also allows customization of the customer experience for *Stimulating arts and entertainment* (pattern A9) sites, emphasize nearby places for *Organized search results* (pattern J3), and enable new ways of doing *Personal e-commerce* (pattern A1).

Jörg Roth addressed some of these problems too, proposing separately *Browse-it* as a pattern that allows a handheld user to browse the web without struggling with device limitations such as screen resolution [27]. The proxy pre-processes web pages, down scales graphics and pre-computes the appropriate layout. As a result, the amount of data transferred to the handheld devices is drastically reduced, and the devices are relieved from heavy rendering tasks.

B. Intelligent environments

Intelligent environments and their occupants interact in a natural yet adaptive way. Remagnino, Monekosso and Kuno [31] explain that in such environments the interaction occurs in a way that is natural for a human (for example, speech, motion, gestures), and the environment learns to recognize and change itself depending on the identity and activity taken by its occupants. Intelligent environments are made possible by permeating spaces with intelligent technology that enhances the quality of life, ranging from private to public spaces. The user information is gathered via wearable devices (such as RFID tags in badges) and/or via pervasive sensors.

A further example provided by Remagnino, Monekosso and Kuno [31] is the *Intelligent Classroom*. In it, gestures and movement of the lecturer are interpreted by the environment and trigger actions, such as dimming the lights, opening blinds or switching on the overhead projector. In this way, the lecturer can concentrate on his lecture instead of on the technology, minimising unwanted breaks and therefore maintaining the attention of his audience. This corresponds to the inspirational pattern "interactive and broadcast media combine to form a positive spiral of participation".

Another example is the intelligent environment for supporting independent living [31], in which the environment learns to recognise the activities an elderly occupant is performing in order to detect anomalous behaviour and alert their caregivers if needed. Pervasive sensors are used to gather information about the occupant (in particular, motion detection) and the activity performed is recognised using classifying algorithms, so the system would record whether the occupant is out, asleep, watching television, cooking, eating or bathing, to cite a few. Taking this research a step further would be not just alerting a caregiver in case of the detection of anomalous behaviour, but supporting the occupant's lifestyle: by switching off lights and other appliances when the occupant is away, or asleep, for example, if forgetfulness were a problem. The pattern solving such a problem could be named "Assisted living".

Another application of intelligent environments is in workplaces where staff are required or encouraged to work in a variety of locations, for example in colleges or multi-site corporations. In these cases, locating a given individual at a given time becomes a problem. Intelligent environments could allow for "Continuous tracking", which not only solves the problem of locating an individual at a given time, but could trigger other actions in their environment as well, just as "hovering the pointer over a desktop in graphical user interfaces" does [32] . Therefore, this may well be a pattern of interaction for pervasive systems, corresponding to the inspirational pattern "virtual information is tied to positions in the material world", or vice versa, since it is the location of the user that is the trigger of the actions in the environment.

C. Collaborative work

When people get together to collaborate in some way, they should not have to spend a lot of time configuring their devices. For example, during a meeting, the appropriate files, including contact information, should appear automatically on each person's laptop or PDA. Landay and Borriello [29] propose as a solution: "when users are near one another, it should be easy for their devices to connect and create an association that lets them share information over the life of a session". A context-sensitive I/O device provides the appropriate output for making a Physical-Virtual Association. Some associations can occur automatically when two known devices come into physical proximity, but creating other associations might require direct user action (to grant permission for the interaction to occur). One example is Bump™ [5] , an application developed for iPhones and Android phones, which permits the swapping of contact information and photos by bumping two phones together. This corresponds with Löwgren's inspirational patterns "material objects are tokens of virtual information" and "material objects qualities influence interaction qualities", as the phones are held in the hand as tokens of personal information, and, instead of a more personal handshake, people wishing to perform the exchange bump knuckles (being "restricted" by the physical dimensions of their phones).

[4] Also available online at www.flaminco.net

[5] A registered brand by Bump Technologies. http://bu.mp

V. CONCLUSIONS

The application of design patterns to pervasive computing systems opens up interesting research questions. The diversity and abundance of the research in this new area is an indication of how difficult it is to create a pattern collection that is universally accepted. Questions remain about how to validate the collection given the time and expense required to test each interaction pattern; and how to evaluate the process of using them, since conducting controlled studies is sometimes seen as prohibitive because of the creativity and skill involved in the act of design. As Landay and Borriello point out, the process of developing design patterns is still fairly *ad hoc* [29]. All of these elements suggest that the adoption of a widely accepted pattern collection for interactions is unlikely in the immediate future.

Despite this apparent disadvantage (compared to the field of software engineering, which count on the GoF patterns to aid developers), patterns are also a very useful aid to inspire designers of pervasive systems, letting them focus on how to improve the quality of the diverse interactions that occur is such systems. Therefore, we believe as the need for a pattern collection becomes more prevalent in future, pervasive systems developers will refer to such a pattern collection and ongoing efforts into cataloguing the emerging interaction patterns would be then well rewarded.

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