Spatial data and mobile applications – general solutions for interface design

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ABSTRACT
Nowadays, spatial data are totally widespread in mobile applications. They are present in games, map applications, web community applications and office automations. However this kind of spatial information potentially needs a large display area and the hardware constraint related to the limited screen dimensions creates many usability challenges. Our investigation in the last few years to find solutions to these challenges has led us to the discovery of general usability principles that a well-designed interface should adopt. In this paper we describe the mental path we have followed to derive those principles from the experience gained in developing mobile interfaces for different application domains. The principles are formalized in terms of two interaction design patterns, specific for mobile interfaces managing spatial data. They extend existing HCI patterns and are completed, as usual, with concrete examples of their applications.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: Graphical User Interface, Interaction styles, Style guides

General Terms
Design, Experimentation, Human Factors.

Keywords
Mobile interaction design, context aware interaction, information visualization, interface metaphors, multimodal interfaces.

1. INTRODUCTION
Mobile phones are spreading faster than any other information technology. Currently there are 800 million PCs vs approximately 4.5 billion mobile phones so that Weiser's visionary prediction on ubiquitous computing [18] has come true:

"... [the age] when technology recedes into the background of our lives"

Many people possess more than one mobile device (tablet, Pda, smart phone). While often people in Western countries own a mobile device and a PC; a large number of people in developing countries own only mobile devices whilst they have never seen a PC, so that local governments encourage the diffusion of mobile devices as a means of bringing education to masses. Indeed Jain, in "Middle Of the Pyramid" [19], states that mobile phones can bridge the digital divide of the people in developing countries allowing them to reach part of the remaining world population.

Modern mobile interfaces are expected to improve the user's interaction experience with the surrounding environment and offer different adaptive views of the real world. So the usability of the mobile interfaces is paramount in order to allow people of any cultural background to be involved in this process.

Research along that direction is further encouraged by the advanced technological configuration of mobile devices. Single devices encompass different hardware and software technologies such as camera, GPS receiver, movement sensors, 3D graphics, permanent internet connection, Java, Adobe Flash, etc. The integration of these technologies supports the design of advanced mobile applications such as Geo-Social networks, augmented reality, life tracking, bank trading and office automation. So that new applications bring forward new challenges, in particular to usability engineers.

In the book "Designing software for the mobile context" [20], the authors describe the design of usable mobile applications as a real challenging task. Indeed, designers have the difficult problem of dealing with a continuously changing technology that always offers new sets of challenges. Many issues are directly linked to the hardware. First of all, the limited screen size, which causes a lack of room for displaying data. Squeezing data to fit the display

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often results in the loss of relevant information, especially if the meaning of the displayed data depends also on their spatial components. This kind of data is very common in mobile applications. Spatial data are present in games, map applications, mobile community applications and office automations. For this reason, enhancing the visualization of spatial data on small screens should be considered a key usability issue.

In this paper we report on the experience we have gained in the last years with problems related to the visualization of spatial data on mobile interfaces, in different domains. This has led us to the discovery of general usability principles that a well-designed interface should adopt. The principles are formalized in terms of two interaction design patterns, specific for mobile interfaces managing spatial data, the *Infinitive Area + Context* and its extension the *Multimodal Infinitive Area + Context*. Both extend existing HCI patterns [12] and are completed, as usual, with concrete examples of their applications.

The paper is organized as follows. Section 2 describes some information visualization techniques adopted as successful solutions to the problem of managing spatial data on limited-sized screens. These form a new body of knowledge from which the two specific interaction design patterns were derived, as described in Section 3. In Section 4 we briefly describe a spreadsheet-mediated collaboration system and illustrate the successful application of the *Infinitive Area + Context* pattern to design appropriate mobile interfaces for that collaborative environment. Some final remarks conclude the paper in Section 5.

2. Spatial data visualization. Repetitive approaches

In this section we describe some approaches that researchers have used in the last years to overcome difficulties associated with visualizing spatial data. These difficulties are more evident when spatial data have to be visualized on small screens.

A common rationale behind the approaches that we are going to present is to provide users with clues about spatial objects by using visual metaphors. These are used to lead users toward relevant spatial elements that are not visualized on the screen because they are located outside or because they overcrowd the same area.

The first approach has been presented in [2]. Here, compact graphical representations such as points, lines or arcs are placed along the borders of a window or a sub-window to provide awareness about off- screen objects (fig. 1). The figure shows the use of this technique to support navigation in a spatial hypertext system.

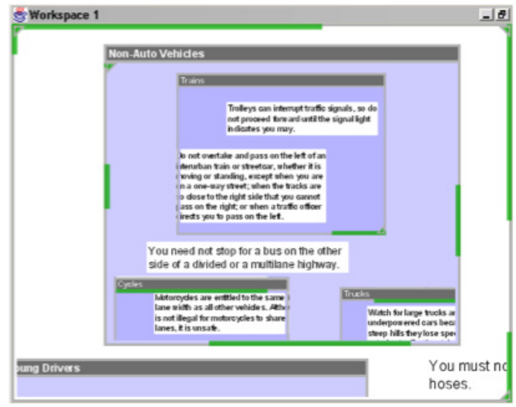

figure 1 – CityLights interface, reprinted from [2]

Lines convey information about the size of unseen objects. Orthographic projection produces a line length equal to the width or height of the corresponding object.

A similar approach was proposed in Halo to enhance contextual awareness during map navigation from a mobile device [1]. Portions of circles visualized along the borders indicate the presence of off-screen points of interest on the visualized map. The radius of each circle raises or decreases depending on the distance of the corresponding point of interest from the interface focus.

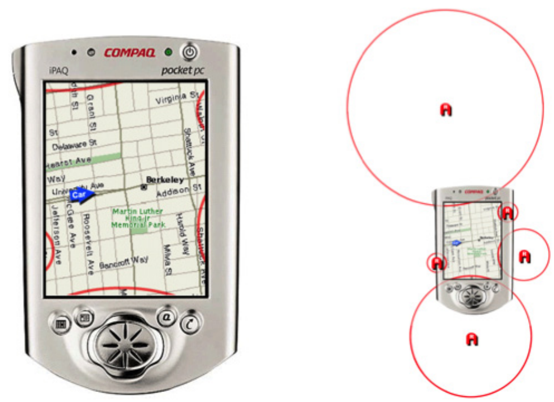

Figure 2. Halo interface, reprinted from [1]

In such a way, the user may verify anytime the proximity of a given point (fig 2).

In [3][4] exploration of geographic information from mobile devices is enhanced with visual clues about the surrounding context represented by one or more (nested) semi-transparent colored frames depicted along the borders of the device screen (fig 3). Each frame is related to a different category of points of interest (map layer) and it is divided into portions. A different off-screen sector is associated to each frame portion as depicted in figure 3. The color intensity of each portion gives information about the points of interest located in the corresponding off-screen sector. In order to make multiple frames distinguishable, Itten's theory [5] of colors is used to combine appropriate frame colors.

A comparative usability study was conducted between a mobile application leveraging the Framy visualization technique and a traditional mobile map application, which allows users to navigate maps by common panning and zooming functionalities.

Using Framy users have a visual representation of the surrounding POIs so they know where looking for them. A between-groups technique was followed by two groups of 10 participants each to evaluate if such knowledge gives a significant advantage in terms of efficiency and effectiveness. The experiment has been described in details in [22].

The first task is designed to evaluate the time spent by users to explore POIs on a map by using, alternatively, a map application enhanced with Framy and a traditional map application. The second task is used to understand if Framy helps to explore POIs depicted on a map decreasing the number of unexplored POIs.

Results demonstrate that the visualization technique gives a significant advantage both in terms of efficiency and effectiveness. The data collected during the experiment show that participants who worked with the application embedding our visualization technique were, on the average, 36% quicker than the others to complete their task. The same group was also able to explore 95% of the represented POIs while the others only explored 73%. In order to prove that the improvements were not casually derived a one-tail t-test has been applied on the collected results for each pair of groups. The test actually demonstrate that users employ less time to perform the first task using Framy than using the traditional map application and in the second task users explore more POIs using Framy.

Given the interest that the solely-visual version of the technique attracted in users who experienced the use of the prototype, it soon became apparent that the approach could be extended so as to convey contextual information also in situations when visibility is low and other human senses should be exploited. Thus, a multimodal interface was designed which is functionally equivalent to the former prototype while providing a more complete interaction experience [6]. To achieve that, tactile input and non-speech sound output were added as alternative interaction modalities. In particular, the visualized portions of each frame were associated with auditory feedback triggered by user's touch. Given a touch-screen display, users can drag their finger along the frame and hear a sound whose pitch is a representation of the color intensity of the corresponding frame portion.

figure 3 – Colored frames as visual clues about off-screen objects.

In [14] a pilot study was conducted with visually impaired users as well as some interviews with a group of knowledgeable people. This study demonstrated that the multimodal interface is equipped with many features which allowed visually impaired people to use our technique profitably for navigation tasks. However, useful insights were found on the way this category of people perceive audio-tactile information and the multimodal interface has been redesigned accordingly, while leaving the basic principles of our technique unchanged.

When investigating the quite different setting of mobile connection to social networks, we realized that the principles adopted in the framed mobile interface for map exploration could be used, in combination with augmented reality, to summarize information about members currently connected in the area surrounding the user. The system described in [7] exploits the augmented reality technology so that network participants located inside the visual cone of the camera are visualized on the real image captured by the camera phone, whereas clues about members located outside the visual cone are visualized in the form of a semitransparent colored strip on the bottom of the display (see Fig.4).

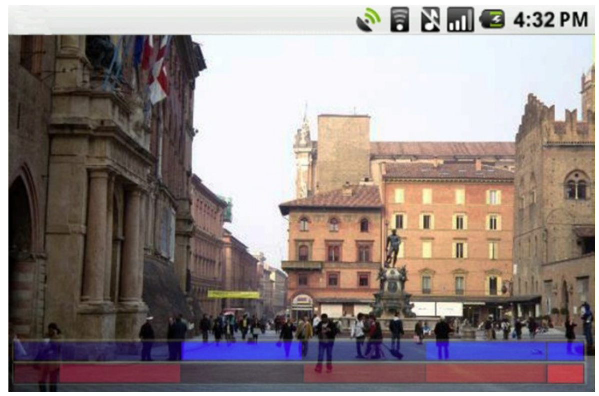

Figure 4. Stripes give information clues about members located outside the visual cone

The idea is to divide the space around the user into n sectors S1,…, Sn of equal width, 360°/n. Figure 5 gives an idea of this subdivision using n = 16.

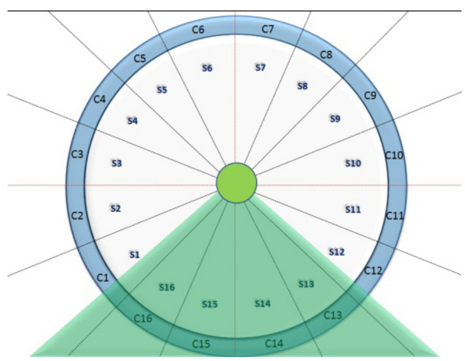

Figure 5. An example of screen subdivision accomplished by Framy and visual cone of user

The surrounding physical environment is augmented by a semi-transparent colored strip which is divided into the corresponding n portions $C_1,\dots, C_n$. Once the user poses a query, the color intensity of each C_i, is modified on the basis of the value of an aggregate function such as sum, count, etc., applied on a property of the social network users who are located in Si.

To summarize information distributed within an area of interest another visual metaphor is used in Link2You. The idea is to map on the basic cartography places, where usually groups of network users can be found (e.g., the library of the university campus). When the user is outside an area of interest, the information about users connected in that area is summarized in a unique icon, which evokes the presence of a group as shown by the associated label (see Fig. 6). As the user enters the area of interest the visual aggregation disappears and the separate network participants are visualized again.

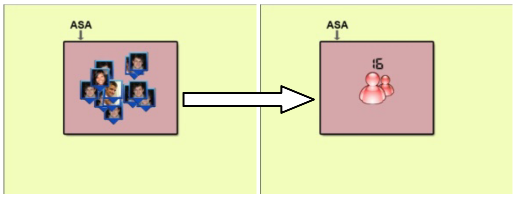

Figure 6. Visual aggregation technique

As a matter of fact, both visualization methods, the colored strip and the aggregation metaphor, allow the user to capture a general vision of the world surrounding him/her avoiding the sensorial overloading that may arise from the juxtaposition of social network users.

3. New interaction design patterns to visualize Spatial Data

The famous principle *focus plus context*, from the field of information visualization, asserts that a good design should support user's focus on a specific point of interest while providing some useful information about the surrounding context [23]. The described spatial data visualization techniques follow this principle taking into account the limited size of mobile interfaces, hence in a way quite different from traditional desktop approaches, such as the 'overview plus detail' or the 'fisheye view' design strategies. Therefore, such techniques form a new body of knowledge for information visualization on mobile interfaces, with common principles applied to different domains. The derived design guidelines can be formalized in terms of two interaction design patterns, specific for mobile interfaces managing spatial data.

A few years after the seminal work by Christopher Alexander [9], who introduced the design pattern concept in the architectural domain, researchers in HCI recognized the approach as mostly appropriate to user interface and interactive system design [11][16][17]. Since then, several pattern languages have been introduced, as lingua franca [17], by which not only are the interface designers able to share their expertise with one another, but also an effective participatory design process can be carried out.

In spite of the great number of pattern collections proposed in different sectors of HCI, very few of them can be successfully adapted to the context of mobile interface design. As a matter of fact, only recently this approach has attracted the interest of scientists working in the area of mobile user interfaces. Apart from some useful collections issued as supporting documentation of commercial development environments for mobile platforms, such as Android [13][21], a valuable work has been done by Steven Hoober and Eric Berkman, who have introduced a new interaction design pattern language dedicated to the design of generic mobile interfaces. In [12] the core principles of mobile interactive design are summarized as “user centred design”, context and other principles. According to the authors, designers should always take into account those principles to determine the appropriate pattern for the current situation and to integrate the elaborated solution into the system. Studying their catalogue we found out the pattern 'Infinitive Area', which is used to represent information that is potentially infinite such as maps, big detailed images or complex charts as shown in figure 7.

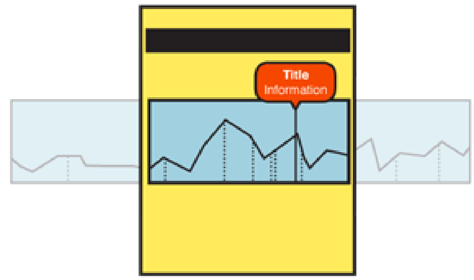

Figure 7. examples of infinite information: a complex chart, reprinted from [12]

Infinitive Area manages the whole data set as a large, two-dimensional graphic, whereas smaller subsets can be viewed as they were "zoomed in" portions of the larger image. Users can navigate the image by scrolling it in each direction. Zooming shows further details, generally with updated images that constitute additional information layers. For example, on the city level of a map only highways are labelled, whereas the names of the streets appear only when they are really useful without overcrowding the screen.

We realized that this pattern could well represent the basis upon which a new pattern (together with its multimodal extension) could be built as a general solution supporting the *focus plus context* principle in the design of mobile interfaces.

In table 1 we describe only the extension of the *Infinitive Area Pattern*. A detailed description of the original pattern is given at http://4ourth.com/wiki/Infinite%20Area.

Name	Infinitive Area + Context. *This pattern extends the Infinitive Area*.
Problem	A complex and/or interactive visual information that should be presented as a single image. Consider the need to convey a lot of specific spatial information - either of homogeneous or heterogeneous type but interconnected in some way – that are located in off-screen space.
Solution	The solution is to display coloured visual metaphors, which provide information clues about different sectors of the off-screen space. Use different colour intensities or dimensions to give qualitative and quantitative information about objects located in the corresponding off-screen sector.
Variations	Multimodal Infinitive Area + Context Infinitive Area
Interaction Details	When users change the spatial focus the information represented by the visual

	metaphors are automatically updated.
Presentation Details	The visual metaphors position must be significant. It gives intuitive information about directions. In a general way they can be inscribed along the borders of the view of the application that in many cases corresponds to the whole screen of the device.
Antipatterns	Use caution with the size of the metaphors. Graphic objects which are too small may be misunderstood by users. Be careful with the number of the graphic objects. A large number may reduce the usability of the ordinary user interface. Use Itten's theory to choose the right colour combination of the contiguous graphic objects. A wrong combination may make users confused.
Examples and figures	**Consider** a high resolution image where the subjects are human faces. Supposing that the software automatically recognizes the faces as points of interest, the frame can guide users towards them. (fig 8) **Consider** a spread text like the web page of a newspaper wherein users look for a particular word through the appropriate search tool. A frame can guide users to find the word in the text, the colour intensities could give information about the number of the words in the given direction or the distance from the current view. (fig 9) **Consider** the case when people use a map application to find restaurants and bus stops around them in a range of 3 km. Restaurants and bus stops are two different categories of POIs. Two nested frames – each one related to a specific category of POIs – provide users with information about the directions to take. (fig 10) In each case the colour intensities of a given portion of the adopted visual metaphor can give information about different qualitative elements such as the distance from the current focus, the number of elements located outside the screen or a combination of them.

Table 1. - Infinitive Area + Context pattern

Figure 8. Example of exploration of a high resolution image

Figure 9. Example of research of words in a web site

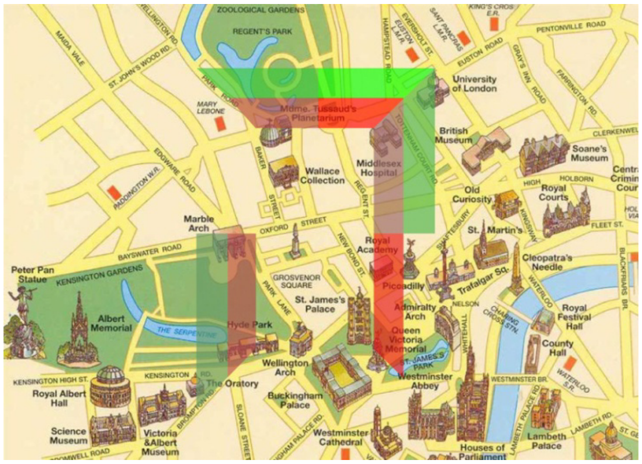

Figure 10. Example of exploration of POIs on a map

The next pattern is a further extension of the Infinitive Area. The pattern synthesizes the multimodal principles and should be used when the interface has to deal with particular situations of low visibility and multimodal interaction modes should be devised to convey relevant clues about the context.

Name	Multimodal Infinitive Area + Context. *This pattern extends the Infinitive Area + Context.*
Problem	Consider the need to support users through different senses (to deal with diverse users capabilities or with extraordinary environmental situations).
Solution	The visual metaphors are associated with auditory or vibro-tactile feedback. Use different sound sources for each metaphor or modulate tactile vibration.
Variations	Infinitive Area Infinitive Area + Context
Interaction Details	When users change the spatial focus the information perceived changes accordingly. Users interact with the multimodal interface either performing gestures on the screen, or triggering the movement sensors off or through the GPS module.
Presentation Details	Different sound sources must be clearly discernible as well as vibro-tactile modulation.
Antipatterns	Use caution with the usage of vibration, it may annoy users.
Examples and figures	**Consider** the case when a visually impaired user needs to orient himself while walking. He can use a mobile map application assisting his impaired sight with sounds and vibrations triggered off by his touch on the screen or his movements.

Table 2. Infinitive Area + Context pattern

4. The new pattern in practice

In this section we explain how the pattern "*Infinitive Area + Context*" has been used to overcome spatial issues in the design of a mobile application. We chose an application field totally different from those we presented in Section 2 to show the adaptability of the pattern to different areas. The example is in fact related to the area of collaborative systems for the context of Small and Medium sized Enterprises (SME).

In [15] we investigated SME business in order to understand which problems and which solutions can be adopted to improve their work and, then, increase their opportunities. The goal of that research project was to enhance the business processes presently carried out by SME using spreadsheets, designing and developing a web based spreadsheet mediated business collaboration system.

After a first study we were able to identify some user interface requirements for a web based spreadsheet mediated collaboration system.

Figure 11 shows the collaborative web interface of the spreadsheet-based prototype, as it appears to one of the participants. The web interface was developed using Adobe Action Script 3 and runs directly inside a common web browser.

The shared spreadsheet is provided with a window which lists the users currently connected. Each element of the list is associated to a given color which indicates the user's status. Any single cell may be accessed in Read/Write, Read-Only or Hidden mode depending on individually assigned privileges. The user sees a red cell if it is hidden, yellow if it is read-only accessible, or in the original background color if he/she has R/W privileges on that cell. Whenever a participant is editing a cell/a block of cells, those cells are colored with the user's identifying color so as to appear 'locked' to the others, and avoid undesirable overlapping. If a user tries to modify a locked cell, he/she is notified by means of an error message. After the user changes the content of a cell and unlocks it, the system draws a line along the border of the cell with the color identifying the user. The colored border is visible to each participant, who may click on the cell to acknowledge the other's update and make the border disappear.

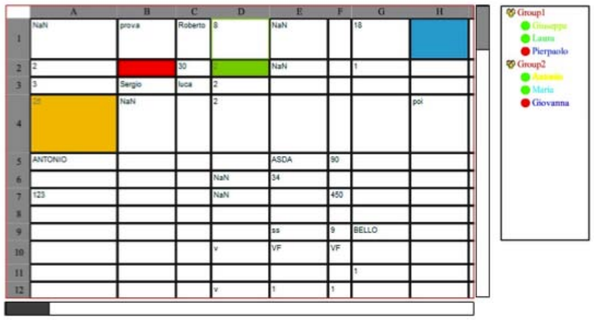

Figure 11. The interface of the Web Collaborative spreadsheet

The web system allows users to collaborate and share information everywhere thanks to the web. The new challenge now is to allow users to collaborate everywhere and anytime in complete mobility. For this reason mobile devices play a fundamental role in the field of office automation in the perspective of a real “anywhere” collaboration.

We designed the mobile interface trying to meet the original interface requirements. All the requirements were met in the same way as in the web interface with the exception of the first one, which required a constantly visible list of participants. In fact, on small screens the list would cover a good portion of the document, making it unreadable. For this reason, we provided a semitransparent list available on users' demand.

Figure 12 shows the collaborative mobile interface of the spreadsheet-based prototype.

We observed that the cell visualization problem which arises when dealing with limited sized screens, could be addressed applying the Infinitive Area +Context pattern. Accordingly, the mobile interface was designed with the spreadsheet presented as a single image at a prefixed zoom level. In the prototype users can explore the spreadsheet by panning it with their fingers in all directions (as suggested by the basic Infinitive Area pattern). Incidentally, it is worth to note that when users touch a cell they do not trigger off the appearance of the text input interface. This choice was due to the fact that users may touch one or more cells to pan the document. When they want to modify the content of a cell they have to explicitly require the appearance of the text input system by selecting the desired cell and then touching the text area on the top of the document.

The pattern also provided a precious solution to the necessary loss of context, due to the limited size of the mobile interface. When users visualize the spreadsheet on a large screen they do not have problems to perceive the changes of the majority of cells. They know which cells are updated and who worked on them. On the contrary, on the mobile interface they can just visualize a couple of short columns out of the whole document (fig. 12), which may strongly limit the perception of off-screen changes of cells contents. Adopting the Infinitive Area + Context pattern, we addressed this issue drawing semitransparent frames to give information about the off-screen distribution of the modified cells. In order to avoid confusion due to the overcrowding of the frames on the screen, the interface displays at most one semitransparent frame at a time (fig 13). The default frame gives information clues about the position of all modified cells. The color intensity of each frame portion is proportional to the number of cells located in the corresponding outside sector.

Users can also retrieve information about the cells modified by a specific user. By clicking a specific username presented in the contact list the frame gets the color of the given user and the color saturation function refers to the cells modified by that user.

Figure 12. The interface of the Collaborative spreadsheet

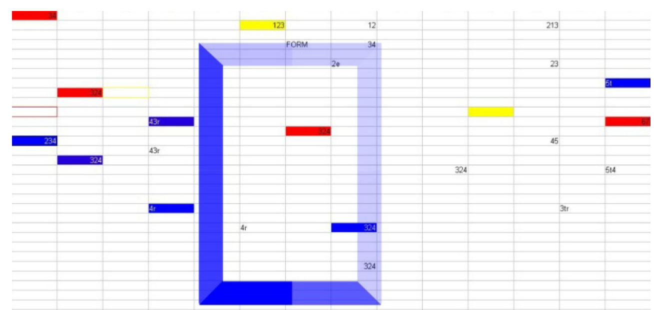

Figure 13 – the subdivision of the device screen

5. Final Remarks

In this paper we have discussed some emerging challenges in the context of mobile devices, which have today a worldwide diffusion, much higher than PCs and are considered vital to bridge the digital divide of the people in developing countries [19].

We have focused in particular on issues related to the visualization of spatial data, which can be considered paramount for the usability of mobile applications.

We have reported recent investigations focused on these issues highlighting common principles of their solutions. The successful applications of similar techniques in different fields to solve repetitive problems have demonstrated the effectiveness of those principles. Therefore, we were able to formalize them in terms of a new interaction pattern *Infinitive Area + Context* and its multimodal extension, conceived as design strategies which support the basic principle of 'focus plus context' in the specific area of mobile interface design.

The practical example of adoption of the pattern in the completely different setting of spreadsheet-mediated collaboration, is intended to demonstrate the appropriateness of the pattern as a general design solution for spatial data visualization on mobile interfaces.

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