VISUALIZING INFORMATION ON MOBILE DEVICES

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Abstract
Visualization has a relevant role in almost every domain of computer applications. It is thus natural to think about bringing visualization techniques to mobile devices (such as PDAs and mobile phones) to harness the power of visualization anytime, anywhere. Unfortunately, limitations of mobile devices make it impossible to follow a trivial porting approach from desktop computers. A considerable research effort is needed to understand how to design effective visualizations for mobile devices. This paper deals with the different aspects of visualizing information on mobile devices. We first discuss in detail the peculiarities of the mobile visualization context that motivate research needs. Then, we summarize the different steps of mobile visualization design. We provide concrete examples from a mobile application we have recently developed and also present a taxonomy of the different classes of visualizations that are being investigated in the mobile context.

Introduction
People are used to rely on visualizations to better understand problems they have to solve and to take better decisions in less time. Thanks to the continuous increase in power and graphics capabilities of computers, visualization has a growing role in almost every domain of computer applications, ranging from business to medicine, from engineering to science.
It is thus natural to think about bringing visualization techniques to mobile devices (such as PDAs and mobile phones) to harness the power of visualization anytime, anywhere. Unfortunately, limitations of mobile devices (e.g., limited screen size) make it impossible to follow a trivial porting approach from desktop computers to mobile devices. A considerable research effort is thus needed to understand how to design effective visualizations for mobile devices. While a growing number of researchers is working at proposing specific mobile visualization techniques, no paper in the literature has yet provided a broad discussion of mobile visualization that could be useful to any developer of mobile applications. This paper will thus deal with the different aspects of visualizing information on mobile devices.
In the following, we first discuss in detail the peculiarities of the mobile visualization context, that motivate research needs. Then, we deal with the different aspects of mobile visualization design. We especially focus on the presentation problem, since the limited screen size of mobile devices makes it particularly complex. Concepts are exemplified on a concrete map-based mobile application we recently developed, because maps are familiar to anyone so the examples can be quickly understood. Moreover, maps play an important role in location-based services, that are a relevant application of mobile devices. However, the ideas we present are not specific to maps and apply to other visualizations as well. Finally, we propose a taxonomy of the different classes of visualizations that are being investigated in the mobile context.

Mobile Visualization vs. traditional Visualization

Mobile devices have limitations that are not typical of desktop computers and the mobility context is different in many ways from that of traditional visualization. This section illustrates the differences that have to be taken into account in developing a mobile visualization.

Compared to desktop computers, mobile devices are characterized by the following differences:

- Displays are very limited (small size, low resolution, less colors,…);
- The Width/Height ratio is very different from the usual 4:3;
- The on-board hardware (CPU, memory, buses, graphic hardware,...) is much less powerful;
- The input peripherals (e.g. tiny keypads, micro-joysticks, rollers,…) are often inadequate for complex tasks;
- The input techniques are different, e.g. hand-writing and pattern recognition on a small surface, one-hand thumb-based input, point-and-tap with stylus,…
- Connectivity is slower, affecting the interactivity of applications when a significant quantity of data is stored on remote databases;
- There is an extreme variability in form-factor, performance and input peripherals among different models of mobile devices on the market;
- There is a lack of powerful, high-level graphics libraries (currently available tools tend to be low-level or limited).

As a result of these limitations, visualization applications developed for desktop computers do not scale well to mobile devices. Unfortunately, some of these limitations are not likely to disappear in the near future because mobile devices need to remain compact in size.

The mobility context introduces further complications with respect to the desktop one:

- The physical environment is extremely variable. For example, a mobile device can be used in lighting conditions that range from glare to total darkness and this affects the perception of colors and graphics.
- Different/new applications and services are needed by mobile users, and many traditional applications would fail on mobile devices. For example, a clinician that has to carry out an epidemiological study on 10000 patients will still prefer to work at her desktop, but if she wants to visualize the progress of one of her current patients, she would appreciate being able to do it in any situation, e.g. at the patient's bedside, in the hospital cafeteria or while commuting. As a different example, consider CAD schematics of aircraft engines. The designer of the engines will still draw them using CAD workstations, but a maintenance technician would appreciate a mobile device strapped to her arm that visualizes the schematics and procedures for the parts she is working on.
- Unlike office environments, mobile contexts make it difficult for users to focus their attention mainly on the device, due to a significant number of external events that have to be considered and to which one often has to respond (e.g., think about being in an airport waiting for a flight) or to activities that are carried out in parallel (e.g., walking). Users have thus less cognitive resources available, and using the device becomes a secondary instead of a primary task.
- Serious safety issues can be involved in using mobile devices concurrently with other activities, even common ones. For example, distraction caused by a mobile device can limit the capability of a walking user to follow a safe path and to be aware of surrounding dangers.

Interestingly, the issues concerning limited cognitive resources and safety are not only a difference from the traditional context to take into account, but also an additional motivation to employ effective mobile visualizations as a way to provide information at-a-glance that is easily understood with less cognitive resources and distracts the user as less as possible from her current primary task.

In proposing new mobile applications and services, context-awareness gives considerable added value to mobile visualizations: the system can be aware of the lighting conditions (e.g, to adapt brightness and contrast of the visualization), the geographic location (e.g., to draw the appropriate map, schematic,…), user's interests (e.g., to highlight personalized points of interest in the visualization).

Disciplining Visualization Design

As we have seen in the previous section, mobile visualization requires to be approached differently from traditional visualization. Unfortunately, there is very little knowledge and experience available on developing visualizations for the mobility context. However, although the applications studied so far in in the field of Information Visualization[1,2] do not concern mobile devices, some ideas about the design process are so general that they can apply to any visualization. Undisciplined visualization design is indeed likely to result in typical failures such as graphics that might look impressive but are very difficult to read or understand or, even worse, apparently intuitive graphics that actually mislead users. Users getting lost in navigating the graphical space on a small screen is also a common problem.

To approach the design process in a disciplined way, it is convenient to organize it in different aspects and steps. In the following, we formulate and discuss a sort of checklist (made of 6 questions) that quickly highlights the major steps one should go through and allows one to identify more precisely at what level an error has been made in the process of designing a visualization:

- *Mapping: How is information visually encoded?* A visualization turns data (numbers, strings, data structures,…) into graphics that can be characterized by several visual features (lines, colors, lengths, positions, curvatures, animations,…). A precise mapping among data objects and relations and visual objects and relations needs to be defined and followed consistently all over the application. A mapping has to be found in such a way that *conceptually important* aspects are made *perceptively important.*
- *Selection: Among the data available, what is relevant to the considered task?* On one side, visualizing insufficient data would lead users to take suboptimal or plainly wrong decisions; on the other side, burdening users with unnecessary data will make it more difficult to reason about the problem at hand. Although the selection problem is important in any visualization, it becomes even more important in mobile visualizations because limited screen space allows one to show a much smaller amount of information that needs to be chosen wisely.
- *Presentation: How is the visualization laid out on the available screen space?* Even if one has identified a clear, intuitive visual mapping, and selected the data the user really needs, the application can still be ineffective because the display is too little to show everything. A convenient way to present the visualization on the available screen is thus needed. The presentation problem becomes so serious with mobile devices that we devote an entire section to it in the following.
- *Interactivity: What tools are provided to explore and rearrange the visualization?* An high level of interactivity is important to increase the engagement of the user in the observed data and enhance her exploration abilities.
- *Human Factors: Are human perception and cognitive capabilities being taken into account?* A visualization must be quickly browsed by the human eye and easily interpreted by users, so knowledge about human visual perception and cognitive aspects can make it easier to design an effective visualization. General knowledge about visual perception can be easily found in textbooks[2]. Research results that are specifically targeted at mobile visualizations are becoming available, e.g. to determine what one can communicate with a very limited number of pixels[3].

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- *Evaluation: Has the effectiveness of the visualization been tested on users?* Tests should be carried out following the rigorous user evaluation procedures that are common practice in the field of Human-Computer Interaction. A survey of visualization evaluation challenges has been recently proposed by Plaisant[4]. Evaluating interfaces on mobile devices requires additional considerations[5], e.g. the use of phone emulators might lead to unreliable results[6] or additional complex variables should be measured such as distraction[7].

A Mobile Visualization Example

Let us consider a frequent need of mobile users: the visualization of a database of geo-referenced points of interest (POIs). A typical mapping is based on associating a specific icon to each category of POIs and then drawing the proper icon for each POI on a map in such a way that spatial relations (position and distance) among POIs are visually maintained. An example is shown in Figure 1a (in this case, hotels and restaurants are the considered categories). By tapping on a chosen icon, the user can access the full record describing the POI (e.g., price, telephone, number of stars,…). Although the visualization is clear and intuitive, it is extremely unlikely that a user in a mobile context will systematically tap on each icon and read the corresponding record to come up with a decision about which hotel and restaurant to choose. This is a selection problem: the visualization should not simply draw all POIs as if they were equally relevant to the user's goal. A typical way to approach this problem is through selection algorithms that draw only the POIs that satisfy a set of user-provided constraints. The limitation of this approach is that if the constraints are too loose we end up again in the situation of Figure 1a, while if they are too strict we end up with an empty map or with a map like the one in Figure 1b that limits flexibility (e.g., the user might not like to stay in that street, but has no clue about how many and which constraints to relax to find a better solution). By refining the visual encoding and exploiting interactivity, one can help the user in better exploring and learning about the database of POIs. For example, Figure 1c shows a solution we have employed: the visual mapping on each icon now gives an indication of how many constraints a POI satisfies through the colored vertical bar in the icon. If a POI meets all the constraints, the associated bar is green; if some constraints are not met, the bar is divided into a lower green area and an upper red area; the size of the two areas is proportional to the number of satisfied (green area) and unsatisfied (red area) constraints. Users can interactively play with the constraints (through sliders), visually perceiving the result of their queries by observing real-time changes in the color areas. By tapping on a POI, one can get a report about which specific constraints are met or not by the POI.
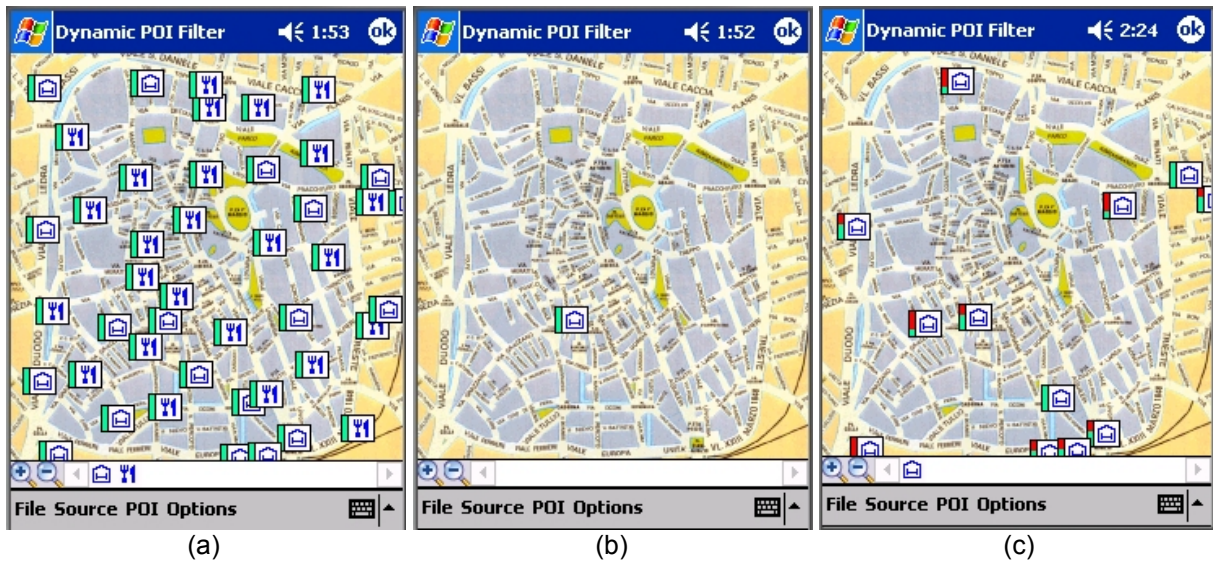
Figure 1. Visualizing points of interest (POIs) on a map in a real mobile application.
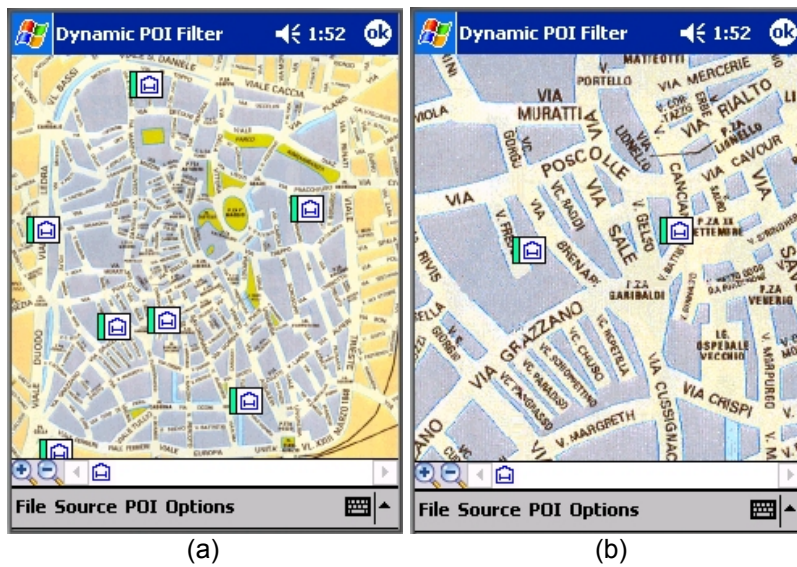

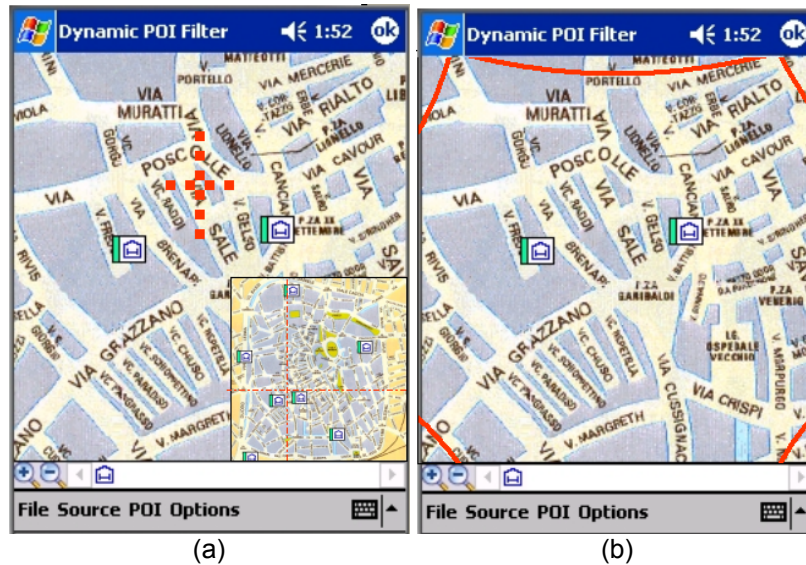**Figure 2. The presentation problem.**

Figure 3. Solutions to the presentation problem.

Facing the Presentation Problem in Mobile Visualizations

Due to the limited screen space, any non-trivial mobile visualization can quickly end up with too much to visualize in a too little display area. A common attempt at facing this problem is based on navigation functions such as scroll and zoom that allow the user to move among parts of the visualization. Unfortunately, this insufficiently alleviates the problem, because it (i) makes it cognitively complex to navigate the visualization, and (ii) forces users to lose the global context when examining the details of the visualization and vice versa. As a practical example, let us consider again the application of Figure 1 and a real scenario where the user has identified a set of POIs and wants to travel in the city to reach them: she can obtain either an abstract view with all the POIs visualized (the context, see Figure 2a) but not enough details or a detailed view that is unable to show all the POIs (the detail, see Figure 2b).

The solutions to the presentation problem that came out from visualization applications on desktop computers fall in two classes. We describe and discuss them with respect to their applicability in the mobile context:

- *Overview+Detail* approaches provide two separate views simultaneously, one for the context, one for the detail. Although feasible on desktop computers, this approach tends to fail on mobile devices. Due to limited screen space, it becomes indeed more difficult to relate the two different views, and it can even be impossible to properly fit the two views on the same screen. As an example, Figure 3a shows a traditional Overview+Detail visualization applied to the scenario of Figure 2. The smaller view is extremely difficult to read, and although two crosshairs have been added to help relating the same location in the two views, it is very hard to cognitively connect them, even for people who are already familiar with the map of the town.

- *Focus+Context* approaches provide context and detail information simultaneously without separating the two views. *Fisheye-views* are probably the best known example of Focus+Context: the optical fish-eye view magnifies the objects visualized in the point of greater focal attention for the user, and progressively decreases the size of more distant objects. In general, implementing

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an efficient fisheye on a mobile device is not easy. In the case of maps, fisheye may not work well[8]. A mobile solution that has been successfully tried for visualizing maps is magnification of the parts that are more useful to the user (e.g., complex intersections) and compression of the parts that are less useful (e.g., long roads with no intersections).

However, the presentation problem is so serious in mobile visualizations that is leading researchers to propose new approaches that are specifically designed for mobile devices, without resorting to classical Overview+Detail or Focus+Context solutions. In particular, the following two approaches are emerging:
- *Visual references to parts of interest that are outside the view area*. In this approach, the detail view is augmented with interactive visual references to the context. Therefore, although the context view is not shown, users are made aware of some of its parts that are relevant to the current task. For example, arrows in the detail view of a map can indicate the direction of POIs that are outside the view area and specify their distance with a number. New metaphors are also being proposed, e.g. Halo[9] is a "lamp shining onto the street": each POI outside the detail view is seen as a "lamp" with an associated round aura, that produces a red arc at the borders of the detail view. The arc length gives a visual indication of the POI distance, the arc position shows the POI direction. Figure 3b shows the Halo metaphor applied to the scenario of Figure 2.
- *Intuitive ways of switching among parts of the visualization*. This approach keeps the traditional idea of navigating a visualization by scrolling and zooming among different parts of the visualization, but aims at reducing the cognitive complexity of the activity, taking also into account the input techniques used in mobile devices. For example, ZoneZoom[8] has been designed for the smartphone class of devices: it automatically divides the context view in 9 areas and maps them on the 9 numbers in the phone keypad; pressing a number produces an animated combined zooming and panning to the corresponding area. Users' familiarity with common phone keypads is exploited to allow for easy one-handed navigation of the visualization. The idea is recursively re-applied to support multiple zoom levels.

Classes of Mobile Visualizations
As we have previously mentioned, it does not make sense to consider any traditional application as a candidate for the mobility context and there are also new applications (such as location-aware ones) that are specific to this context. Data that researchers are currently investigating for mobile visualization can be categorized into 5 main classes:
- *Text* (e.g., list of names, menus, e-books, documents,…);
- *Pictures* (e.g., photographs, figures, artwork,…);
- *Maps* (e.g, tourist maps, first-responder maps, architect maps,…);
- *Physical objects* (e.g., CAD models, interactive engineering instructions, scientific visualizations,…);
- *Abstract Data* (e.g, time-oriented data such as calendars, medical records, stock market data,…).
In the following, we discuss each class, also mentioning some of the tested techniques.

Visualizing Text on mobile devices. While a desktop system is able to properly visualize a good amount of text, the small screens of mobile devices allow only for a very small quantity of text to be shown on a single screen with an adequate font. This seriously affects readability and a number of important tasks (e.g., reading reports and books, visiting Web sites, selecting from long menus and lists,…). Moreover, this is an additional example of the seriousness of the presentation problem on mobile devices. Researchers are trying to apply different techniques to face the text presentation problem. Dynamic text

presentations are being tested in the mobility context because they require very limited screen space. For example, *Leading Presentation* scrolls the text horizontally on one line, while *Rapid Serial Visual Presentation (RSVP)* displays text as small chunks appearing in sequence at a single location. Dynamic presentation techniques have been tested on mobile devices at Ericsson Research[10], pointing out that:

- Leading presentation is more familiar and thus initially more acceptable to users;
- It is possible to effectively read long texts with RSVP: it is as efficient as reading from a book or on a large screen, but is cognitively more demanding;
- RSVP appears to be faster than MS Explorer on a PDA for text presentation of *short* texts, and just as fast for *long* texts.

An alternative solution can be given by Focus+Context presentations, e.g. fitting more lines in the same screen and dynamically expanding and compressing the size of lines to provide a focus area around a currently selected line.

Visualizing Pictures on Mobile Devices. Moving from text to large pictures, browsing problems on mobile devices become even more serious, and the task requires a considerable effort to users. Visualization techniques that help users reducing the number of zooming and scrolling operations are needed. It is interesting to note that ideas from text visualization can be extended and adapted. For example, RSVP can cycle among a sequence of regions of a picture. The selection of the regions can be based on the automatic identification of likely user's regions of visual attention, e.g. Liu et al. 11 proposed an RSVP browser for photographs where an image processing algorithm identifies possible centers of interest (e.g., people's faces in the photograph). Results of user evaluation have shown that the browser works well with photograps of groups of people, but tends to be less effective with generic photograps taken from the news.

Visualizing Maps on Mobile Devices. Several mobile map-based applications are being proposed for contexts with different requirements (cities, museums, fairs and exhibitions, mountain tracks, sea routes,...), and we have already discussed some aspects of map visualization in previous sections. Considerable added value for maps on mobile devices is given by interactivity (e.g., adaptation to user's interests and needs) and location-awareness. Maps are indeed used for much more than navigation: an interactive map can select and display only the information that is of interest to the user (e.g., stands dealing with a desired product in a fair; restaurants and museums, but not shops and monuments in a city;...), taking into account means of trasportation (car, feet, public buses,...). Legends can be dynamically generated including only the graphic elements that are needed in the currently displayed screen. If the device is location-aware, selection of the right portion of map can be automatic. Some telecom operators are exploring the idea of mobile yellow page services augmented by the visualization of (2D and 3D) interactive maps (e.g., the SIMCAR project by France Telecom). Location-aware 3D visualization of the visited area also allows users to get information about POIs in the most intuitive way: as they move in a city, a corresponding location-aware 3D visualization is shown on their mobile device; when they are interested in something in the real-world, they have just to touch the corresponding object in the currently visualized part of the virtual world. We discussed the implementation of this functionality in a specific paper[12]. A relevant class of applications for map visualization is given by Mobile GIS (Geographic Information Systems) where interactive maps augmented with different kinds of information are crucial for several in-the-field users, ranging from urban planners to emergency responders.

Visualizing Physical Objects. Thanks to mobile devices, CAD models could be accessed in the field, both for viewing and for data collection purposes. However, tests carried out at NIST[13] on construction models

have shown that the hardware limitations of current mobile devices severely affect efficiency of 3D CAD model visualization. Researchers are thus exploring both software (e.g., "teleporting" among viewpoints to prevent the need for animation) and hardware (e.g., carry out rendering on remote powerful computers and receive results wirelessly as a video sequence) solutions to the problem. However, it must be noted that tasks carried out with mobile devices often do not need the same level of detail and precision of the original CAD model. This allows for simplifications that make the model manageable on mobile devices, e.g. the 3D city models we used in our mobile application are rendered in real-time on current PDAs[12].

Visualizing Abstract Data. Abstract data can be both atemporal (e.g., voltage range for reliable operation of an electrical device) or temporal (e.g., value of a share in the stock market). Calendar-based applications such as agendas are widespread in the mobile device market. However, current commercial products suffer from the presentation problem. For example, on small phone displays, it can be impossible to visualize a simple one-month calendar. PDAs offer a larger space, but commercial calendar-based software forces users to jump around through multiple screens, making it harder to relate disparate pieces of information together and to use the device for analysis and planning[14]. The Datelens application[14] tries to face the problem using multiple levels of detail and fisheye-views, e.g. the user can start from a calendar overview of a large time period, then specify a focus by tapping on a day and expanding its details without losing the global context.

Time-series are another example of temporal data that is ubiquitous in several domains, ranging from medical records to the stock market. Current applications (and Web sites) for mobile devices try to squeeze the traditional desktop time-series graphics in less space with scarcely readable results. It is thus interesting to find ways of conveniently visualizing time-series on mobile devices. For example, alternative ways of drawing bar charts on small screens of mobile phones have been tested by visually encoding the sign (e.g., with the color of the bar) so that positive and negative bars can grow in the same direction and more screen resolution becomes available for discriminating the relative size of bars[15]. More radical solutions can be adopted, e.g. drawing a time-series as a spiral so that it can fit the screen, and coloring the different pixels of the spiral according to the values of the series in time.

Conclusions

Visualization can be an important component of a mobile application and allow one to build mobile applications that are more useful, intuitive and productive. This paper has discussed mobile visualizations and the main issues involved in designing them with the aim of both inspiring designers of mobile applications to exploit the power of visualization in their systems and helping them to better approach the problem.

From a purely technical point of view, developing visualizations on mobile devices will become easier due to on-going improvements such as new, possibly standard software APIs (e.g., OpenGL | ES) and more powerful devices (e.g., benchmarks on the last generation of Pocket PCs see performance double, and with some graphics operation performance increases by a factor of 10).

Although these improvements do not change most of the limitations of mobile devices and the mobility context we discussed in this paper, they will make it easier to create and experiment with mobile visualizations. Expanding the currently limited set of mobile visualization techniques will make it more convenient for people to get information from and take decisions with mobile devices.

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