Designing Map Symbols for Mobile Devices: Challenges, Best Practices, and the Utilization of Skeuomorphism

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Abstract. In this work we make three contributions to the design and use of map symbology on mobile devices. First, we present an overview of the current state of mobile symbology and best practices based on previous empirical findings. Second, we demonstrate the design of a new set of map symbols for mobile devices based on these guidelines and proposed design strategies. These new symbols were developed for comparison with an existing standard used by emergency management and disaster relief professionals. Lastly, we discuss the role of skeuomorphism in the context of affording interaction in map symbol design. We believe this work advances the science of mobile symbology and demonstrates a practical application of skeuomorphic design in modern mapping applications.

Keywords: Design, Symbology, Interaction, Skeuomorphism

1. Introduction

A number of recent technologies and tools have demonstrated the utility of mobile mapping devices in a wide range of settings. The potential utility of mobile maps is particularly clear in mission-critical environments such as law enforcement or emergency response and recovery. Within such settings, mobile devices must not only be reliable in both form and function, they must have utility to the mission. This requirement places particular emphasis on the visual interface of the device, as it connects the user to the application where information must be interpreted and acted upon quickly. With a growing number of location-based applications and support tools being developed for these purposes, great care must be taken in the way events are symbolized.

In addition to mission-critical usage by professional users, mobile maps have permeated consumer environments and are ubiquitously employed to aid navigation, enhance tourism, and enable a wide array of location-based services that range from tracking a lost phone to local dating services (Lee, Zhu and Hu 2005). Whether for profession or pleasure, the success of many mobile maps relies on interactive functionality that transforms geographic data into actionable information.

At the same time, most maps are still largely static; base maps rarely need updating, key points of interest (POI) tend to reflect a constant location and information (e.g., a name and address), and many elements of cartographic design are typically not interactive (e.g., highway labels, POI). For these reason, we argue that an effective mobile map is one that successfully distinguishes interactive and non-interactive symbology.

This paper reviews research on mobile mapping with an emphasis on map symbology for and interaction with mobile maps. Based on the review, we elucidate some of the design challenges and considerations required for providing meaningful maps on a range of mobile devices reliant on interactive symbology. Emphasis is given to applications in emergency management and law enforcement where decisions must be made quickly and accurately, though we extend our findings to the broader range of mobile map uses. We conclude the paper with preliminary guidelines derived from the literature for design of mobile maps and then outline some key research and development challenges focused on leveraging technological advances to achieve effective mobile mapping applications.

1.1. Mobile Devices: Scope, Limitations, and Considerations

Mobile devices are considered here to be ones that are essentially portable and can be used remotely. These include laptop computers, smartphones, tablet computers, wearable devices, Personal Digital Assistants (PDAs), and in-vehicle units that include but are not limited to navigation systems. For the purpose of this paper, we focus on the subset of mobile devices that are held in or used by one's hands while mobile. This focus excludes laptop computers as well as wearable devices used primarily for augmented reality applications. Accordingly, the remainder of this article deals primarily with smartphones and tablet computers.

Mobile devices defined in this way have many potential benefits, including: collecting information in the field or during a police patrol (Bragdon et al. 2011), obtaining live updates remotely when in the field (Weakliam et al.

2005), communicating with natural/manmade disaster first responders (Erharuyi and Fairbairn 2003, MacEachren et al. 2006), and visual collaboration among large teams during urban emergencies (Monares et al. 2009).

Despite the advantages suggested above, mobile devices are not without their limitations. Most notable of these are reduced screen size and display resolution (Burigat and Chittaro 2011), reduced capability for input and interaction while the user is in motion (Bragdon et al. 2011), and limited processing power and memory (Follin and Bouju 2008). Each of these limitations influences how symbology can be applied and whether or not a particular approach is effective. These limitations can often be compounding. For example, limited screen space will dictate limits on the number and size of symbols that can be displayed legibly on the screen and the extent of territory that can be displayed. A desktop environment, in addition to supporting display of larger territories and more symbols can alleviate the constraints it does have through zooming, panning, and other interactions. However, the mobile utility of smaller devices is hamstrung by the increased effort similar interactive behaviors require when using the device in concurrence with another common task, like walking or driving. If this increase in effort to interact and the attention that must be directed to that interaction is too onerous, it can impede the device's advantages as a mobile aid (Willis et al. 2009).

A number of attempts have been made to understand and combat these limitations. The remainder of this paper will discuss several of these efforts that are most relevant to mobile mapping with an emphasis on issues of map symbology and interaction with the map display for mobile devices. Through this discussion, the latest directions in the literature and key challenges that remain for future research are also identified.

The existing literature on mobile map symbology is diverse and addresses many specific goals and interests. It is therefore useful to identify common themes that are prevalent. We have identified three themes that appear within the broader context of map symbology and interface design for mobile devices; specifically, the literature can be categorized as emphasizing:

1. **Symbology.** This work addresses use-specific symbol design, the salience of the symbols due to display parameters, figure-ground relationships, semantics, and the performance of symbols in task-driven evaluations.
2. **Interaction.** Research in this area emphasizes how users interact with devices, operate menus, allocate attention, and respond to displays that use symbols as part of a greater suite of functions. Examples include graphical hints that alert the user to symbols existing outside of the currently active view, symbols that aggregate when

they are too numerous for the screen, and the role of touch, gestures, and buttons to manipulate the display.

3. **Remote information access and collaboration.** Mobile devices are frequently used to report, update, collect, and communicate information remotely. A growing body of literature is centered on the use of map symbology and interface design to facilitate these collaborative tasks

There is considerable overlap between these themes and they are by no means absolute. We continue in the following sections with key lessons learned, emphasizing those most relevant to items 1 and 2: symbology and interaction.

2. Previous Research: Symbol Design and User Experience

Map symbols have been categorized in multiple ways and there is a wide range of terminology used to discuss map symbology in the literature. To create consistency across the studies that will be cited below, this paper will use the terminology described by MacEachren (1995), focusing on the relative abstractness or iconicity of symbols as it related to three categories of positional symbols that each exhibit a range on this continuum: pictorial, associative, and geometric.

Many mobile devices in current production utilize touch-screen displays, thus it is crucial that new symbol designs consider existing work in this area. Morrison and Forrest (1995) conducted one of the earliest studies evaluating pictorial symbols on touch-screen devices within the context of tourist maps. Their work highlights the need to consider design not only from the standpoint of variables affecting individual symbols (e.g., size and hue), but also semantic relationships across and between multiple symbols. For example, their results show that for many symbols, size does not influence the accuracy of visual search tasks but may greatly affect how quickly symbols are found. This relationship is moderated by the semantic context suggested by other symbols on the map. A telephone symbol for example may be interpreted as the location of a pay phone when used in isolation or in tourism maps, while the same symbol might be interpreted as a service for calling help if nearby symbols reflect first-aid and medical care. In other words, how users interpret a symbol is influenced as much by context and nearby symbols as by the symbol's own design.

In addition to suggesting semantic context, the design of nearby symbols can also influence the effectiveness of individual symbols by affecting the overall salience of a particular symbol. Kuo-Chen refers to this as complexity contrast and it greatly influences the time required to identify symbols (2008). Related work suggests that associative symbols, such as the simple monochrome pictorial symbols that are typically part of standards-compliant recommendations, are not as strongly affected by changes in size as are realistic, multi-colored, sketch-based, or 3-dimensional pictorial symbols (Elias and Paelke 2008). Although this limitation is important to consider for map symbols in general, it is especially important for mobile devices with limited screen space. Such a limitation encourages the use of simple, abstract symbols over complex symbols with more detail and realism (Lee, Forlizzi and Hudson 2008).

While the interpretation of abstract symbols is less affected by changes in symbol size, abstract symbols (particularly geometric symbols) are subject to misidentification since the relationship between the symbol and what it refers to is often arbitrary. A trade-off therefore exists between accommodating a limited screen size through smaller, abstract symbols and maintaining semantic clarity.

Isolating symbology from the total experience of using a mobile device is at first an attractive idea since it removes complexities of human-computer interaction and a potentially limitless variety of application contexts. However, the appropriate design of symbols for mobile devices requires a complete understanding of how existing symbols are used, which symbol design traits and interactions between the devices and symbols improve or impede performance, and under which conditions or scenarios certain symbol types or designs are most useful. The factors influencing user experience are subject to varying abilities of individual users and an ever-changing range of device capabilities (Baus, Cheverst and Kray 2005, Meng 2005).

On par with the contentions of the previously mentioned work, Apple asks designers of their mobile applications to “embrace simplicity,” (2011, p. 152-153). In addition to generic advice, the human interface guidelines provided by Apple impose specific requirements for size and quality of icon designs to ensure that the designs are effective visually and tactically. The requirements derive from limitations on the user’s ability to see a symbol and the device’s ability to recognize the user’s fingertip when touched. Similar recommendations are provided by the interface guidelines from Google, which offers less specific advice but again reiterates the need to avoid complex, highly detailed, and realistic icons (2011). Additionally, both firms insist that designers consider icon design in the full context of the other elements of the interface and the purpose for which they will be used.

3. Design Recommendations and Suggested Guidelines

Together, the studies reviewed allow us to make the following suggestions:

1. Well-designed symbols should utilize black and white figure-ground relationships or be based on mixed colors that have established meanings, such as the U.S. interstate shield's use of red and blue, and have high contrast against the base map. Since the majority of vector base maps are by default light in color, this suggests that symbols for such maps should maximize figure-ground with a dark frame and light symbol.
2. Symbols with strong semantic relationships with their referent can be identified more quickly on smaller screens than those that are arbitrary and geometric, sketch-based, or based on a 3-dimensional rendition of the referent. However, increasing levels of abstraction may impede the accuracy of symbol identification, and even readily identifiable symbols can be misidentified if their purpose is ambiguous (e.g., the telephone symbol in Morrison and Forrest's research (1995)). Thus it is important to balance the *speed* with which users identify semantically strong pictorial symbols and the *accuracy* with which simpler abstract symbols can be located on the map.
3. Symbols should be smaller when displayed in large numbers - potentially removing the symbol frame if necessary as long as figure-ground is maintained and the symbols remain touchable (for symbols that require interactivity).
4. Symbols intended for concurrent use should be similar in complexity to avoid a large contrast gradient in symbol design, except in the case where greater salience is desired for particular symbols (e.g., a hospital symbol). High complexity contrast between regular symbols and those deemed important would then be preferable (e.g., a hospital symbol made with an "H" will stand out amongst other symbols made from simple geometric shapes, like squares and circles).

Three additional factors that should be taken into account by symbol designers are:

1. ***The capabilities of the target device(s).*** Touch-screen devices have additional symbol size requirements not present on devices that use other input methods. If the symbol requires tactile interaction, it must be large enough to be touched by a fingertip. This complicates the task of accommodating small screens and avoiding clutter.

2. ***The purpose of the device or application should influence the method of interaction***. Symbols used alongside other tasks that are cognitively engaging (like driving) should require as little interaction as possible. If interaction is required, it should be in the form of gestures, spoken commands, or make use of hard buttons that do not require the user to look at the screen.
3. ***Symbols that can be interacted with should be visually distinguishable from those that cannot***. How this is achieved will depend on the other variables employed in the symbol design. A bold frame may alert the user that a symbol is an aggregate and can be clicked for more information, however this approach would be less effective if symbol frames were employed for other purposes (e.g., event status or the degree of damage due to a disaster).

There is a complex relationship between each of these design decisions. It is unlikely that a symbol will be optimal for every setting, to every user, on every device. The application developer, cartographer, or designer must weigh the costs against the benefits and evaluate the performance of their symbology whenever possible.

3.1. Symbol Shape and the Map Symbol Box Model

In addition to the position of icon shape on the abstract-pictorial continuum, the shape of the frame surrounding the map icon is a vital consideration. The shape of the frame dictates how much space exists for the icon, and thus the actual size of the interpretable icon depends on the symbol frame's overall shape and border thickness (Figure 1, right). In general, symbols with square frames (or rounded rectangles as in Figure 1) provide more internal space than other frame shapes to maximize the icon size, which is beneficial in visual search tasks (Morrison and Forrest 1995). Moreover, the additional space afforded by maximizing the space around an icon can be utilized for other cues, like indicating interactivity as discussed in 3.2.

To aid in design decisions and the specification of design variables, we propose the *map symbol box model* (Figure 1, left). Similar to the box model specified for cascading style sheets (CSS) for HTML documents[1], the map symbol box model clarifies the foundational elements upon which a symbol is constructed. Defined in this way, individual design variables can be isolated and discussed explicitly, greatly enhancing the design process for new symbols and allowing precise critique of existing symbology.

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[1] http://www.w3schools.com/css/css_boxmodel.asp

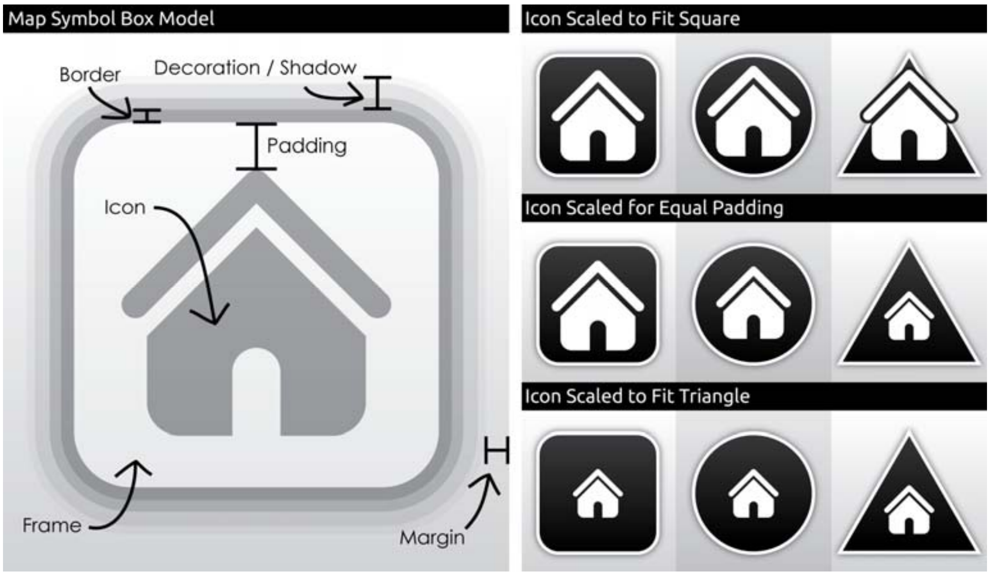

Figure 1. The proposed map symbol box model (left) and an example of specifying symbol size relationships using the padding element of this model (right).

By deconstructing map symbols into 'boxes within boxes,' each with a specific attribute, the design process can more accurately reflect the relationships between the various features of a complete map symbol.

3.2. Interactive Cues via Skeuomorphism

Skeuomorphs, typically defined as design elements that reflect ornamental references to previous (and potentially obsolete) analogs, are ubiquitous in current user interfaces. The uses of skeuomorphism in digital interfaces are typically aesthetic, such as realistic textures (leather and stitching) used in the design of mobile applications. Skeuomorphism can also be used to suggest semantic relationships. For example, the 'save file' feature in most software applications is represented by a 3.5" floppy disk, even though these disks are rarely used and new computers no longer come with the ability to read floppy disks. Despite a lack of academic literature on skeuomorphic interface designs and criticism for their form-over-function nature, we contend that when used sparingly, skeuomorphic designs have the potential to enhance the performance of map symbols.

We hypothesize that an effective use of skeuomorphism is to indicate that a map symbol is clickable (or touchable). By evoking a heuristic response akin to what we experience in the real world, map symbols – like elevator buttons and doorbells – can indicate interactivity by appearing to have a touchable surface different than their surroundings.

Figure 2 provides an example of a skeuomorphic interactive cue:

Figure 2. A subtle, 3-dimensional knurled skeuomorphic cue gives the interactive symbol (right) the appearance of being touchable.

4. GeoVISTA Symbology and Future Work

Within a project supported by the Department of Homeland Security, the Penn State GeoVISTA Center designed mobile symbology as a possible alternative to the existing Homeland Security Working Group (HSWG) symbology[2]. The GeoVISTA symbology (Figure 3) was designed in compliance with the guidelines presented in this paper. In follow up research, we plan to compare the symbol sets in a user study with several tasks completed on a mobile device.

Figure 3. The DHS HSWG symbology (left) and their redesigned GeoVISTA counterparts (right). The GeoVISTA symbols also have an interactive, skeuomorphic version using the cue in Figure 2.

Notable design decisions that distinguish the GeoVISTA symbology from the HSWG set are outlined below.

[2] http://www.fgdc.gov/HSWG/index.html

1. The GeoVISTA symbols are arranged in a square frame. This provides space within the symbol frame to increase the size, and therefore legibility, of the icon.
2. To have high figure-ground contrast with the greatest number of base maps, which are typically light in color, the GeoVISTA symbology uses a light icon within a dark frame.
3. The GeoVISTA symbology is intended to have a strong semantic relationship with the events or places being depicted.
4. The GeoVISTA symbology is designed as an entire set to have consistent visual complexity from one symbol to the next.
5. To further promote figure-ground relationships, the GeoVISTA symbology has a slight shadow and raised appearance, which helps separate the symbols from the base map.

Symbols intended to be interactive with feature a skeuomorphic cue that distinguishes them from non- interactive counterparts.

The user study evaluation will be based on four tasks that cover visual search, semantic relationships, interactivity, and preference. Results are forthcoming.

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