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# Semantic distance as a critical factor in icon design for in-car infotainment systems

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ABSTRACT

In-car infotainment systems require icons that enable fluent cognitive information processing and safe interaction while driving. An important issue is how to find an optimised set of icons for different functions in terms of semantic distance. In an optimised icon set, every icon needs to be semantically as close as possible to the function it visually represents and semantically as far as possible from the other functions represented concurrently. In three experiments ($N = 21$ each), semantic distances of 19 icons to four menu functions were studied with preference rankings, verbal protocols, and the primed product comparisons method. The results show that the primed product comparisons method can be efficiently utilised for finding an optimised set of icons for time-critical applications out of a larger set of icons. The findings indicate the benefits of the novel methodological perspective into the icon design for safety-critical contexts in general.



## 1. Introduction

As vehicle technology evolves, the complexity and connectivity of in-car infotainment systems continually increase. This surge in technology means that the driver increasingly has access to a large number of novel in-car online applications, which can offer improved communication, entertainment, route finding, as well as other useful in-car services on the road. One unfortunate downside of this progress, however, is the increased potential for drivers to be distracted from the safety-critical primary task of driving while utilising the services (Victor et al., 2014; Klauer et al., 2006).

The evolution of in-car systems has led to a large growth in system functions and, along with this, a growth in visual icons that represent these functions. Furthermore, as novel applications are introduced into vehicle systems, easily distinguishable new icons are needed to represent these functions. In the driving context, a two-second glance off road can already be risky (Liang et al., 2012), which means the driver should be able to find and locate the desired function from the in-car menus as fast as possible. This leads to novel challenges for the in-car interface designers to find an optimised combination of such menu icons that can be recognised with a brief in-car glance (Dobres et al., 2017; Dobres et al., 2014). Thus, effective icon design that enables fluent communication in human-computer interaction (HCI) is especially critical for interactions with in-car infotainment systems while driving.

In this interaction context, time is of the essence owing to the pressure to return eyes on the road. An action to be conducted by selecting an icon can be demanding owing to the competition of attention by the other icons on the display. Therefore, the focus of this paper is to examine the cognitive processing fluency of icons' semantic distance, and the relationship between an icon's visual representation and its intended meaning. Previous research has mainly focused on studying the semantic distance of individual icons (e.g., Isherwood, 2009; McDougall et al., 1999). However, icon menus always include sets of icons, whose meanings are required to be distinguishable from the meanings represented by the other icons in the same icon set. Every icon in a menu needs to be semantically as close as possible to its intended function while also being semantically as far as possible from other icons' functionalities in the same icon set, so that the driver can recognise and select the required function safely while driving. Here, our aim is to present and validate a methodology to investigate and optimise icons' semantic distances in safety-critical user interfaces, and thus to provide insights into icon design for safe interactions while driving.

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In order to find an optimised set of icons for time-critical applications out of a larger set of icons, we first explored four sets of possible icons and their semantic distances to four different in-car navigation system functionalities by studying participants' preference rankings and their verbal protocols. To examine how quickly these preferred icons can be processed, in the second experiment, we tested how quickly people are able to make the preferential judgments concerning the icon functions. Finally, in order to find set of icons where the icons of different functions are easily distinguishable, in the third experiment, we tested how quickly users identify icons of a given function when compared to icons of a different function. As a result, we present an icon set for the given functions, optimised for being individually quick to interpret, by referring to their intended meaning, as well as by being distinguishable as the icon of their intended function in the complete icon set.

## 2. Icon design in the automotive context

Icons stand for the objects they represent, that is, the displayed features and properties in icons resemble or imitate the objects they signify (Peirce, 1986). Icon metaphors are often elicited from real objects to emphasise familiarity (Blackwell, 2006), and in technological artefacts, can be defined as graphical representations that symbolize actions in technological environments (Ware, 2004). Icons are powerful elements in visual communication (Poulin, 2011) and enable users to accomplish technological tasks visually (Kay, 1990). Properly designed icons reduce system complexity and mental workload (Gittins, 1986), and provide better cognitive affordances than textual user interfaces (García et al., 1994). Moreover, the large extent of icon-based user interfaces highlights visual icon design, not only to enhance communicability, but also to match user preferences (Huang et al., 2002).

Additionally, effectively designed iconic representations make objects, concepts, and actions easier to find, recognise, remember, and learn (Lidwell et al., 2003). Thus, icons are more universally recognised than textual information (Lodding, 1983), are recognised quickly (Caplin, 2001), and are well remembered (Weidenbeck, 1999). Therefore, icons can be perceived immediately and enhance fluent communication and visual usability of interactive systems. This perceptual immediacy enables well designed icons to be grasped and understood effortlessly (Mullet and Sano, 1995) and the graphic representation of an icon affects its recognition rate and, therefore, influences user perception (Gatsou et al., 2012). Immediate recognition and long memorability of icons raise challenges for efficient icon design. In practice, the intended functions of the icons might gain different meanings across users (Bocker, 1993; Isherwood, 2009; Isherwood et al., 2007), because icons convey semantic information through visual language that does not rely on strict rules in the same way as written words (Carr, 1986). Further, icons follow less strict rules than written language, which also contributes to their ambiguity between individuals.

Several studies have focused on visual icon characteristics and design principles in general (e.g., Byrne, 1993; Frutiger, 1997; Gaver, 1991; Gittins, 1986; Goonetilleke et al., 2001; Ng and Chan, 2008). For example, some cognitive features in icon effectiveness include familiarity, concreteness, visual complexity, meaningfulness, and semantic distance (McDougall et al., 1999; Ng and Chan, 2008). Familiarity refers to the frequency of encounters with icons, concreteness to the abstraction level of the icons visual representation, complexity to the number of visual elements in the icon, and meaningfulness is how the icon's meaning is perceived (Ng and Chan, 2008). In addition, several icon design principles, aiming towards cognitive processing fluency, have been presented. For example, immediacy refers to effective recognition and cognitive processing fluency, in which the design focus is on the most essential visual elements through simplification and abstraction, not merely reducing the elements (Mullet and Sano, 1995). Icon design should follow the principle of generality by representing a broader category (e.g. painting supplies) of the idea, rather than an exact object (i.e. detailed photographic representation of some specific paint roller) in a cohesive manner within an icon set. Characterisation is utilised to emphasise the most essential features of a representation, including the most advantageous viewpoint. To design for communicability, knowledge of the users, culture, and context of use is required (Mullet and Sano, 1995). In addition to these icon design principles, understanding of cognitive processing fluency of icons' semantic distance is needed to design for safe interactions while driving. Cognitive effectiveness of semantic distance has not been studied in terms of icon sets, merely concerning individual icons, and thus, icon design principles would need to include this viewpoint of semantic distance, especially in time- and safety-critical interaction contexts.

For visual information processing to be fluent and effective, pictorial representations must activate correct mental models that match the representation's function (Isherwood, 2009). In icon design, this relationship is called semantic distance, a necessary factor in cognitive effectiveness of icon interpretation (Isherwood et al., 2007; Isherwood, 2009; McDougall et al., 1999; McDougall et al., 2001; McDougall and Reppa, 2013; Ng and Chan, 2008). However, methodological approaches to semantic distance research have not addressed the role of semantic distance in a set of icons, or the requirements that a specific application context can set. Icon sets for specific interaction contexts have been studied in relation to, for instance, transportation and leisure activities (Prada et al., 2015), emergency medical information systems (Salman et al., 2012), and user interfaces for pre-schoolers (Chiu et al., 2012). A few studies have concentrated on icon design and testing in the automotive domain (e.g., Johann and Mahr, 2011). There are general guidelines for in-car user interface icons based on human factors principles and standards (e.g., ISO 15008, 2009), but these are typically limited to enabling legibility and clarity of the icons while on the move. Thus, icon design research lacks studies of users' interpretations and semantic meanings of visual icon design in in-car infotainment systems for icon sets in which individual icons' semantic distances can be recognised quickly.

Recently, this interaction context has become a significant challenge for visual designers because of the explosion of in-car functionalities and services that are made available to the driver (e.g., Norman, 2007). This stresses the requirement that all the different functions available in the in-car infotainment system should have descriptive and intuitive icons communicating meanings unambiguously. Icons are required to be designed as enabling interactions with in-car systems as efficiently as possible in order to minimise the potential for distraction while driving (NHTSA, 2013). In this time- and safety-critical interaction context, milliseconds can truly make a difference. User interfaces for in-car infotainment systems in particular require icons for which the semantic distance to the associated functions are as close as possible. The driver should be able to locate and select the correct function within a brief in-car glance.

According to the analysis and the early visual sampling model of Wierwille (1993), drivers prefer to keep off-road glance durations on average between 0.5 and 1.6 s depending on the demands of the driving situation. In addition, naturalistic driving studies have found significant statistical associations between safety-critical incident risk and the off-road glance duration. According to Liang et al. (2012), the risks start to significantly increase with off-road glances that last more than 2 s. A subsequent analysis on the same 100-car study data by Liang et al. (2014) suggested the