Designing Automatically Generated Perceptually Optimized Displays

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To my dad & aunt

Missing you always

ABSTRACT

Most current user interfaces do not carefully consider particular "situations" or contexts of use, thus providing information to the user with the same demands of attention no matter what the user's attentional state is. This can result in serious breakdowns in communication between the user and the system in some situations, and is witnessed very often in our daily lives.

The driving context is a good example of a need for situationally appropriate user interaction. Drivers often need assistance when navigating an unfamiliar route. But the displays created by location-based software such as GPS mapping applications are often not straightforward enough to use in the context of driving. Information is crowded and overloaded on the display. Critical information is designed and presented in a way that slows down the rate of uptake, interfering with the process of learning and remembering the route, encoding the information in memory, and making decisions at critical points. To address the attentional demands of reading a map while driving, we developed the Maps Optimized for Vehicular Environments (MOVE) in-car navigation display, which provides situationally appropriate navigation information to the driver through optimization of map information.

In this dissertation, we describe the iterative design and evaluation process that shaped the MOVE system. We describe the map reading and navigation studies that led to early designs for our system. We present a study on visual search tasks that refined the renditions used for the system. Then, we present our second study on the effectiveness of several variations of a perceptually optimized route map visualization with a desktop steering system. The result of this study shows that MOVE's perceptually optimized navigation information can reduce the driver's perceptual load significantly. Our laboratory experiment shows that the total map display fixation time was decreased six-fold, and the number of glances to interpret the map display were decreased about threefold, when comparing the contextually optimized display to a static display.

We then describe the process of implementing the MOVE system, bridging the design and research we have taken from our preliminary studies. The implementation process presents the following steps: First, the implementation of the Road Layout process generates the entire route as simply as possible, while making the important portions of the route segment salient. Second, the Rendition Selection and Rendition Scoring process selects the appropriate forms of map features to lower the driver's attention to the display by reducing the overall amount of information presented. Third, the Final Placement Tuning process uses an intervention technique to prevent possible conflicts and clutter within the selected renditions when presented on the display. Then we present our final evaluation study of the perceptually optimized displays in the context of real driving. The result of this study also shows that the MOVE's perceptually optimized navigation information can reduce the driver's perceptual load significantly.

Finally, we present a summary of contributions and plans for future work.

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1 _ INTRODUCTION

The rapid advance of computing technology enables us to think of a new computing environment, pervasive computing, where a computer that isn't just a device that always occupies some space on my desk. It could be hidden in a dashboard of my car, and it also could be in my mobile phone, which I always carry in my pocket. Today, computers can be found everywhere in every situation. At the same time, the pervasive computing environment is also resulting in fundamental changes in the design process of current user interfaces. For example, users have been interacting with 'ready-made' user interfaces to systems, which are carefully designed for every predictable situation. When designing a user interface, a designer usually begins with researching the situations where the system is being used, and the people who use the system. During the design process, there can be many constraints or variables that user interface designers need to handle, and usually designers create the most appropriate user interface for the user and the situation through an iterative design process.

The user interface of a pervasive computing system follows similar steps. The only difference we might see is that the constraints of variables of the system are not as pre-defined as usually seen in other systems. The variables of a pervasive computing system will vary more widely, changing over time as the circumstances change. For instance, in a route map display, a driver's attention level is quite different when driving than when stopped. Thus, the type and amount of information presented to the driver might be also different. A user interface of a system used in non-interruptible situations such as meetings or presentations should also be different from the one used in interruptible situations. Whether the user interface is being used in a public space or private space will also affect the design. Therefore, when designing user interfaces for the pervasive computing environment, we need to more carefully consider the user's dynamic environmental variables, and the constraints caused by them.

Similarly, the design of a dynamic navigation system has many conditions to consider. Unlike static paper maps, information on the screen changes dynamically as a vehicle moves on; this is one great advantage and a benefit of new technology. Various conditions are considered in creating the optimal map visualization. The vehicle's location within a route, driving time, the level of attention of the driver, and other driving conditions may affect the design of the navigational display. Due to the nature of those dynamic aspects, designers of the system have to consider the conditions that surround the system, which are often referred to constraints by designers.

The term, "constraints," however, wouldn't sound new to most designers. Instead, they always deal with constraints; constraints of price, of size, of balance, of user, of time, of client and so on — almost any kind of constraints (Neuhart, Neuhart, & Eames, 1989). In his interview, even Charles Eames mentioned that, *"Design depends largely on constraints."* (Neuhart, Neuhart, & Eames, 1989) Many designers and design researchers will agree on the statement that design is a process of problem solving through the intervention of colliding constraints, which surround the problem. So, well-trained designers can handle the constraints of the system easily, and find a solution to a problem through their experience of design practice.

One obstacle we confront in the design of navigational information display is the dynamic nature of the system. Each bit of information that is to be presented on the display would likely be treated very differently by the designer as the vehicle moves. For example, a crossroad may be considered to be important when the vehicle is approaching the street, but it will be also treated as a trivial thing soon after the vehicle has passed. So, if the designer has various forms of design alternatives for representing a crossroad, then he or she will have to choose the right form among the alternatives to make it appropriate to the given situation.

Unlike a static display, for which all design decisions can be made by a human designer during the design process, a dynamic navigational information display makes decisions on-the-fly while the vehicle is moving. Since no human designer will be available while driving, many of the design decisions should be made automatically — and for the designer of the system, it is almost impossible to consider every condition that might be happening while driving during the initial design process. Instead, the system itself must make design decisions for the map display by considering the conditions that surround the driver at any given moment. So, in order to make the system automatically do this, it has to bring in human design decision processes into its architecture.

However, generalizing the designer's design decision process and making it as a deployable computational algorithm for the purpose of simulating design planning is not easy. This is because the kinds of problems that designers deal with during design planning are different from the problems that scientists or engineers deal with. Unlike problems in science and engineering, which are definable, separable, and often solvable, the problems of design planning are not defined as true-or-false. They are inherently ill-defined and evaluated as good-or-bad (Rittel & Webber, 1973).

In order to find a solution to ill-defined problems, designers try to recognize and understand the nature of the problem and narrow down the large problem space to a manageable size (Conklin, 2005). Once the problem becomes manageable, then designers seek an optimal solution through an iterative design process. Herbert Simon explains the design process as the adaptation of standard logic to the search for alternatives (Simon, 1996). He says, *"Design solutions are sequences of actions that lead to possible worlds satisfying specified constraints. With satisfying goals the sought-for possible worlds are seldom unique; the search is for sufficient, not necessary, actions for attaining goals."* (Simon, 1996) In practical design activities, designers create many design alternatives of a specific element and choose the appropriate form of the element among the prepared alternatives iteratively throughout the design process. Each iteration is evaluated to see whether it satisfies all the design criteria and constraints that need to be considered. For example, when a designer designs a page layout, he or she considers the target audience, the place where the page is being presented, colors, themes, typeface styles, and so on. Even though an experienced designer may have built up his or her own design rules and disciplines through the design practice, there are always conflicts caused by constraints. When this happens, an experienced designer assesses conflicts by weighing the problem and considering the priority of each condition through an iterative design process. During this process, several design alternatives are created, and one of the alternatives is selected for the most optimized design solution for the situation.

The numerical optimization process, like the design process, systematically generates and considers design alternatives. Numerical optimization is an iterative method to find minimum or maximum values for a given function. During the process, a temporary solution is created and then evaluated to see whether the solution was improved to satisfy constraints. If it doesn't satisfy the constraints, then the process creates a new temporary solution and evaluates it.

Through this iterative process, a solution is ultimately found that meets most of the given constraints.

Prior research has examined the possibility of automatically designing visual presentations that satisfy certain constraints. Mackinlay (1986) has presented APT (A Presentation Tool) that automatically designs effective graphical presentations of relational information through artificial intelligence technique. Feiner and McKeown (1991) presented a system called COMET (coordinated multimedia explanation testbed), which interactive generates multimedia explanations automatically based on the type of request from the user of the system. Lokuge and Ishizaki (1995) presented an interactive mapping domain, GeoSpace, which provides information upon a user's inquiry. This system demonstrated the combination and automatic generation of various visual design techniques, such as typography, color and transparency.

Later, Roth et al. (1991, 1997) developed a system called SAGE, which automates the process of creating new visualizations. With this system, users can automatically and interactively create visualizations based on the characteristics of data and goals users need to perform with it (Roth, Chuah, Kerpedjiev, Kolojejchick, & Lucas, 1997).

The LineDrive system has successfully presented a method for the automatic creation of navigational information displays using a numerical optimization process (Agrawala & Stolte, 2001; Microsoft, 2005). This method uses abstraction and generalization techniques to generate the route, unlike many other map databases. For example, a typical map generated from an online database maintains the same scale throughout the whole map. But LineDrive varies the scale of the route, placing different importance on different sections of a route. This important research contribution illustrates how computer algorithms can compare and select design alternatives within a complex design problem. Finally, research from Fogarty et al. presented a robust toolkit that works on generating optimized displays (Fogarty & Hudson, 2003).

However, prior research on automatic layout design has not focused on the human cost and the effect of information that is delivered. Most current user interfaces do not carefully consider particular “situations” or context of use, thus providing information to the user with the same demands of attention no matter what the user’s attentional state is. This can result in serious breakdowns in communication between the user and the system, and is witnessed very often in our daily lives.

The driving context is a good example of a need for situationally appropriate interaction. During the last few years, drivers have greatly benefited from new vehicular technologies. Modern in-vehicle navigation systems that use global positioning systems (GPS), digitized geographic information, and automatic route calculation have helped drivers navigate unfamiliar routes successfully. Those systems not only provide convenience to drivers, they also enable drivers to get the most optimized route just by entering destination information. Navigation systems also can reduce a driver’s time spent searching for the vehicle’s location on the route map, by providing the car’s location information, which is available through GPS receivers and satellites. As a consequence, we now know that contextual information such as location information can be a great help for any navigation task.

However, driving requires a lot of concentration. Drivers can be easily distracted by other in-vehicle activities, such as chatting with passengers, talking on a cell phone, manipulating instrument panels, or changing radio stations. This can sometimes make driving hazardous. Not surprisingly, in-vehicle navigation systems, while offering considerable advantages over paper maps, can present similar issues. In particular, current navigation systems typically do not carefully consider a driver’s cognitive load and attentional state. These systems deliver all information in the same way regardless of context. Information is crowded and overloaded on the display. Critical information is designed and presented in a way that slows down the rate of uptake, interfering with the process of learning and remembering the route, encoding the information in memory, and making decisions at critical points.

The term “context” is often mentioned throughout this paper. For the purposes of our work, we define the notion of context as the environmental information that is part of an application’s operating environment and that can be sensed by the application, following Salber, Dey and Abowd (1999). This typically includes the location, identity, activity and state of people, groups and objects (Salber, Dey, & Abowd, 1999).

Context in the driving environment is defined as the geographic area that contains a route from an origin to a destination. Every map feature, including road segments along the route, road labels, cross-streets or landmarks is included in the driving context. Additionally, we consider the vehicle’s current location (latitude/longitude), remaining time and distance to destination, and vehicle speed as it traverses the route as part of the context. Other driver-centric information such as familiarity of the area, time (day/night/specific time), weather, or road conditions could be important, but are not considered part of the context within our system (Lee, Forlizzi, & Hudson, 2008).

We often see navigational information with insufficient context that leads to failure in navigation tasks. For example, a turn-by-turn route map, which can be easily obtained from most Internet-based map sites, doesn’t provide any contextual information such as cross-streets or landmarks. Moreover, understanding the actual location of the vehicle on these maps is not easy. The lack of contextual information often causes a problem, especially when the driver fails in following the directions correctly, since there is no way to go back to the route when lost. For this reason, many current in-vehicle navigation systems, whether they are pre-installed or after-market products, are equipped with rich navigational contextual information.

However, a route map with rich contextual information may cause another problem. As Simon pointed out, human attention is a scarce resource (Simon, 1969a; Simon, 1969b). The limitation of human attention impedes drivers from absorbing every bit of visual information displayed on the screen, especially during driving, which requires a lot of attention. Nonetheless, many current navigation systems are not designed to consider the human ability of information processing. They are inherently complex. Therefore, research has suggested that, due to the visual complexity of map data, it is important to limit the amount of information presented to the driver when they are driving (Streeter, Vitello, & Wonsiewicz, 1985; Labiale, 1990; Parkes, Ashby, & Fairclough, 1991), and it has even been suggested that map information only be presented when the vehicle is stationary (Michon, 1993; Ross, Vaughan, Engert, Peters, Burnett, & May, 1995).

To address these issues, we present the MOVE (Maps Optimized to the Vehicular Environment) system, a route map display that perceptually optimizes contextual route information (Figure 1.1). The system presents optimized geographic information for vehicular environments by working on our principle that different information has different importance within a given situation and driver attention should be used on the more important information. The navigation interface of the system should only take appropriate amounts of attention from the driver by abstracting visual information and also by being sensitive to driver's current context (Lee, Forlizzi, & Hudson, 2005; Lee, Forlizzi, & Hudson, 2008).

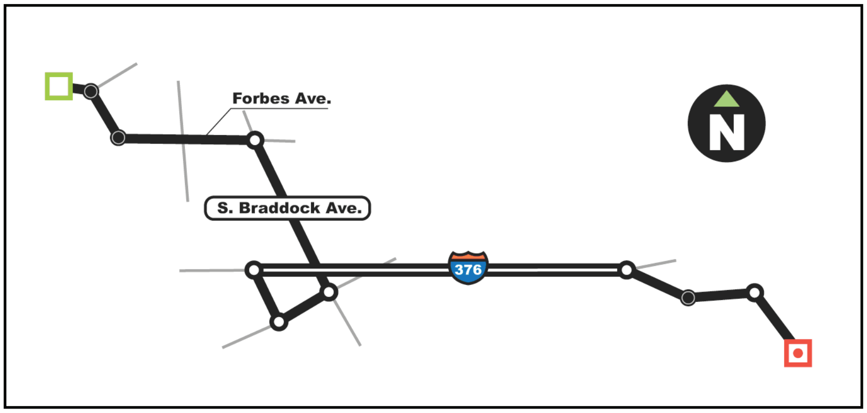


Figure 1.1 A sample of the MOVE display

In designing the MOVE system, we brought a human designer's design rationale to the system, but did so in a way that can be generalized and automated (Lee, Forlizzi, & Hudson, 2005). Generally, experienced designers can handle many of the constraints that surround problems and derive optimized solutions among the large set of design alternatives. They can leverage the amount of information to present based on the situation that a user might encounter, and make some information more salient than other information. The problems we could foresee in designing the navigational information system is that the constraints of variables of the system are not as static or pre-defined as we see in other systems. The variables of this system will change over time as the circumstances of the user changes. Thus, the type and amount of information to be presented to the driver might also be different. Instead of bringing a designer's pre-designed interface to the system, we have to bring a designer's design rationale to the system and generate the display automatically by following the design rationale.

Typical displays on current in-car navigation systems are often modeled on those of a paper map, and have similar visual complexity. Because relatively small displays are often used, such systems almost always allow the user to zoom into areas of interest in the current context. However, this tends to provide a myopic view that lacks route-tracking cues. Further, even with views of only a small area, drivers still need to use a significant amount of attention in order to find the right information on the display. One solution attempted in some current systems has been the use of very simple iconic depiction of turns (Figure 1.2). While dramatically reducing the associated visual search task, this approach eliminates nearly all the contextual information that a driver normally uses to maintain a mental model of their location. Further, it can also eliminate the cues needed to choose between several physically or temporally close alternatives, making it hard to match the display to the current driving context.

Figure 1.2 Iconic form of a route

In contrast, the MOVE display seeks a balance which makes the information most likely to be important in the current context easy to spot in the display, while maintaining overall global context. Our goal in designing this system can be simply stated as reducing the time a driver needs to spend looking away from the road to use an in-car navigation system.

To achieve this result, we employed a thorough HCI and design process, which mixes more intuitive methods from the discipline of design with testing and analysis methods rooted in the behavioral sciences. In particular, we began work with needs finding, looking at issues of the current systems to be addressed in our research through literature review and structured observation of users. We then developed our initial idea of the system and sketches of possible display components. A study was later undertaken to more rigorously measure the perceptual effects of these concepts. These measurements validated our initial design concepts and allowed us to develop principles and guidelines for the system. A full design and accompanying prototype was created, and the effects of our approach were again carefully measured. After that, we developed an automated framework for perceptually optimized displays. This framework encapsulates the design rationale provided in an executable form delivering situationally appropriate route map information to the driver based on the dynamic situation he or she is in. In this dissertation, we will discuss how the system selectively chooses the most appropriate rendition sets from a large set of design alternatives. Then we will discuss the process and the algorithms used in the implementation of the system. Finally, a study was undertaken to compare the effectiveness of our optimized display with other type of displays, ones that have more or less context. The remaining chapters of this dissertation will follow and expand upon the steps outlined above.

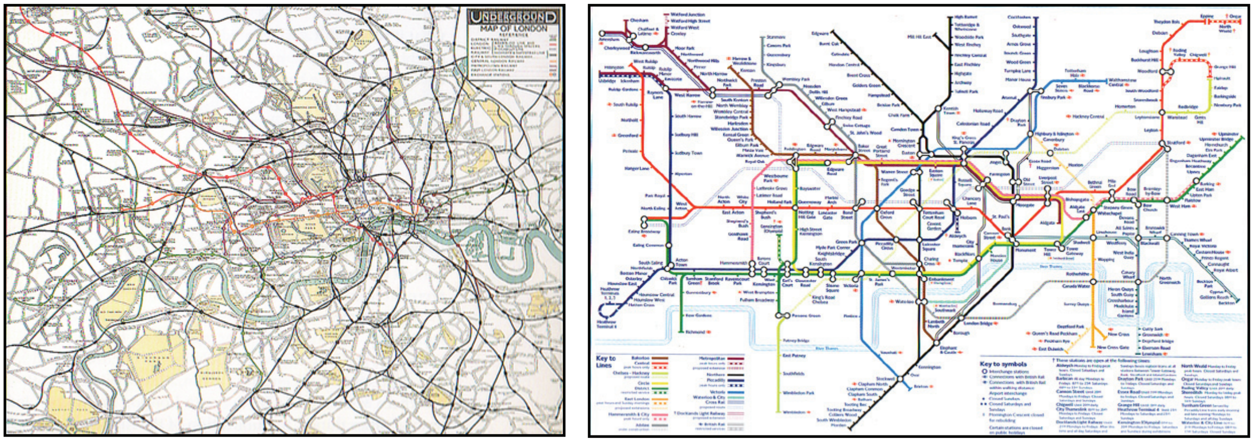
2_RELATED WORK

Related work can be categorized using several themes. First, long-researched cartographic design principles and research on map reading and navigation are useful in finding representation and navigation issues that apply to the MOVE system. Second, most work on map reading and navigation has been done in the foundation of traditional cognitive science related to visual perception. So, research on visual search and visual attention can serve as a guide on how to maintain attentionally affordable visual elements in the navigation system. A third related theme specifically addresses the human factors of recent vehicular interfaces. The resulting data from these studies provide a series of safety guidelines, which were used to evaluate the early prototype of the MOVE system. Fourth, research on dynamic information visualization systems, for small and limited screen real estate that considers how to visualize various types of information within a small display, is also of interest for our research. Finally, the LineDrive route navigation display in particular previously explored issues similar to those in our system, although it only focuses on static route maps. Its research on automatic map generalization techniques is closely related to our research.

2.1 Cartography and Map Generalization

A map is an abstracted two-dimensional representation of a three-dimensional reality, which is rich in detail. As such, all maps are based on the use of abstraction. Some forms of abstraction act by simply omitting information that is less relevant to the task at hand. Other forms of abstraction may retain (partial) information, but simplify or distort it to make it more discernable in a given task context (Monmonier, 1996).

The London Underground maps of the 1920s (Figure 2.1a) and now (Figure 2.1b) are outstanding examples of how the use of abstraction can improve the legibility of a map rendition. Figure 2.1a is a depiction that remains true to the curvature of the land, employing significant detail and accurate paths for each underground line. In contrast, Figure 2.1b abstracts away detail, presenting routes in a schematic rather than realistic fashion. In Figure 2.1b, the reduction of detail and the distortion of the route relative to the city's geometry make it easy to focus on the most relevant information.



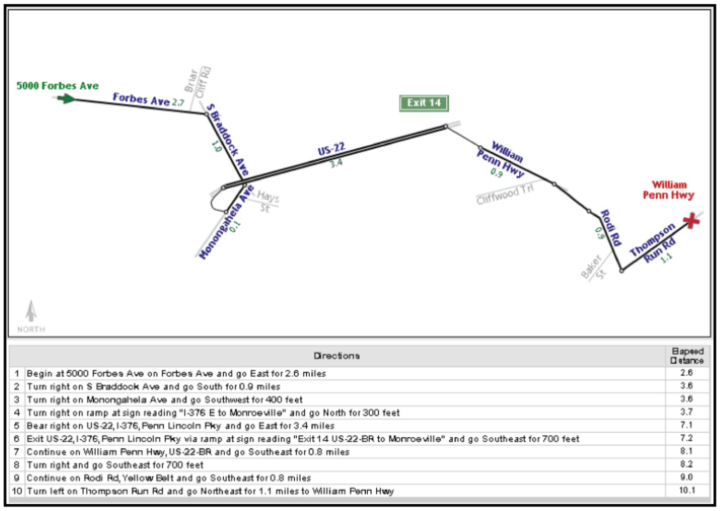
(a) (b)

Figure 2.1 a: London Underground Map (circa 1920), b: London Underground Map (2006, the diagrammatic form first appeared in 1933)

Abstraction techniques such as those used in the London Underground map have been used by cartographers for years. Gradual refinement of this technique has resulted in the process of map generalization. Monmonier (1996) has categorized the generalization process into several steps. Our design has been guided by at least five of these: *selection*, *simplification*, *displacement*, *smoothing* and *enhancement*. Features are selected in a map to support the specific task of the map. Selected features will be more prominent than other features to draw more of the user's attention. *Simplification* reduces detail from map features. For example, in the London Underground map, the angularity of lines has been reduced by removing points along the path. *Displacement* avoids possible graphical overlap or clutter by mediating the size and location of each feature. *Smoothing* also reduces detail. In contrast, *enhancement* adds details to the selected features to convey more information when essential to the task.

The LineDrive system (Agrawala & Stolte, 2001), shown in Figure 2.2, is a good example of how abstraction can be successfully applied to a static route map. Unlike many other Internet-based route maps, LineDrive uses a generalization technique to create an abstract route map. For example, many online map services use a constant scale factor to generate a traditional map. LineDrive uses varying scale factors for each road segment, based on the importance of the segment. Unnecessary features are also removed from the map. Distortion, simplification and other abstraction techniques are also used based on the importance of the segment in the route. Landmarks are used sparingly. All of these techniques make the map easy to read, and reduce the driver's perceptual load while driving.

The LineDrive system has been inspiring to our research. However, because it is static, LineDrive cannot provide an optimized route that is sensitive to the context of the driver. A contextually optimized route display could provide appropriate route information to a driver through awareness of the driver's situation at various times during the drive. For example, the system could display more or less detail based on the current location in the route or speed of a car.



	Directions	Elapsed Distance
1	Begin at 5000 Forbes Ave on Forbes Ave and go East for 2.6 miles	2.6
2	Turn right on S Braddock Ave and go South for 0.9 miles	3.6
3	Turn right on Monongahela Ave and go Southwest for 400 feet	3.6
4	Turn right on ramp at sign reading "I-376 E to Monroeville" and go North for 300 feet	3.7
5	Bear right on US-22, I-376, Penn Lincoln Pky and go East for 3.4 miles	7.1
6	Exit US-22, I-376, Penn Lincoln Pky via ramp at sign reading "Exit 14 US-22-BR to Monroeville" and go Southeast for 700 feet	7.2
7	Continue on William Penn Hwy, US-22-BR and go Southeast for 0.8 miles	8.1
8	Turn right and go Southeast for 700 feet	8.2
9	Continue on Rodi Rd, Yellow Belt and go Southeast for 0.8 miles	9.0
10	Turn left on Thompson Run Rd and go Northeast for 1.1 miles to William Penn Hwy	10.1

Figure 2.2 LineDrive

2.2 Navigation

The goal of navigation is to achieve movement through space to reach a specific location. It is generally assumed that mental representation of a geographical area is based on three kinds of knowledge: landmark, route, and survey (Wickens & Hollands, 2000). Landmark knowledge is a representation that includes the appearance of prominent landmarks in the region — gas stations, tall buildings, or parks. Landmark knowledge is gained by direct experience in the environment, and is highly relative to the individual viewer. Route knowledge is proceduralized knowledge about how to get from one place to another. Landmarks are usually incorporated into route knowledge. Route knowledge is also centered on the individual, but does not supply a great deal of information for learning more about the route. Survey knowledge is abstract, spatial knowledge that allows the individual to draw an accurate map of the environment. It usually represents geographical knowledge that has been generalized over many experiences, and so is more objective than either landmark or route knowledge. Individuals most commonly gain knowledge in the order of landmark, route, and survey information when repeatedly visiting an area.

Several researchers have introduced models for how navigation occurs during a driving task. Michon uses three different levels: strategic, maneuvering and control (Michon, 1985; Ross & Burnett, 2001). The driver plans a route at the strategic level, maintains their position on the route at the maneuvering level, and controls the vehicle (e.g., acceleration or deceleration) at the control level. Burnett extended Michon's model by integrating a driver's requirement and goals for a navigation system. The model has six overlapping stages: trip planning, preview, identify, confirm, trust, and orientation (Burnett, 1998; Ross & Burnett, 2001). In the trip planning stage, the driver will specify a destination and plan a route. In the preview stage, sub-goals will be established by assessing perception of remaining time and distance to the next maneuver, and building a mental picture and preparatory knowledge of the maneuver. In the identify stage, the driver will identify the direction to travel, control suitable speed of the vehicle, and establish correct positioning of the vehicle on the road. In the confirm stage, the driver will verify whether the correct maneuver has been made. In the trust stage, the driver will gain assurance that the correct route is being driven. Finally, in the orientation stage, the driver will remain aware of their current location in the entire route, especially in relation to final destination (Ross & Burnett, 2001).

2.3 Map Reading

A map is one of many potential representations of a space that the viewer may draw upon as an aid to decision-making. A particularly valuable approach is that of MacEachren, who seeks to combine both low-level perceptual theories, such as those derived from Gestalt psychology, with higher-level cognitive processes, such as those derived from an information-processing theory of cognition, into a comprehensive theory of how maps are read and interpreted (MacEachren, 1995). These encompass both bottom-up (sensory stimulus driven) and top-down (goal or cognitively driven) approaches, although MacEachren reports a debate in the literature as to how much the bottom-up approach plays a part in map reading. MacEachren's view of map comprehension is based on three stages of processing: a precognitive visual array, where shapes, edges, and boundaries are detected; a 2.5D sketch, or visual description, where a visual description is held in short-term memory, and the representation is initially mediated with the viewer's existing knowledge; and finally, a representation that holds meaning and generates knowledge for the viewer.

2.4 Prior Knowledge and Preferences

As people become more familiar with an environment, they become more confident in their own cognitive representations and their dependency on external aids, such as landmarks, written or verbal directions, and signage, decreases.

Golledge (1999) maintains that cognitive maps, or representations of prior knowledge about a route, can be defined in two ways: as representations of analog maps that are retained in memory, or as metaphorical representations that enable a person to act as if he has access to a map (Golledge, 1999). According to Golledge, the term cognitive map implies deliberate and motivated encoding of environmental information which can be used to determine where one is at any moment, where specific encoded objects are in surrounding space, how to get from one place to another, or how to communicate spatial knowledge to others.

Landmarks play an important role in cognitive maps because they might have a peculiar form, or sociocultural significance. In addition, unremarkable environmental attributes may attain salience for particular individuals, because they are tied to one's history (for instance, a place of work or the home of a childhood friend). Landmarks are hierarchically organized in cognitive maps based on significance and location.

As people stray from their initial paths in an environment, they integrate new environmental information into the existing cognitive map and eventually progress from route-based knowledge to survey knowledge. Since certain routes are better learned than others, survey representations are often incomplete, distorted, or incorrect. However, survey knowledge has been shown to be more reliable than route knowledge.

2.5 Human-Factors Research on Vehicular Interfaces

Human factors research provides information on numbers of glances and fixation times measured in studies of a variety of driving tasks from several cultures (Kishi, Sugiura, & Kimura, 1992; Taoka, 1990; Wierwille, Antin, Dingus, & Hulse, 1998). Studies show that on average, a driver usually spends approximately 0.78 seconds (*SD* = 0.65) and 1.26 glances (*SD* = 0.40) to read a speedometer and 1.10 seconds (*SD* = 0.30) to check the left mirror. These research results have led to safety guidelines for the design of devices to use while driving. According to the VICS (Vehicle Information and Communication System)

Promotion Council's report (1993), an average of 2.7 glances and a total of 4.10 seconds fixation time is the maximum safely allowed when driving at 30km/h. Rockwell (1998) also noted that drivers are reluctant to go without roadway information for more than two seconds (and rightly so) (Rockwell, 1988). This is known as Rockwell's 2-second rule.

Additionally, guidelines have been created for the amount of text-based information that can be safely read while driving. Ito reported that drivers can read an average of 6.2 Japanese characters per second while driving, which is the equivalent of an average of 11 Roman characters per second (Green, Goldstein, Zeltner, & Adams, 1988; Ito & Miki, 1997).

Overall, human factors research and safety guidelines clearly point to the fact that only a limited amount of information can be conveyed safely to the driver. As a result, any design for a new system cannot overtax the driver perceptually. If a system can be designed that reduces the number of glances and fixation times, it may very well increase safety while driving.

2.6 Dynamic Information Visualization

While driving, it is difficult to scan a map or directions and to find needed information without taking one's eyes off the road for periods of time. One possible remedy for this situation is to render important or complex map details at an enlarged scale within the context of the rest of the representation of the route, giving the driver only the detail that is currently needed within the context of an existing body of information. We were inspired by a body of HCI literature that examines methods for presenting information at greater detail while maintaining a sense of the surrounding information context.

Considerable prior work in information visualization has explored how detail can be rendered in context. Zoomable UIs, “magic” lenses, and fish-eye views are examples of detail-in-context visualizations, which distort reality to provide detailed information without losing the context of the information (Bederson, 2000; Bederson & Hollan, 1994; Bederson, Meyer, & Good, 2000; Bier, Stone, Pier, Buxton, & DeRose, 1993; Furnas, 1986; Mackinlay, Robertson, & Card, 1991). With detail-in-context UIs, the user can access detailed information when it is needed, and other contexts that are not important to the user are perceptually minimized (but not removed). All of the content is still accessible at any time.

Other research has examined dynamic information that exploits the element of time to make bodies of information accessible beyond the constraints of the display. For example, a dynamic newsreader used time, combined with visual cues such as size, color, and emphasis, to present key headlines which faded in importance as time passed (Ishizaki, 1996).

3 _ DESIGN APPROACH

In this chapter, we present our preliminary MOVE design based on the result of the navigation study, and then discuss the visual search study, which was conducted to understand the perceptual effects of the renditions to be used in the design. Detailed design principles will be presented, and the evaluation study of the prototype design will follow.

3.1 Preliminary Studies on Navigation

In order to understand additional factors that influence a driver's ability to navigate within a space, and more directly inspire our design process, we conducted a four-month qualitative research study. We wanted to understand how people read maps, make directions, and use directions while driving. We theorized that personal preferences for navigation, particular criteria of existing directions and maps, and prior knowledge of the route would be the most significant factors. We drew inspiration from research on navigation, on map reading, and on the role of prior knowledge in helping people find their way to a destination to provide an overarching structure for our research and to generate themes and protocols for our studies.

As a preliminary investigation, fifteen participants ranging in age from 20-54 performed a series of three pilot studies on the topic of navigation. In the first study, we wanted to understand how participants give written or drawn directions to familiar, not so familiar, and unfamiliar places. We also wanted to understand what criteria are valued about printed maps and atlases. In the second study, we wanted to understand how generating directions differs when one is driving, navigating, or creating a route for a third party. In the third study, we wanted to understand how preference for using directions might differ when people were navigating to an unfamiliar destination on a small street as opposed to a familiar destination on a large street that transpires a number of miles. For that study, we limited the resources available to LineDrive computer-generated directions (Microsoft, 2005).

We found that drivers continually monitor their location relative to a given route, possibly involving a map or some representation of the route, and occasionally change route if circumstances warrant. Road maps can be helpful to drivers; line-by-line directions were found to be somewhat less helpful.

When navigating, we observed that drivers break the route into smaller steps, or sub-goals. The steps may be as small as those in line-by-line directions, or they may be made up of schematized sections of the route that drivers already know (for example, home to the on-ramp of the nearest major highway). To find the way from goal to goal, drivers rely mostly on information about landmarks, paths (important streets), and nodes (intersections of two important streets). For a number of reasons, some landmarks are more salient than others, but they are used to guide the journey, acting as both confirmation points and ways to mark the next important turn on the route. Landmarks are also used for error prevention, and to reorient oneself to the route when lost.

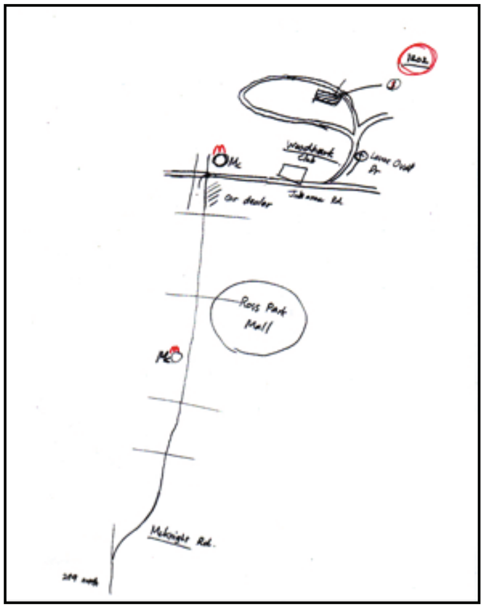


Figure 3.1 A representation generated for other people driving who did not know the route. Landmarks play an important role here, and details have been abstracted away.

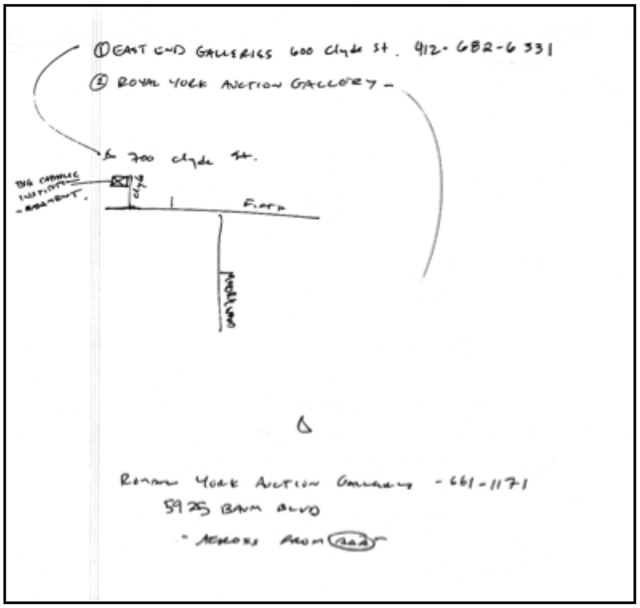


Figure 3.2 A representation generated for a participant to use himself. Neighborhoods play an important role in this representation; arrows mark the exact location of the destinations and provide important annotations.

When asked to create a representation of the route, participants often made two versions of maps: a version for other people driving who did not know the route (Figure 3.1), and a version that they would prefer to use for themselves (Figure 3.2). Abstracted, flattened, and simplified representations were consistently produced. When following directions, landmarks were salient in the following order: neighborhood, known (usually large) street, orientation of destination street (parallel or perpendicular to a known street), number on destination street, right or left side, and nearby landmark. We routinely observed participants seeking landmarks in such a focused way that they would miss a landmark if they had not found the prior one.

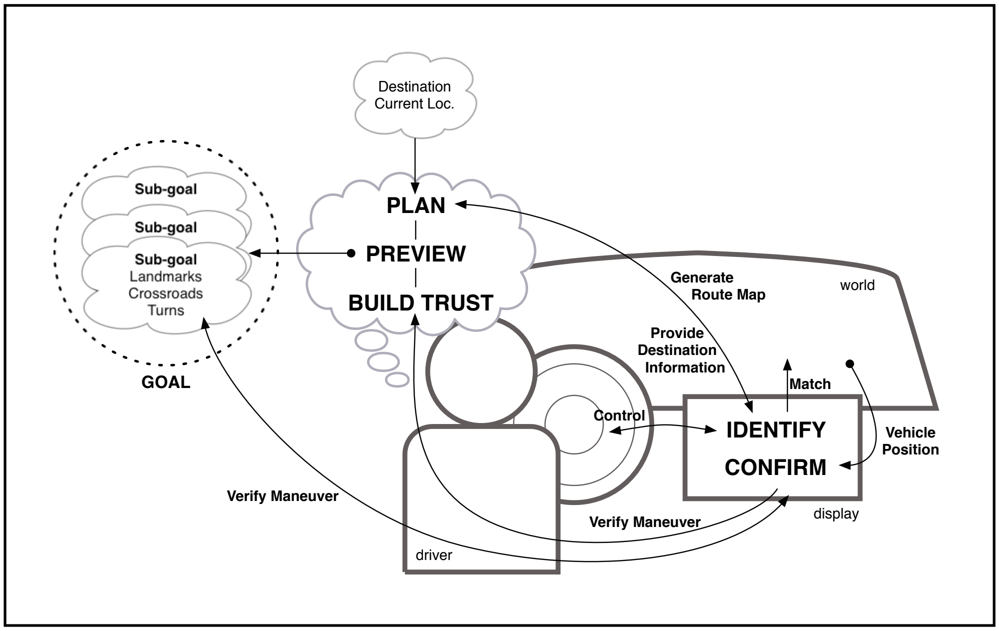


Figure 3.3 Driving & navigation model when using in-vehicle navigation display

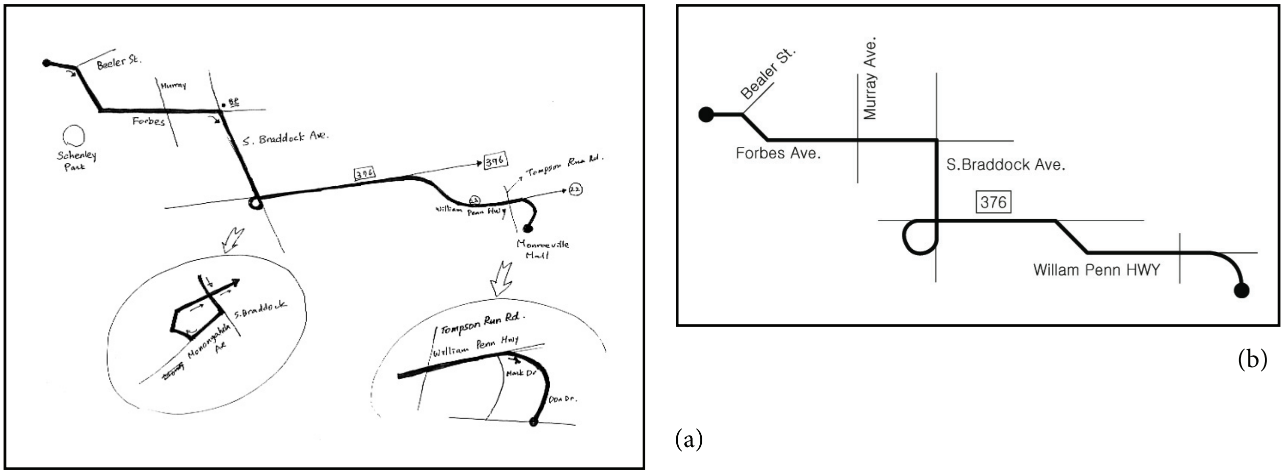
The findings from this study are similar to the navigation model that Ross and Burnett have presented (Burnett, 1998; Ross & Burnett, 2001). So, based on Ross and Burnett's navigation model and our study results, we created a diagram that describes the process of driving and navigation when using a route map display (Figure 3.3).

First, the driver plans the route by providing destination information to the navigation display, and previews the automatically generated route to setup sub-goals using turns, landmarks and crossroads. Then the driver views the directions on the display and controls the vehicle. Meanwhile, the driver verifies and confirms whether the correct maneuver has been made. Once a maneuver has been performed, the driver will confirm its correctness and thus build trust in the success of the current navigation task.

3.2 Preliminary MOVE Design

The navigation study described in the previous section provided information about how people plan and visualize a route. Many people use abstraction in their visualizations and selectively place information on the map based on their own judgments. Figure 3.4 is a good example of a route representation. Figure 3.4a is a hand-drawn route map to be used to navigate to a local shopping mall. Much of the pertinent information such as cross-streets and road labels are left off the map. Additionally, the actual length, shape, or direction of a road section is arbitrarily distorted. However, the main critical roads on the route are presented as thicker lines and junctions where critical turns need to be made are represented with details. Some landmarks, cross-streets, and road labels are used selectively.

Making use of the abstraction techniques used in these hand-drawn route maps, we produced preliminary concept sketches for the MOVE design as illustrated in Figure 3.4b. This MOVE route map uses turns as a main unit of representation and removes unimportant roads and labels from the map. Additionally each junction and road is presented with a rendition style based on its importance in the current context. We also designed an initial set of symbols to be used in the MOVE display — for example, node symbols for major turns, various types of cross-street markers, road labels, and other symbols such as the vehicle position mark, route start and route end.



(b)

(a)

Figure 3.4 a: Hand-drawn map, b: early sketch of the MOVE display

Our early exploratory interviews and designs led us to the high level design principle of optimizing the balance between the positive communicative benefits of selected map elements and the potential negative effects of distraction. In particular, our goal was to produce for each situation a map which helps the user maintain the context of where they are in the route, make the information most important to that situation easy to perceive, and minimize the distraction caused by other information. A more detailed refinement of these principles will be described when discussing the final design below.

3.3 Visual Search Study

In order to obtain a detailed understanding of the perceptual effects of the renditions we had devised in our initial sketches, we performed a study of how particular renditions affect visual search, both when they are the target of the search (providing positive communicative benefit), and when they serve as distraction from the target (inducing a negative effect). Quantitative information from this study allows us to place our final design on a firm scientific footing and ground the optimization tradeoffs it makes.

Finding targeted information in a map is a visual search task. Researchers have found that there are two major types of visual search mechanisms. The first type is a *top-down* mechanism, which is goal driven and implements our cognitive strategies (Connor, Egeth, & Yantis, 2004). The second type is a *bottom-up* mechanism. Bottom-up mechanisms are thought to operate on raw sensory input, rapidly and involuntarily shifting attention to salient visual features of potential importance. Many scientists have pointed out that neither type of mechanism works in isolation in a particular situation; instead, the mechanisms work together interactively. Typically, bottom-up mechanisms act early in the visual perception process, and then top-down mechanisms take over, generally within a time on the order of 100 milliseconds (Connor, Egeth, & Yantis, 2004).

Within *bottom-up* mechanisms the concept of *pop-out* (Treisman & Sato, 1990; Baldassi & Burr, 2004) is an important one, which has implications for visual design. *Pop-out* is a bottom-up drawing of attention to an object, which occurs when an object within the visual field is distinctive along some visual dimension (for example, possessing a distinctive color or brightness when compared with other objects in the field). Prior studies have identified a range of visual features, which can induce pop-out effects, including color, brightness, movement, direction of illumination, distinct curvature, and tilt (Beck, 1982; Julesz, 1984; Treisman, 1986; Treisman, 1998). Notably, size has not been shown to strongly induce this effect (Baldassi & Burr, 2004).

We would expect the same visual search phenomena to apply to the specific case of a map reading task. When a driver looks for a target, they will generally have in mind what they are looking for (e.g., an indication of where the next turn is, or how far from the next turn they currently are). Correspondingly, we would expect to see baseline performance effects related to goal directed top-down perception, modified when pop-out effects occur. In our case, the effect of bottom up pop-out effects will be positive for objects which are the target of the user's search (they will tend to lead to finding the target object faster) but negative for objects which are not the target of the user's search (which will become more distracting and slow down finding the target object). The details of how large these effects are relative to one another and which symbols induce pop-out effects in relation to others are important to determining which symbols should be selected and where they should be placed. To uncover these details, we undertook a visual search study using the specific renditions proposed for the MOVE system.

3.3.1 Experiment Overview

In our study, participants were asked to find target information within a display. We measured their reaction time and error rate for this task. A map stimulus with a road depiction containing several symbols was presented (Figure 3.5). Participants were verbally prompted to select a target rendition from a map stimulus, indicating the position of the rendition by pressing a keyboard key. We analyzed response time for renditions treated both as search targets and as distracters, considering all rendition pairs in order to understand their performance effects in light of both top-down and bottom up (*pop-out*) effects. In the remainder of this section, we describe the experiment in more detail and present its results.

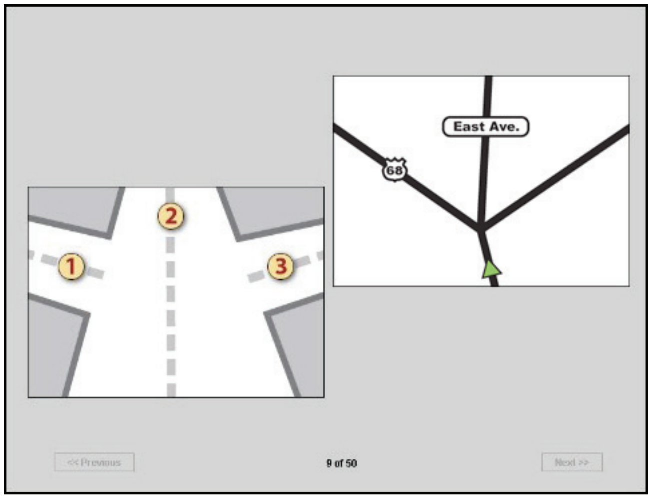


Figure 3.5 Search task screen

3.3.2 Subjects and Experimental Procedure

Twenty people from our university community participated in the study — 12 females and 8 males aged 18 to 33. The study was carried out in a lab setting under typical office lighting. After signing a consent form, subjects read simple instructions describing the overall process of the study, saw an overview of the renditions that the participants would see during the study, and were asked to perform selections as rapidly as they could. After becoming familiar with the renditions, they were presented with an example session of the study (employing 5 randomly selected study tasks) designed to give overall understanding of the study task. Finally, subjects completed a series of timed trials that formed the body of the study.

During the study trials, the participants were presented with a voice prompt using a pre-recorded female voice, indicating which symbol to select. For example, before Figure 3.5 was presented, a participant would hear “East Avenue” while being presented with a blank screen. Immediately after the voice prompt, a visual stimulus would appear. Once the correct rendition was found, the participant indicated its position in the display by pressing 1, 2 or 3 on the keyboard. Trials were repeated until every map stimulus was presented.

To record reaction time, the experiment software started a timer when the visual stimulus was placed on the screen and stopped when a participant pressed a key. Reaction time was recorded in milliseconds. We also recorded error responses. Error rates were extremely low and do not allow any useful distinctions to be made between the renditions, and thus will not be considered further.

3.3.3 Stimuli

Figure 3.6 shows a typical stimulus screen. The stimuli were generated based on 13 renditions chosen from our earlier MOVE sketches (Figure 3.6). These included six different node (or intersection) renditions, five different forms of road labels, and two other renditions (route start and route end). In addition to this, as a check of our stimulus manipulation we also included an extra rendition we expected to be highly salient — a McDonald's logo (Table 3.1). To create the stimulus for each trial, we selected two renditions out of the 14 and placed them in two of three positions. Three different road renditions were employed. For each trial, one rendition was designated as the target (and the other was a distracter). Trials covered every target-distracter pair (but did not present a rendition paired with itself) for a total of 182 (14x13) pairs each presented once for each road type for a total of 546 (182x3) trials. The placement of selected renditions in the road positions (left, right, and center) and ordering of trials was randomized.

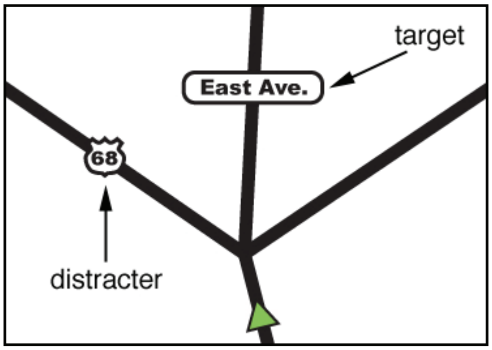


Figure 3.6 Stimuli – target-distracter combination

A	B	C	D	E
○	—○—	◉	—◉—	①
F	G	H	I	J
—①—	36	68	83	West Ave.
K	L	M	N	
East Ave.	□	⊡	McDonald's	

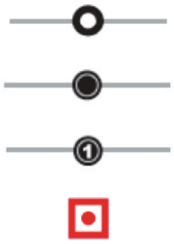
Table 3.1 Selected renditions for the study

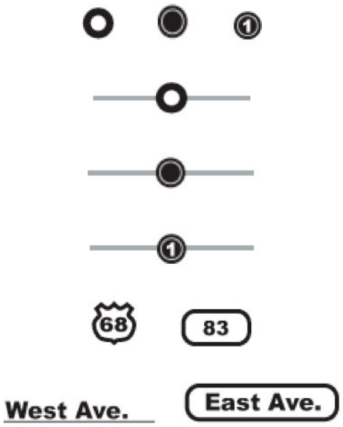
3.3.4 Results and Discussion

To understand the base salience of each rendition, we initially compared the mean reaction time for each rendition alternative when used as a target (across all distracters). As expected, the McDonalds icon was highly salient — its distinctive shape and color scheme makes it likely to induce pop-out effects when combined with the other symbols. (We have eliminated this rendition from the remainder of the analysis to avoid skew).

To help simplify target reaction time results it is useful to group the renditions into *symbolic* and *semantic* categories. A symbolic rendition conveys its meaning through shape, while semantic renditions contain information conveyed through text and/or numbers. The more detailed road signs in our experiment (renditions G, H, I, J, and K) are *semantic*, while the remaining renditions (A, B, C, D, E, F, L, and M) are *symbolic*. We also analyzed a more detailed set of sub-categories: *semantic text* (J, K), *semantic numbers* (G, H, I), *complex symbols* (B, D, F, M), *simple symbols* (A, C, E, L), *colored* (G, L, M), *black and white* (A, B, C, D, E, F, H, J, J, K), and finally with respect to the size of each rendition: *large* (B, D, F, J, K), *medium* (G, H, I, L, M) and *small* (A, C, E). (Table 3.2)

	Text	Number
Semantic		

	Simple	Complex
Symbolic		

Colored	
Black and White	

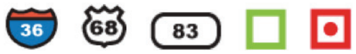
Large	
Medium	
Small	

Table 3.2 Categorized renditions

First, we compared the mean reaction times of semantic and symbolic renditions. As Figure 3.7 indicates, participants had faster reaction times when searching for semantic renditions. This result was statistically significant ($t(19) = -6.24$, $p < 0.01$), and could imply that participants may be able to more quickly interpret the meaning of semantic renditions. Comparison of finer semantic subcategories shows that reaction time for semantic text was the fastest, followed by semantic numbers, simple symbols and complex symbols, and that these results were all also statistically significant ($F(3,57) = 39.11$, $p < 0.01$). (Figure 3.8)

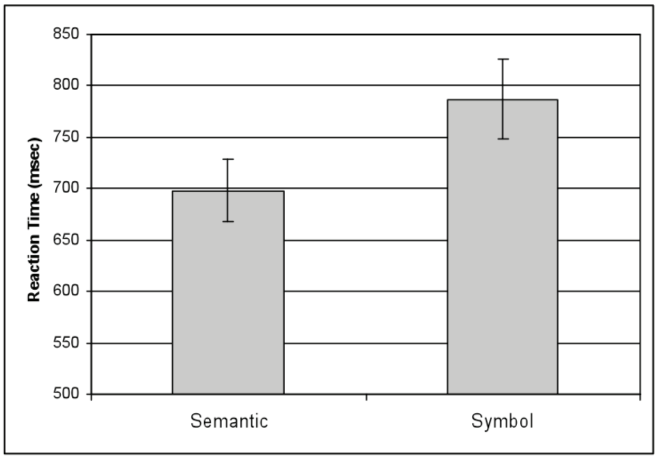


Figure 3.7 Reaction times for Semantic vs. Symbol renditions

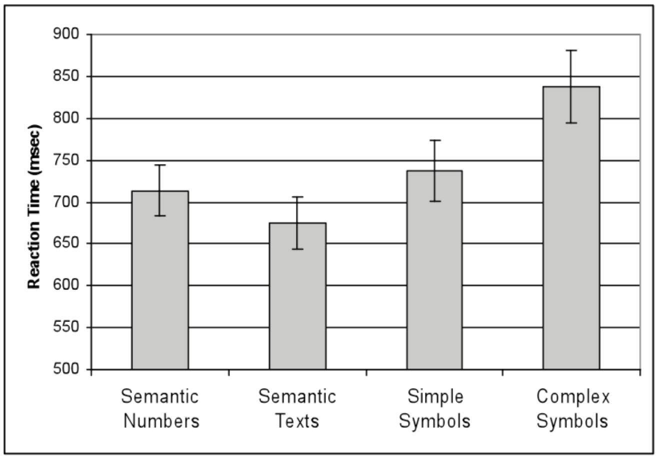


Figure 3.8 Comparison of reaction times for Semantic Numbers vs. Semantic Texts vs. Simple Symbols vs. Complex Symbols

A second set of comparisons allows us to explore the effects of renditions when they serve as distracters. Here we made a comparison of target-distracter combinations: Semantic(T)-Semantic(D), Semantic(T)-Symbolic(D), Symbolic(T)-Semantic(D), and Symbolic(T)-Symbolic(D). Consistent with the results from simple mean reaction times, Figure 3.9 indicates that reaction time was faster when semantic renditions were involved. Further, data shows that if the target and distracter were of the same rendition type, then reaction time was increased. The result is statistically significant. ($F(3,57)=35.10$, $p<0.01$)

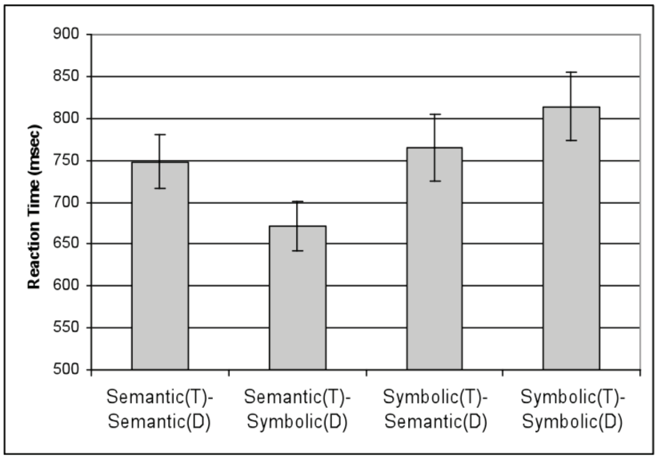


Figure 3.9 Comparison of reaction times for Semantic(T)-Semantic(D) vs. Semantic(T)-Symbolic(D) vs. Symbolic(T)-Semantic(D) vs. Symbolic(T)-Symbolic(D)

Prior work has found that if clear *pop-out* occurs in a search task, reaction time is consistently fast no matter how many distracters are present. This activity is characteristic of a bottom-up search (Goldstein, 2002). As an exploration of this effect we considered reaction times when black and white and contrasting colored stimulus were used together. In comparing mixed stimulus with all black and white stimulus, we found that reaction times for colored targets were significantly faster ($t(19)=7.79$, $p<0.01$) (Figure 3.10).

In contrast, we also determined that rendition size was not effective as a *pop-out*, replicating the findings of Baldassi and Burr (2004). Differences among the three different rendition sizes were not statistically significant ($F(2,38)=1.423$, $p=0.25$). This is in accordance with other research on bottom-up searches (Julesz, 1984; Treisman, 1986; Treisman, 1998; Baldassi & Burr, 2004).

Additionally, we did not find any interaction effects between road types, semantic renditions, and symbolic renditions (F(2,38)=0.6, p=0.55).

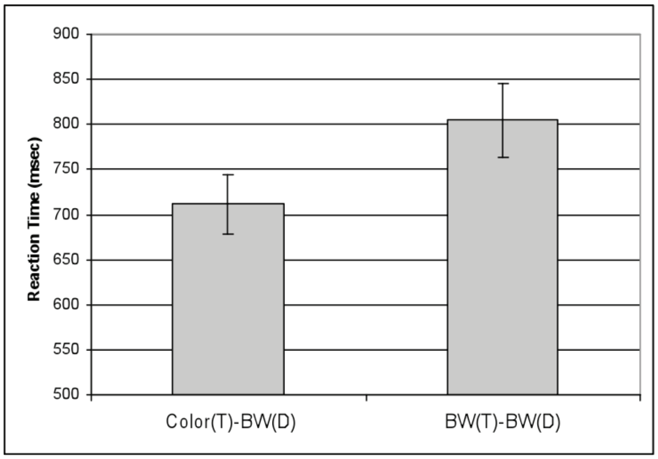


Figure 3.10 Comparison of targets and distracters showing pop-out effect of color

3.4 Detailed Design Principles

Based on our preliminary review of cartographic design, research on navigation, and research on rendition types, we generated detailed design principles for the MOVE system. The overall purpose of the system is to minimize perceptual load while driving. Three principles uphold this purpose. First, specific choices for the display should reflect the likely importance of the information in the current situation. Second, navigational information should be presented in an abstract manner, while considering the driver's current context. Finally, the system should present dynamically optimized information so that the driver's direct interaction with the system can be minimized. In the next sections, we consider the specifics of each of these principles.

3.4.1 Using Importance Differences

In any given situation, not all information in the display will be of equal importance (or equally likely to be the target of a visual search). By using the most salient and attention demanding display elements only for the high importance items, while lowering the salience or even removing others, we can expect to achieve a perceptually efficient display.

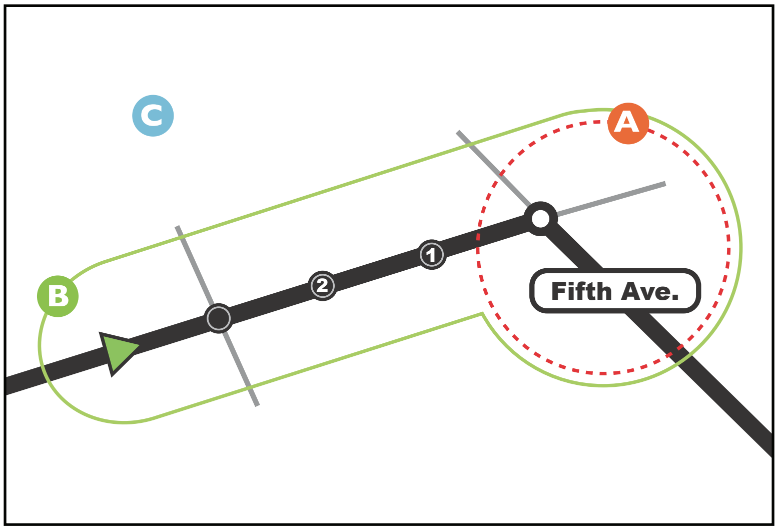


Figure 3.11 Areas of different importance

Figure 3.11 shows a depiction of how different areas of the display are assigned differential importance. The display is divided into three regions. Region A is what is most important to the driver — the information about the next turn. Region B is the next most important information, the area surrounding the current position of the vehicle, working forward to the next turn once it is close enough. Region C encompasses the remaining surrounding area (where minimal or no renditions are used).

The results of the study described in the previous section provide information about the choice of renditions with respect to the importance of the regions they fall within. Semantic renditions should be used primarily for important areas (region A and sparingly in region B), while symbolic renditions should be used in areas that need less visual salience (region B and occasionally in region C). Finally, pop-out inducing renditions should be used very sparingly and only in locations of most likely current interest.

By following the principle of using differential importance, we have created a set of detailed design guidelines. These have in turn been applied to the MOVE system for navigational information displays. Our guidelines focus specifically on visual information. While many modern navigation devices are equipped with auditory information, and some research has shown that auditory information can help to reduce perceptual load of visual displays (Walker, Alicandri, Sedney, & Roberts, 1991; Burnett, 2000; Liu, 2001; Gröhn, Lokki, & Takala, 2005), auditory information is out of scope for our present research. This guideline is presented in two sections: design principles and design recommendations. In the design principles section, high-level principles are presented for designing navigational information displays. The design recommendations section describes more detailed rules to support the high-level principles. The recommendations were generated by considering the treatment of visual elements and their properties such as typeface, size, and color. They are presented as an appendix in this document, and the rest of work presented in this document has been developed using the guidelines.

3.4.2 Abstraction

A second high level design principle involves the use of abstraction and generalization techniques. When designing MOVE, we categorized the map generalization process into the following five aspects.

3.4.2.1 Map Feature Selection

A route consists of several segments that the driver will traverse during the course of the route. Various map elements exist along the route, but not all of them can be presented on the display. Usually, drivers pay attention to the road segment they are currently traveling on. Other sections on the route or nearby, including landmarks such as rivers, parks, municipal boundaries, and other map features are not important, unless they play a key role in navigating the route. For example, a gas station near the next turn could become important as a vehicle is approaching the turn because it could be used as a landmark or a milestone. Feature selection is a process which, in a similar way, determines what features should be included on a particular map. Once selected for inclusion, a rendition for each feature is selected based on its importance (as described in the previous subsection).

The MOVE system normally presents the main route and its related map elements only. Cross streets are selectively displayed based on their importance in navigating the route. Other map elements, such as road labels and landmarks, are eliminated if they are not necessary. Renditions can dynamically become important while driving and are selected to be displayed on the screen based on their distance to the vehicle or turns. (Figure 3.12)

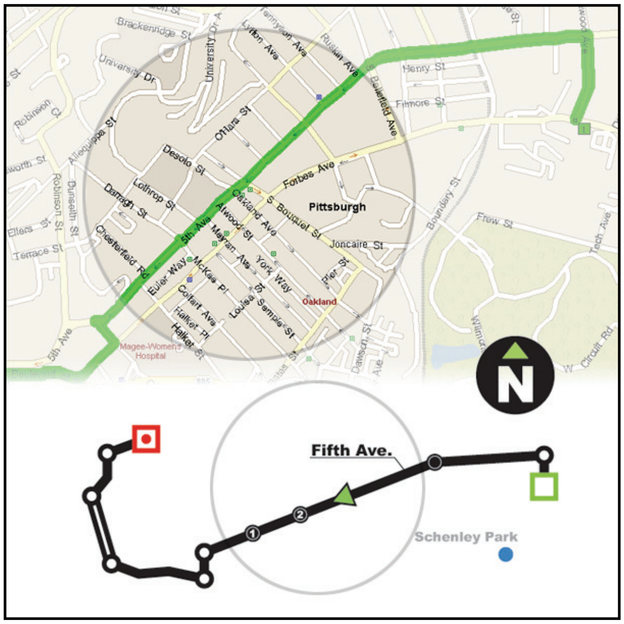


Figure 3.12 Map feature selection

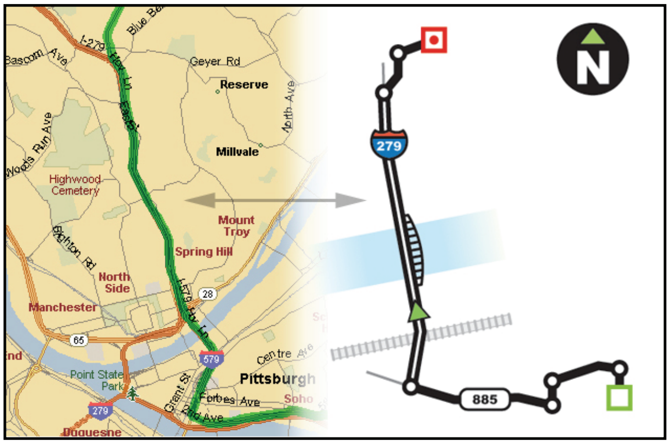


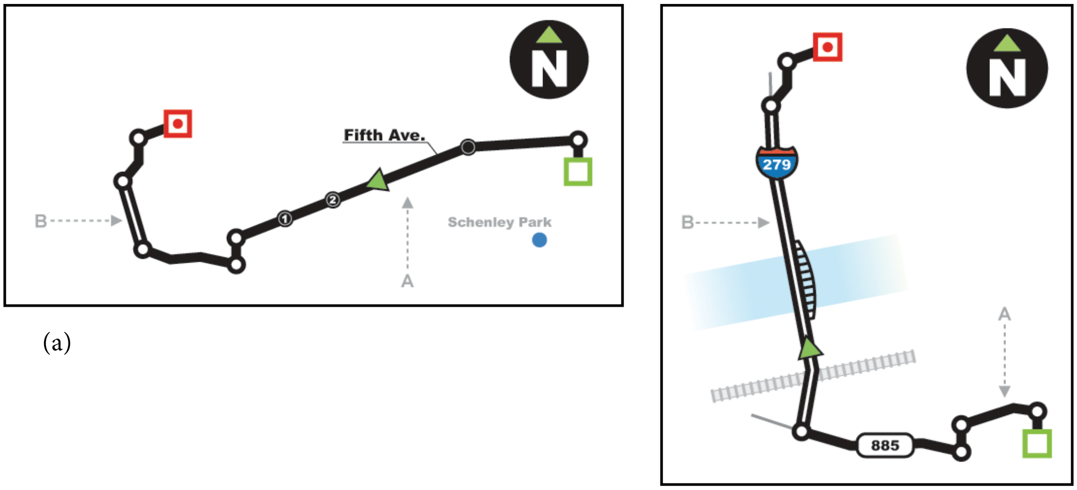
Figure 3.13 Simplification/Smoothing

3.4.2.2 Simplification/Smoothing

Generally, drivers are unaware of a road's actual shape or curvature while driving. For navigation purposes, the shape of the road can be simplified and smoothed in most cases. Presenting the curvature of a road might be important only if it can be used as a milestone or an indication of when and where to turn. This was reflected in our studies, where participants frequently drew maps that distorted the actual curvature of the road (Figure 3.13).

3.4.2.3 Relative Scaling

The importance of different map features can also be reflected through scaling. The MOVE system will arbitrarily distort the actual road length based on the importance of a segment. The current road segment and segments associated with next turns (regions A and B in Figure 3.14) are displayed at a larger scale than route segments that are ahead of or behind the driver. In Figure 3.14a, Route 279 (labeled B) is considerably longer than Fifth Avenue (labeled A), but Fifth Avenue appears longer because a vehicle is currently traversing Fifth Avenue.



(a)

(b)

Figure 3.14 Relative Scaling, Displacement and Enhancement by map generalization. (a) and (b) are representations of the same route.

3.4.2.4 Displacement

Labels and renditions that are displayed can possibly interfere with each other. A label might overlap with other labels or renditions, and cross street labels that are in close proximity might overlap each other when scaling and distortion of the route has taken place. The MOVE system will address such cases by relocating labels and renditions to avoid overlap. For example, in Figure 3.14a, the road label 'Fifth Ave.' has been relocated in order to avoid overlap with the landmark label 'Schenley Park', and the bridge symbol and river in Figure 3.14b have been relocated to avoid the railroad tracks.

3.4.2.5 Enhancement

In the right places, detail can enhance navigation. Although many aspects of the MOVE display abstract away detail, enhancement is used when features are important to the current driving context. More detail is applied (primarily through the use of enlarged scale and the selection of additional features) at the final destination of the route, for features associated with the next or current turn, and for features associated with the road segments between the current position and the next turn. For example, as illustrated in Figure 3.14a, extra cross streets are selected for display when nearing a turn, and these are enhanced with "count-down" number labels indicating how many cross streets are left to pass prior to making the turn.

3.4.3 Dynamic Information Interaction

Our final overarching design principle is dynamic information interaction. Displaying information in the vehicle will present two constraints: screen real estate, and manipulation of the display. Since there is very limited screen size, we cannot put the entire route map within a display. In a traditional in-vehicle navigation system, the driver only sees a small area of the route at once. Typically, scrollbars or navigation buttons are used to access content that is too large for the display. However, such explicit "hands on" interaction is not the most appropriate for the context of driving.

To present dynamic navigation information, MOVE accommodates navigation behavior in two ways. First, as learned in our study of navigation, drivers typically break an entire route into sub-goals, focusing on one goal at a time. Therefore MOVE uses the most detail for the road segment that the driver is currently passing over, relative to the goal within the route. Second, the system, using the speed and position of the vehicle, automatically determines which segment will be displayed with detail in context.

Automating the selection of information based on the driver's context will reduce the total attention that the driver needs to expend on a map display. If appropriate information is presented to the driver, the driver's cognitive and attentional load can be significantly reduced. We can also expect that there will not be any need to physically interact with the display while driving.

To explore dynamic information presentation, we created four different visualization methods as potential candidates for the MOVE system.

3.4.3.1 Zoom in Context (ZC)

In zoom in context (Figure 3.15), the system automatically enlarges the road segment that the vehicle is passing over to the maximum available size. Other road segments are scaled down to fit on the screen. The advantage of this presentation style is that the driver can see the entire route at once, which is useful for getting an overview of the route. However, the vehicle's location, indicated by a cursor, moves around the screen inconsistently, so the driver's fixation target is constantly moving.

3.4.3.2 Route Scrolling (R)

Route scrolling was developed to overcome the fixation problem described above. In route scrolling, the vehicle's cursor remains in the center of the screen and the route scrolls as the driver traverses the route (Figure 3.16). With route scrolling, the driver can easily detect the vehicle's position, but cannot see the entire route at once. Additionally, the route scrolling method does not use screen real estate effectively. Because the vehicle's cursor remains in the center of the display, one half of the screen is always devoted to part of the route that has already been traversed.

3.4.3.3 Zoom in Context + Route Scrolling (ZC+R)

To overcome the problems found in zoom in context and route scrolling, we combined the two methods (Figure 3.17). In this method, the current road segment is displayed at maximum size, while the other segments that have passed scroll from the screen. The driver still can see the overview of the remaining route. However, the driver's fixation target is constantly moving.

3.4.3.4 Zoom in Context + Small Overview (ZC+O)

This method automatically zooms into the section of the route that the driver is currently traversing, while providing a small overview of the route on the lower right of the display (Figure 3.18). While seeing both the overview and the detail together might be beneficial, the driver will have two areas of focus, which may increase perceptual load while using the system.

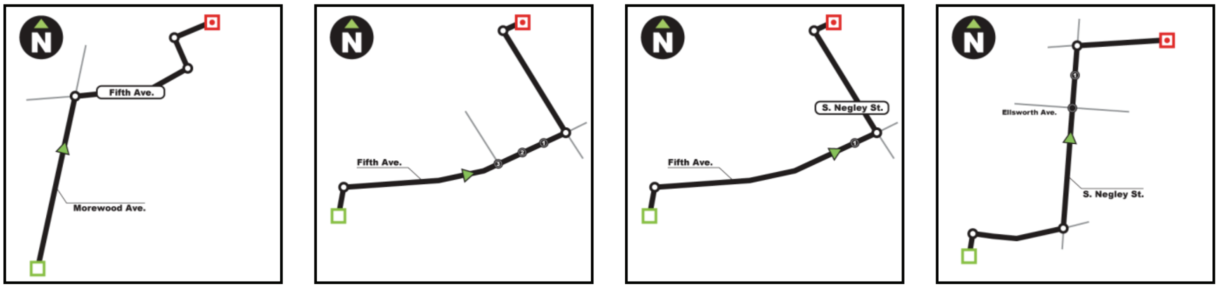


Figure 3.15 Zoom in Context (ZC)

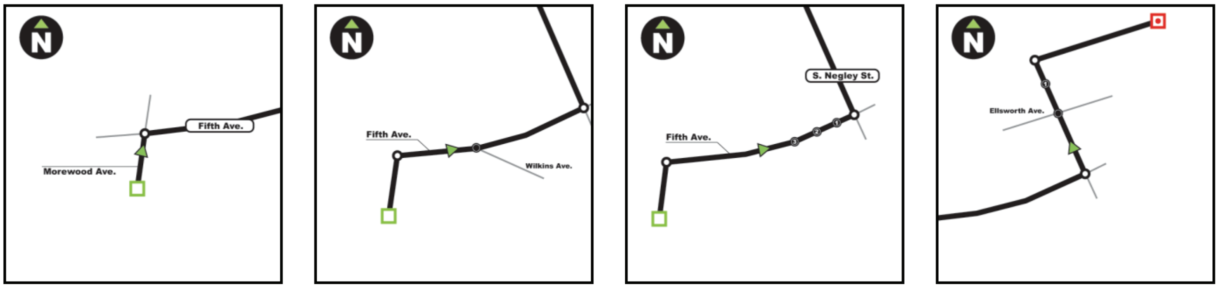


Figure 3.16 Route Scrolling (R)

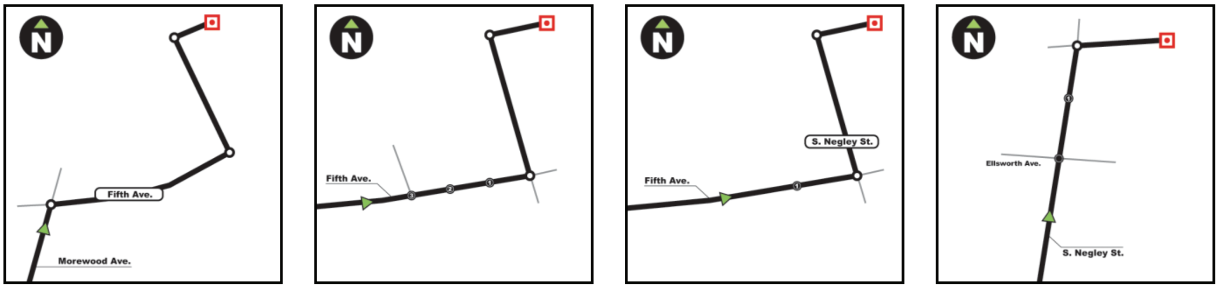


Figure 3.17 Zoom in Context + Route Scrolling (ZC+R)

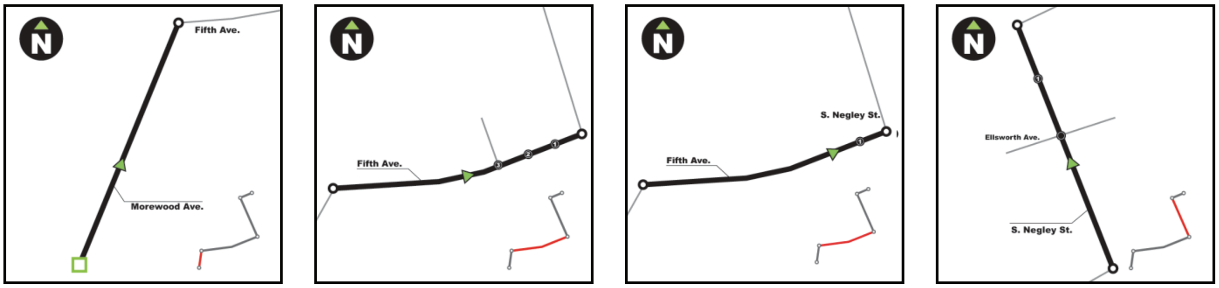


Figure 3.18 Zoom in Context + Small Overview (ZC+O)

In the next section, we describe a study to evaluate the effectiveness of the four visualization methods and compared to a static abstract visualization.

3.5 Evaluating Effectiveness of MOVE Designs

To understand the effectiveness of our candidate designs, we performed a study measuring effects of the four contextually optimized display conditions described above, plus an extra condition related to the use of cursors, on a simulated driving task. Since these displays present information tailored to a given driving context, we believe they should be able to convey necessary information, but at a reduced perceptual load for the driver. Specifically, we hypothesized that the presentation methods would be able to reduce the number of glances and fixation times needed to comprehend them, and therefore reduce the perceptual load needed to use an in-vehicle navigation system. To test this hypothesis, we measured fixation times and numbers of glances in a simple simulated driving task. Our study showed that contextually optimized displays designed for the MOVE system can significantly reduce perceptual load when compared to a static display, a LineDrive display (Agrawala & Stolte, 2001), which we believe to be the best available alternatives. With the contextually optimized displays, total map display fixation time per task averaged 861.98 ms (compared to an average of 5428.72 ms for static displays) and average number of glances away from the driving simulator was 1.52 (compared to an average of 4.53 for static displays).

Our study used a dual task attention-saturating framework, where participants preformed a primary task demanding high levels of attention (using a desktop driving simulator) and at the same time performed a secondary task (interacting with the navigation display) whose effects on the first task could be measured (Wickens & Hollands, 2000). Two displays were used in a laboratory setup, as shown in Figure 3.19.

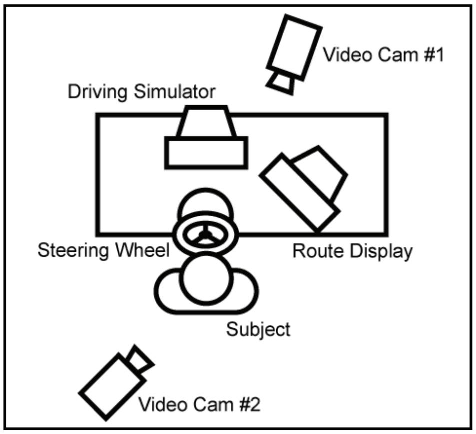


Figure 3.19 Study Configuration

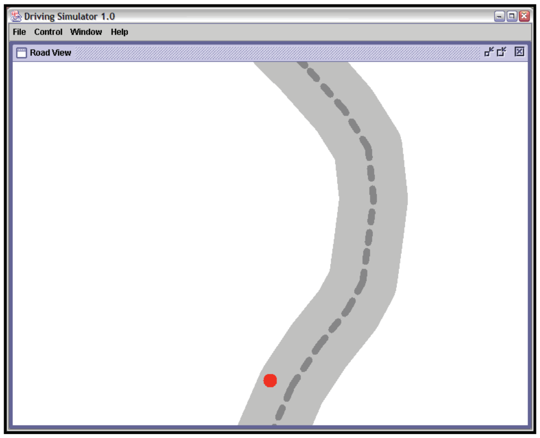


Figure 3.20 Subjects followed the center of the road in the simulated driving game by moving the steering wheel

A second display, used for the contextually optimized route maps or a static map, was placed to the right side of the primary display. While using the driving simulator, subjects were periodically forced to review the route display in order to answer questions related to specifics about the route: for example, *"What is your next turn?" "What is your next intersection?"* and *"How many more minutes to the next turn?"* Subjects answered the questions verbally as soon as they found the information they needed from the secondary display.

Two video cameras recorded the data from the study. The first, placed directly in front of the subject, was used to capture eye movement and fixation times. The second, placed behind the subject, recorded both displays.

3.5.1 Participants and Procedures

Twenty subjects from the university community, aged 19-56, 12 male and 8 female, completed the study. All subjects completed all of the conditions in randomized order. A baseline driving task was performed before the start of the experiment.

In the main experiment, four MOVE presentation methods were used. Each presentation method had four different example routes heading north, south, east and west. LineDrive was used for the static condition for baseline comparison. We chose LineDrive because it reduces visual information significantly as compared to traditional paper maps. We chose not to compare our concept to current in-vehicle navigation systems, because these systems are not using optimization to select and present map elements. While comparison with other in-vehicle system does have merit, we found it most important to compare our work to the best available and closest alternative. To control for typographic consistency, we chose a simple LineDrive route rendition and enlarged it slightly to make it comparable to the MOVE visualizations. The static LineDrive map was also presented on the secondary display. (In a separate experiment we also included a condition where the LineDrive display was presented on paper. While we will not present the details of those results here, there were very similar, indicating that the presentation medium alone is unlikely to alter the large effects described below.)

In order to isolate the effects of having a cursor indicating current position, we also included a fifth display type: a Zoom in Context display (as described above), but without the cursor that indicates the vehicle's current position.

3.5.2 Results and Discussion

We analyzed the data with five criteria. First, we compared MOVE (the mean of the four presentation methods) with LineDrive (LD). Second, we compared LD with ZC without cursor. Third we compared ZC with ZC without cursor. The main purpose of these comparisons was to understand the function of the cursor in the map reading task. Fourth, we compared each presentation method. In this case, ZC was used for baseline comparison. Finally, we compared east, west, south, and north for the four presentation methods. In this comparison, east was used as baseline. As indicated above, we used three measures of performance: number of glances per question, total map display fixation time per question, and average distance off the road in the driving simulation. Frame-by-frame analysis of the video was done at glance points using a method for determining the end frame.

Measure	LD Mean	MOVE Mean	Significance
Number of Glances	4.53	1.52	$t(19)=27.16$, $p<.0001$
Total Fixation Time (ms)	5428.72	861.98	$t(19)=20.77$, $p<.0001$
Ave Dist. off Road (pixels)	0.0996	0.0204	$t(19)= 2.304$, $p=.033$

Table 3.3 Primary study results (N=20). (LineDrive vs. MOVE)

Table 3.3 presents the main results from our study comparing performance using LineDrive maps with the overall performance of the contextually optimized displays. The contextually optimized displays show dramatically better performance in all measures showing six-fold decrease of fixation time and three-fold decrease of number of glances (statistically significant in all cases). The measures of fixation time and average distance off the road, which we would expect to be related, exhibit very similar behavior. Our main hypothesis was supported by the experimental data, suggesting that contextually optimized displays, as in the MOVE system, can reduce the driver's perceptual load while navigating.

Measure	LD Mean	ZCw/o Cur Mean	Significance
Number of Glances	4.53	1.76	*t*(19)=22.08, *p*<.0001
Total Fixation Time (ms)	5428.72	1049.36	*t*(19)=18.77, *p*<.0001
Ave Dist. off Road (pixels)	0.0996	0.0383	*t*(19)= 2.872, *p*=.010

Table 3.4 Primary Study Results (N=20). (LineDrive vs. ZC without Cursor)

Table 3.4 compares LD and ZC without the cursor in order to help understanding the contribution being made by vehicle location information. Interestingly, even without the cursor, contextually optimized displays substantially reduced fixation time, number of glances, and improved driving performance. All of the measures were statistically significant. The reason may be because when reading the static map, participants actually performed two tasks: searching for context and then finding needed information. Within the contextually optimized display, even though there was no cursor to give specific location information, zooming in to the context helped subjects to substantially reduce search time.

Measure	ZC Mean	ZC w/o Cur Mean	Significance
Number of Glances	1.42	1.76	*t*(19)=5.64, *p*<.0001
Total Fixation Time (ms)	787.17	1049.36	*t*(19)=5.35, *p*<.0001
Ave Dist. off Road (pixels)	0.0127	0.0383	*t*(19)= 1.300, *p*=.209

Table 3.5 Primary Study Results (N=20). (ZC vs. ZC without Cursor)

Finally, when we compared ZC to ZC without cursor, we saw a small, but statistically significant difference. Even though this effect is much smaller than the six-fold effect of the primary result, this shows that cursor information is helpful in locating information (Table 3.5).

Measure	ZC & ZC+R Means	ZC & R Means	ZC & ZC+O Means
Number of Glances	1.42 & 1.53 *t*(19)=2.05, *p*=.055	1.42 & 1.57 *t*(19)=3.68, *p*=.002	1.42 & 1.56 *t*(19)=3.43, *p*=.003
Total Fixation Time (ms)	787.17 & 832.25 *t*(19)=1.18, *p*=.094	787.17 & 925.63 *t*(19)=3.90, *p*=.001	787.17 & 902.86 *t*(19)=4.10, *p*=.001
Ave Dist. off Road (pixels)	0.0127 & 0.0182 *t*(19)=0.80, *p*=.435	0.0127 & 0.0258 *t*(19)=1.55, *p*=.137	0.0127 & 0.0249 *t*(19)=1.13, *p*=.273

Table 3.6 Primary Study Results (N=20). (ZC vs. ZC+R, R, ZC+O)

Table 3.6 presents the comparison results of four presentation methods. ZC was used for baseline comparison. In general, there was no significant difference in driving performance. There was also no significant difference found between ZC and ZC+R. However, there was a small but statistically significant difference in the measure of number of glances and total fixation time in the comparison of R and ZC+O with ZC.

This is possibly due to design defects in R and ZC+O. Because R lacks the zoom-in-context feature, it may be less effective. Additionally, this visualization style effectively used only one quarter of the screen real estate for presenting pertinent information (Figure 3.21). In ZC+O, two information sources create complexity on the screen, forcing the driver to perceive two pieces of information at once. Due to the presentation style, sometimes the small overview would overlap the large rendition of the route. This creates additional complexity, and a problematic use of screen real estate (Figure 3.21).

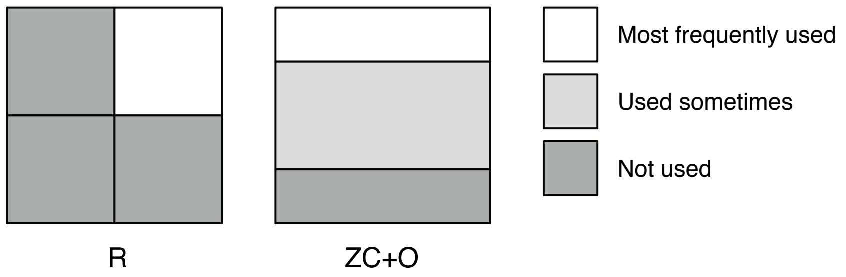


Figure 3.21 Use of screen real estate in R and ZC+O. Only small part of the screen was used for information display

This chapter presented our preliminary MOVE design and the studies to understand the perceptual effects of the renditions used in the design. Followed evaluation study showed that the MOVE system could reduce time for searching information in the display. In the next chapter, we will present the implementation process of the MOVE system.

4_IMPLEMENTATION OF THE MOVE SYSTEM

Our study evaluating the prototype system showed our prototype designs are promising and could address the issues found in current navigation systems. The final steps in this work are the construction of a full proof of concept prototype and its evaluation in a driving context. In this section, we will describe our implementation process, bridging the design and research results we have taken from our preliminary studies.

During the design process, we identified five map generalization principles: *Map Feature Selection*, *Simplification/Smoothing*, *Relative Scaling*, *Displacement*, and *Enhancement*. Our implementation process for the MOVE system addresses these five map generalization techniques. The following sections will present how these principles work in the implementation of the MOVE system. First, the *Road Layout* process works on the principles of *Simplification/Smoothing* and *Relative Scaling*. It makes an entire route abstract, while making the most important segment salient. Second, the *Rendition Selection* process works on the principle of *Map Feature Selection*, which is to present map features selectively to lower the attention paid to the display by reducing the amount of information. Third, *scoring renditions* and *optimization framework techniques* discuss how we determine and assign scores for rendition features and how they will be used in the optimization process of the *Rendition Selection*. Last, the *Final Placement Tuning* process describes the intervention technique for possible conflicts and clutter within the selected renditions when presented on the display. This uses the principle of *Displacement*. Throughout this chapter, we will discuss how those design principles can be realized in the creation of automatically generated route map design.

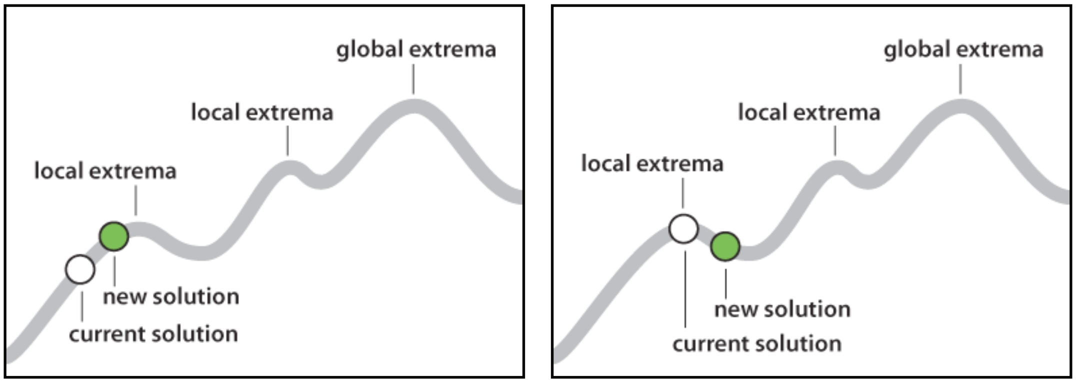
4.1 Design through Simulated Annealing

In Chapter 1, Introduction, we discussed that the designer's iterative decision-making process is very similar to the numerical optimization process. Numerical optimization is an iterative method to find minimum or maximum values for a given function. During the process, a new temporary solution is created and then evaluated to see whether the solution was improved to satisfy constraints. If it doesn't satisfy the constraints, then the process creates a temporary solution and evaluates it. Through this iterative process, we can finally find a solution that meets most of the given constraints. A few algorithms have been developed and explored to solve optimization problems, and some of them have actually been used in solving various kinds of design problems (Agrawala & Stolte, 2001; Fogarty, Forlizzi, & Hudson, 2001; Gonzalez, Rojas, Pomares, Salmeron, & Merelo, 2002). For example, the Simulated Annealing algorithm has been widely used to solve various combinatorial optimization problems and has been particularly successful in complex circuit layout design (Kirkpatrick, Gelatt, & Vecchi, 1983). Other research has shown that a Simulated Annealing method can solve a web newspaper layout problem (Gonzalez, Rojas, Pomares, Salmeron, & Merelo, 2002), simplified route map layout (Agrawala & Stolte, 2001), an automatically generated collage display (Fogarty, Forlizzi, & Hudson, 2001), and so on. In our

MOVE system, we also use a Simulated Annealing method for the route map information selection and the layout of different map design elements.

Simulated Annealing is a method that was adapted from the Metropolis-Hastings algorithm, a Monte Carlo method used to generate a sequence of sample states of a thermodynamic system from the probability distribution of one or more variables (Metropolis, Rosenbluth, Rosenbluth, Teller, & Teller, 1953). As the name indicates, the concept of the algorithm is inspired by the physical process of annealing, which is the process of heating a substance and cooling it slowly until a strong crystalline structure is obtained. In a physical annealing process, a substance is initially in a melted and disordered state at a high temperature, and then it is cooled down slowly so that the substance approximately reaches thermodynamic equilibrium. As the cooling proceeds, the substance takes on a more ordered state and approaches a “frozen” ground state.

This process is simulated in the algorithm. A Simulated Annealing optimization process starts with a Monte Carlo simulation at a high temperature. In each state, the process changes the current configuration several times until a thermal equilibrium is reached. At the initial state, a relatively large percentage of the random steps that result in an increase in the energy will be accepted. After having a sufficient number of Monte Carlo steps, the temperature is decreased and a new state can start with the lower temperature. In each new state, a new configuration will be created by a random displacement of the current one. If the new one is better than the current one, then it will replace the current one. If not, it may replace the current one probabilistically. This is the way that Simulated Annealing algorithm avoids local extrema. As Figure 4.1 describes, if the system just uses a hill climbing method that replaces the current iteration with a new one only when it is improved, the system could easily be stuck in a local extrema. In Figure 4.1a, the new solution can replace the current one since it is improved. But in Figure 4.1b, since the new one is worse than the current one, the system would stay with the current one, and will become can be stuck in local extrema as a result. In the Simulated Annealing method, the system can (probabilistically) accept a new iteration even though it is worse than the current one, so that the system can keep moving to find the better configuration. However, Simulated Annealing is not guaranteed to find the global extrema — the algorithm can only find "good enough" solutions through its process by avoiding local extrema (Kirkpatrick, Gelatt, & Vecchi, 1983).



(a) New solution is improved.

(b) New solution is worse than current one.

Figure 4.1 Hill climbing method finding extrema

Since the Simulated Annealing process only evolves one potential solution instead of a whole population like Genetic Algorithms, it is much faster and can solve a problem in real time (Gonzalez, Rojas, Pomares, Salmeron, & Merelo, 2002). For this reason, Simulated Annealing has been widely used in solving various types of layout problems. In his original paper that introduced a Simulated Annealing method, Kirkpatrick et al. have demonstrated a process that solves complex logic design problems with Simulated Annealing (Kirkpatrick, Gelatt, & Vecchi, 1983). Agrawala et al. also used a Simulated Annealing method to layout simplified route map (Agrawala & Stolte, 2001), and Gonzalez et al. presented the algorithm can layout a web newspaper (Gonzalez, Rojas, Pomares, Salmeron, & Merelo, 2002). Later, Fogarty et al. presented the Kandinsky system, which displays information in a form of an automatically generated collage that tries to maintain certain aesthetic properties. The system used a Simulated Annealing technique to find compositions which best maintain the properties of the original artist's aesthetic expression (Fogarty, Forlizzi, & Hudson, 2001). As related research has discovered, Simulated Annealing methods are useful in solving a variety of problems, we also use the method to solve our design problems in building the MOVE system.

When attempting to solve an optimization problem using a Simulated Annealing algorithm, the following three parts are most important: *a representation of a possible solution*, *an objective function to evaluate a configuration* and *a perturbation function to modify a configuration*. First, for optimization problems, the representation of a possible solution will necessarily be problem specific. For example, in the case of the famous traveling sales man optimization problem (TSP), of finding the shortest itinerary of N-cities, the representation of a possible solution is obviously a list of the cities in the order they are to be visited. After a temporary representation of a solution is established, the objective function will evaluate the temporary solution. In the TSP example, the objective function will calculate the total distance between the cities in the list in order. The objective function will normally be used to compare a new candidate solution to the current best solution in order to choose between them. Finally, the perturbation function will modify a configuration (current solution) to create a temporary solution. In the TSP example, the perturbation function will randomly modify the order of the cities in the list.

While a design approach using optimization has clear advantages, it is not easy to use for design creation. As Fogarty et al. pointed out, programming optimization requires certain level of mathematics, but sometimes it is not easy to describe independent goals and constraints algorithmically. Although there are toolkits available for optimization problems, they are still typically require substantial specialized knowledge because they have mostly been designed for physics simulations and other traditional optimization problems (Fogarty & Hudson, 2003).

For this reason, we use the GADGET toolkit in our implementation of the MOVE system, which was developed to support optimization for interface and display generation. GADGET toolkit provides convenient abstractions of many optimization concepts. GADGET also provides mechanisms to help programmers quickly create optimizations, including an efficient lazy evaluation framework, a powerful and configurable optimization structure, and a library of reusable components (Fogarty & Hudson, 2003). Using the GADGET toolkit made the process of creating a dynamic display design easier and more efficient.

In the following sections, we present an overview of the system and the detailed process of building a perceptually optimized route map display using an optimization-based approach.

4.2 System Overview

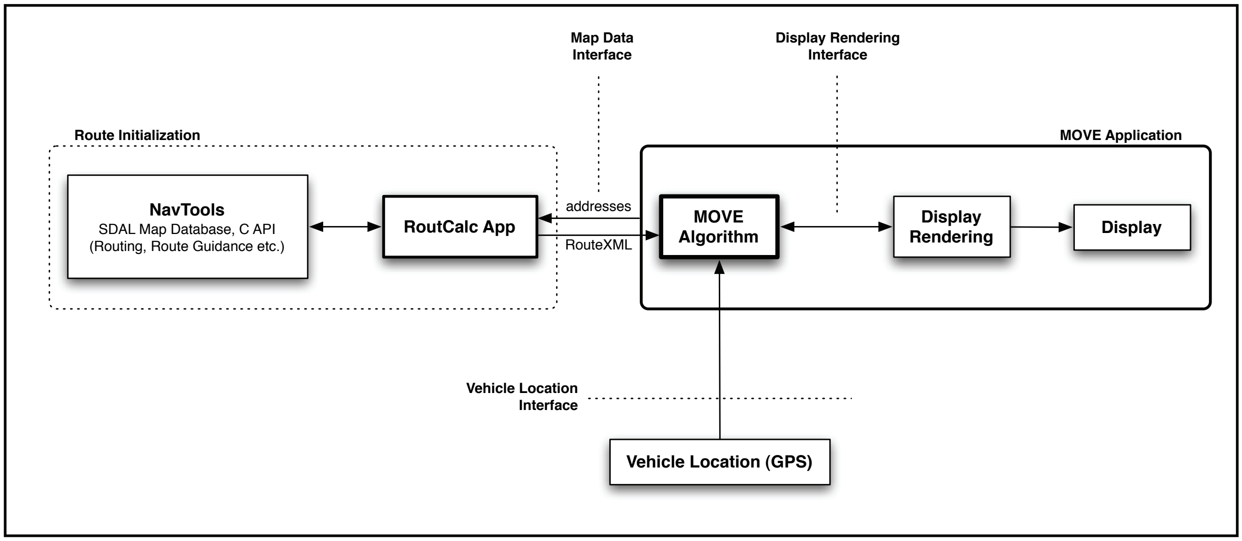


Figure 4.2 System Overview

Figure 4.2 depicts an overview of the MOVE system and its two main applications. RouteCalc works with NavTeq's SDAL database to calculate a route and create a RouteXML data set. As the name implies, RouteXML is a simple XML format data set which contains information about a route, road segments within the route such as latitude, longitude and road name, and a list of crossroads and points of interest (POI). The second application is MOVE, our main application. This application reads RouteXML data generated by RouteCalc, and then parses it to use for data optimization and visualization. The MOVE system also creates an internal data structure for the optimization. Pseudo code in Figure 4.3 shows the overall optimization process of the MOVE display after constructing the internal data structure.

```
route initialization:
   request route data
   translate route into internal data structures
   segment route based on potential features that could be rendered in final map

for each map display update:
   get vehicle location
   register location within segment from original route
   update importance scores along route corresponding to new location
   establish preliminary layout matching geography
   establish curvature break points
   do space allocation for route segments using simulated annealing optimization
   -  using Perturb_Map_Layout as the perturb() method and Score_Map_Layout
      as the score() method
   set rendition choices to default for each route segment
   do rendition selection from route features using simulated annealing
   -  using Perturb_Rendition_Selection as the perturb() method and
      Score_Rendition_Selection as the score() method
   find vehicle location on optimized map
   do final placement tuning
   -  using Perturb_Final_Placement_Tune as the perturb() method and
      Score_Final_Placement_Tune as the score() method
   render optimized map and vehicle marker
```

Figure 4.3 Top level pseudo code

4.2.1 RouteCalc Application

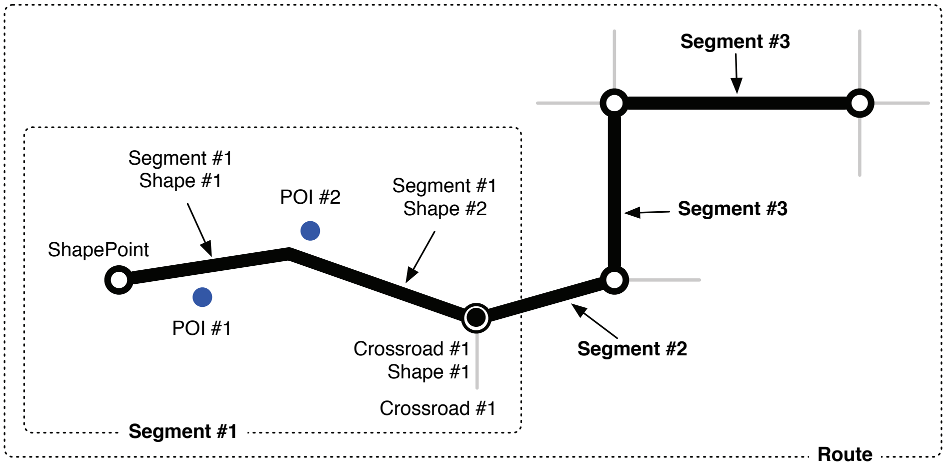
RouteCalc is an application that calculates a route and generates RouteXML code on top of NAVTEQ’s SDAL GIS toolkit. The SDAL software consists of a map database and its associated APIs (NAVTEQ). Once a start and a destination address are specified by a user, the RouteCalc application translates the addresses into geo-location data in latitude and longitude format, and queries the locations in the SDAL map database for route calculation. Once the locations are specified in the database, the RouteCalc application calculates a route and returns the route object. Then, it reads through the route object data structure to construct RouteXML data, which contains descriptive information about route.

4.2.2 RouteXML

RouteXML is an interchangeable data format that the RouteCalc application generates. After it is transferred to the MOVE application, MOVE parses RouteXML and then constructs an internal data structure. Figure 4.4 is an example of a route and its snippet code of RouteXML.

4.2.3 MOVE Application

MOVE is our main application that presents percetually optimized route map information. As the system overview diagram in Figure 4.2 depicts, MOVE gets route data in RouteXML format dataset generated by the RouteCalc application, and then parses RouteXML data to construct an internal data structure that will be used for the MOVE optimization algorithm. The algorithm then creates the most appropriate display for the driver's given situation. In this process, the MOVE application first identifies the vehicle location information on the route. As the vehicle moves forward, the MOVE algorithm performs space allocation for route segments and rendition selection from route features using simulated annealing optimization. After that, the algorithm cleans up the layout to resolve possible cluttering of the map features that might have resulted from previous automatic design layout processes. Once we have the final route map design, then the MOVE application renders it on the display.



```
<route>
<segment no=’3’ id=’5201a7b4.100d4201’ length=’86’ direction=’0’
  time=’4’ feature_id=’4810eb40.1001552f’ roadname_prefix=’’
  roadname=’FORBES’ roadname_suffix=’AVE’>
<shapes>
<shape_pointlon=’-7994379’ lat=’4044469’/>
<shape_pointlon=’-7994330’ lat=’4044469’/>
<shape_pointlon=’-7994279’ lat=’4044463’/>
</shapes>
  <crossroadssegment_id=’5201a7b4.100d41f9’
  feature_id=’4810eb40.1001552f’ roadname_prefix=’’
  roadname=’FORBES’ roadname_suffix=’AVE’>
<shape_pointlon=’-7994606’ lat=’4044463’/>
<shape_pointlon=’-7994545’ lat=’4044464’/>
</crossroads>
<crossroads>
      ...
</crossroads>
  <POI poiid=’38154016.10000155’ name=”1204 CORP” type=’20d’
  lon=’-7991781’ lat=’4043803’/>
  <POI poiid=’38154216.10000a42’ name=”A LA CARTE” type=’5d’
  lon=’-8000019’ lat=’4043995’/>
  <POI poiid=’38154796.100020b5’ name=”ALLEGHENY COUNTY CREDIT UNION”
  type=’13d’ lon=’-7999519’ lat=’4043800’/>
<POI ... />
</segment>
<segment>
    ...
</segment>
</route>
```

Figure 4.4 Example snippet of RouteXML

4.2.4 Data Structures

Figure 4.5 shows an overview of internal data structures used in the MOVE system. Similar to RouteXML data, the MOVE system has one route object, a MoveRoute. Then, the MoveRoute structure contains MoveLocation information and a list of MoveRoad, MoveCrossroad, MovePoi as described in Figure 4.5.

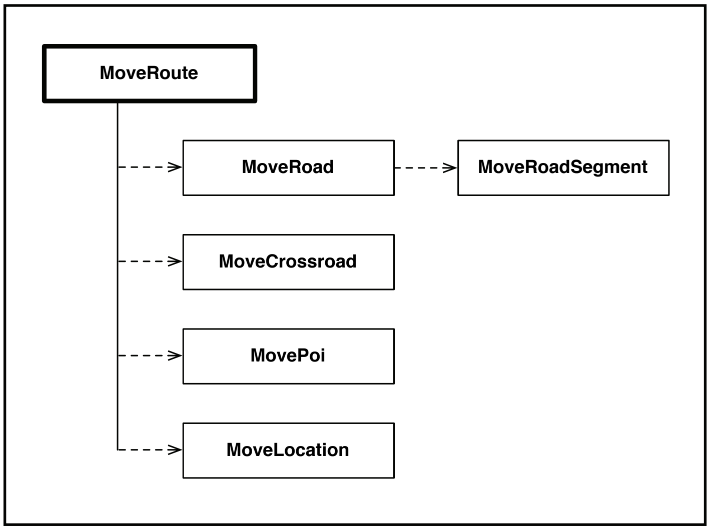


Figure 4.5 MOVE data structure diagram

MoveRoad is a class that contains all the road information, such as road name, various types of road indexes, and a list of road shapes.

The MoveRoad class initially holds only one shape, which is a line segment, but as the road layout process is being performed, the structure will be modified, and may hold more shapes within a MoveRoad. This process will be discussed in the next section. The shapes are called MoveRoadSegment in this MOVE internal data structure.

The MoveRouteXML dataset is basically constructed with set of point objects. This makes sense because a route is a collection of line objects, and a line is a combination of two points. So, an atom of a route can be considered as the absolute coordinate data, and most of the current map displays draw a route, roads, and intersection by connecting the points to make lines.

However, even though this is an easier and more conventional way to draw a route map, the MOVE system is approached in a different way because we distort the original route. When presenting a route in the MOVE system, we sometimes make a road segment salient by giving it a different scale factor than others. For example, in order to make road segment *b* in Figure 4.6 more salient than *a* and *c*, the system enlarges the segment *b* by changing its length and angle. In this case, it is more convenient to have information such as road length and angle of each segment than to have absolute coordinates information.

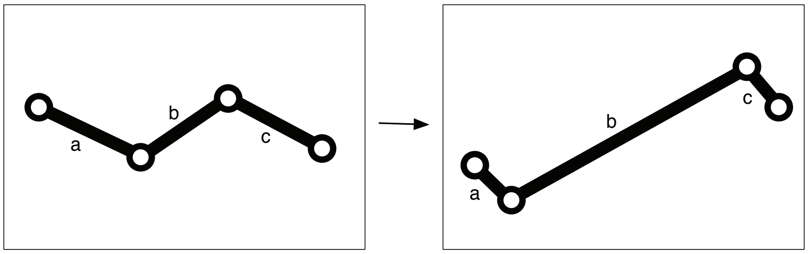


Figure 4.6 Changing length and angle of road segment b

Since variable scaling and other manipulation will be performed on the data, information such as the MoveCrossroad, the MovePoi is stored in both absolute and relative forms. The MoveLocation, which is a representation of a vehicle's current location on the route, will also follow the same convention of placement that used in the MoveCrossroad and the MovePoi. As Figure 4.7 depicts, a crossroad *b* has placed on the 55% of the road segment, and POI (Points of Interest) *c* has placed on the 90% of the road segment and the vehicle marker *a* has proceeded along 20% of the road segment.

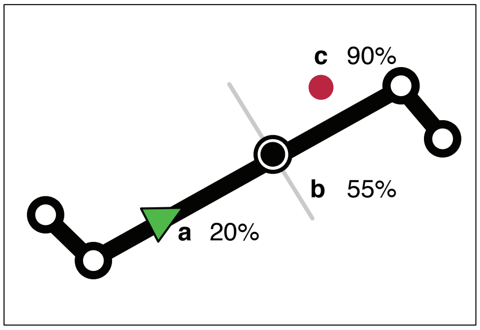


Figure 4.7 Placement of crossroads, POIs and vehicle's position

4.3 Layout Computation

After a MoveRoute object is constructed by parsing RouteXML data, the MOVE application prepares the optimization processes (e.g., Road Layout Optimization, Rendition Selection Optimization, and Final Rendition Placement Tuning). However, this requires preperation before the actual optimization process starts — this includes scaling, simplifying, segmenting of the route and so on. Figure 4.8 is the overview of the route layout computation process.

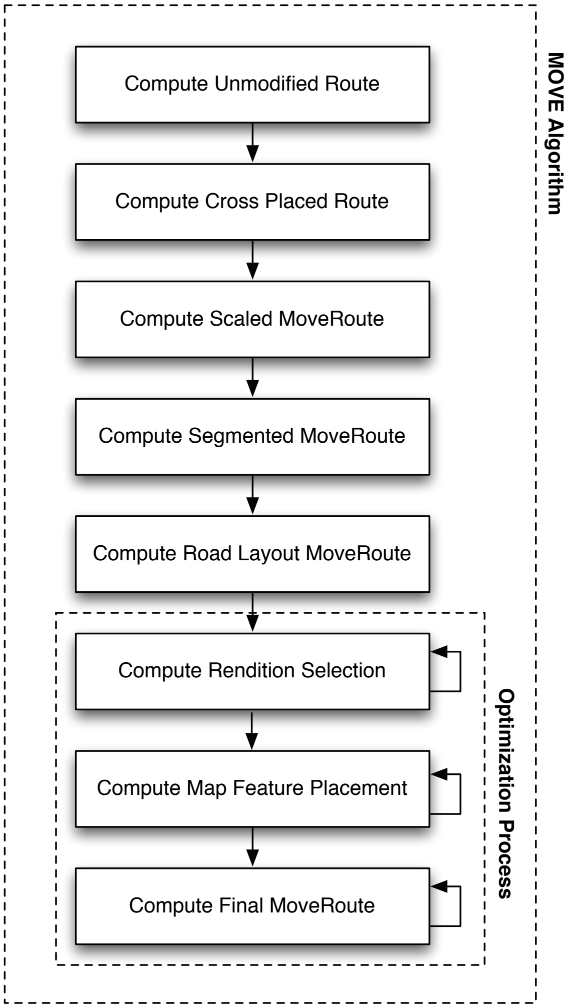


Figure 4.8 MOVE's route layout process (detailed process of MOVE Algorithm in Figure 4.2)

4.3.1 Crossroad Placed Route

Starting from the unmodified route data structure, we build a Crossroad Placed Route. This process performs two simple tasks: removing unnecessary or duplicate crossroads and assigning appropriate road and segment index to each crossroad. Figure 4.9 depicts an example of index assignment. In this picture, the main road consists of two roads. The first road has only one segment, so each crossroad (*a* and *b*) has same road index and segment index, which are both "0." The second road has two segments — the crossroad *c* intersects with the first segment and the crossroad *d* intersects with the second. So, crossroads' (*c* and *d*) road indexes are set identical ("1") and the segment indexes are set differently ("0" and "1").

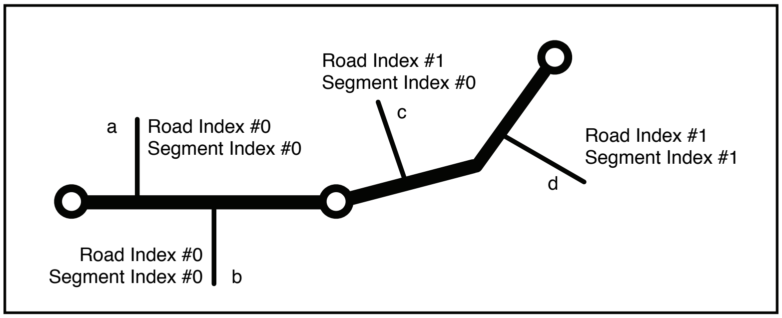


Figure 4.9 Crossroad placed route

During the Road Layout optimization process, the original route shape and coordinates are distorted by aggregating and simplifying its segments. So, with the index numbers that each crossroad has, we will be able to find the right position of the crossroad within the distorted route.

4.3.2 Route Scaling

In this step, the original route is scaled so that it fits in the space available for rendering. The scale factor can be calculated by using the following equation:

```
scale_factor = min( ScreenDim.height / RouteBounding.height,
                    ScreenDim.width / RouteBounding.width ) *
                    safe_area

             where, safe_area = 0.95
```

After calculating the scale factor, a `safe_area` ratio is multiplied to make safe visible area (dotted inner rectangle in Figure 4.10). The safe area will prevent any of route graphic from being rendered partially off screen. We make the safe area 95% of the screen.

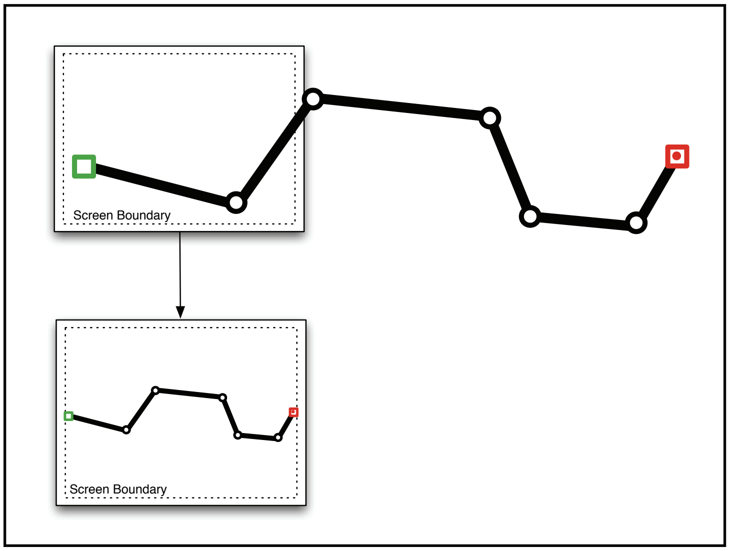
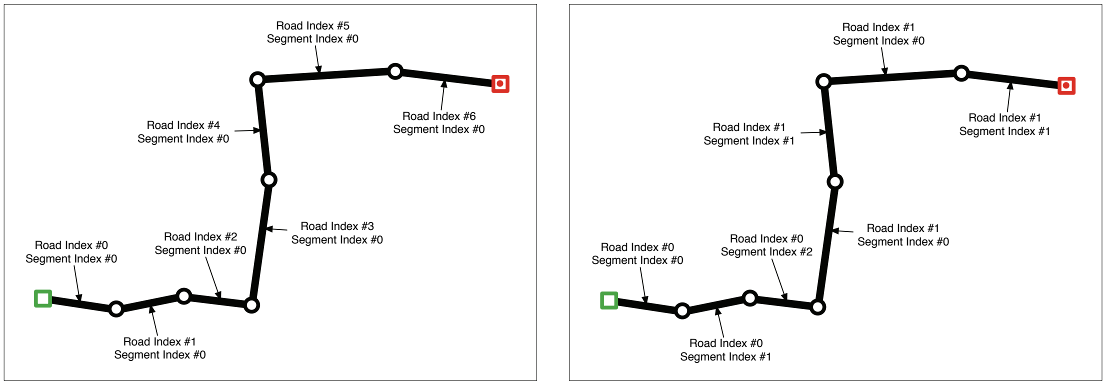


Figure 4.10 Route scaling

4.3.3 Route Simplification

After scaling down the original route to fit the screen boundary, we simplify the route. As we discussed in our map generalization technique, this process simplifies and smoothes the road segments by combining multiple roads into one.

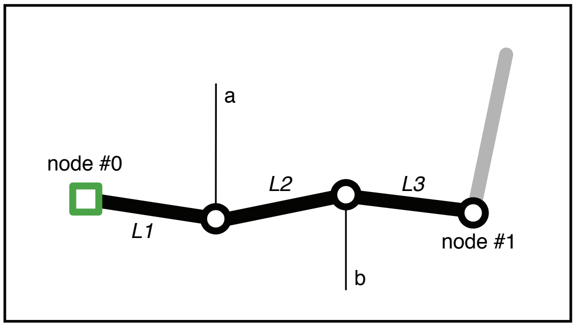
The simplification is based on turns. As the example in Figure 4.11 depicts, there were initially seven road segments in the route. But, the first three segments, which of road indexes are 0, 1, and 2, are actually one road. So, instead of giving them different road indexes, the simplification process merges the indexes as shown in Figure 4.11b. The road indexes of the first three segments have set to "0" at this time, and instead, the segment indexes have changed to 0, 1, and 2. By following the rule, we also need to update the intersecting road indexes of both crossroad and POI at this time.



(a) before the simplification (b) after the simplification

Figure 4.11 Route simplification

After this, in order to find the right placement of each crossroad and POI, we calculate the "distance percentage to crossroad (or POI)." As we discussed in the earlier section, we use relative distance concept for crossroad and POI instead of absolute coordinates when drawing them on the display. However, since each road in a route may have some level of curvature, a calculation of simple linear distance to a node from an element (e.g., crossroad, or POI) can't be correct. So, the calculation should be done by considering the curvature of a road. For example, in Figure 4.12, a distance from the *node #0* to crossroad *b* should be `L1 + L2`. Likewise, the distance percentage from the *node #0* to crossroad *b* would be `(L1 + L2) / L`.



```
L = L1 + L2 + L3
distance percentage upto crossroad a: L1 / L
distance percentage upto crossroad b: (L1 + L2) / L
```

Figure 4.12 Calculation of distance percentage

As Figure 4.13 shows, the process of merging results in a straight line for the road. While doing this, we will set the merged road's new length as the sum of each road segment's length in the original route `(L = L1 + L2 + L3)` and the new angle as the calculated new angle between the *node #0* and *node #1*.

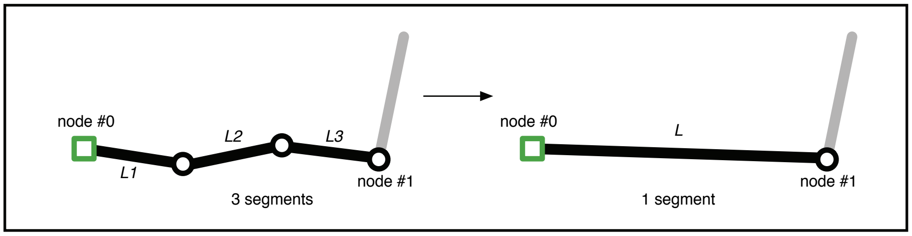


Figure 4.13 Segmented Route

4.3.4 Establishing curvature break points

Since the driver only sees a very limited area of a road while driving, the actual curvature of the road can be ignored in many cases. So, in general, the MOVE system tries to display each road chunk as a straight line through the *Simplification/Smoothing* process. However, if a route segment has a sharp curve, then it may need to be displayed as such because sometimes the curvature itself can be used as a milestone or a landmark. For this purpose, the MOVE system establishes break points while it simplifies a route. As Figure 4.14 depicts, if an angle of a curve is less than 135 degrees, a `road_break_point` is established in order not to remove the point during the *Simplification/Smoothing* process.

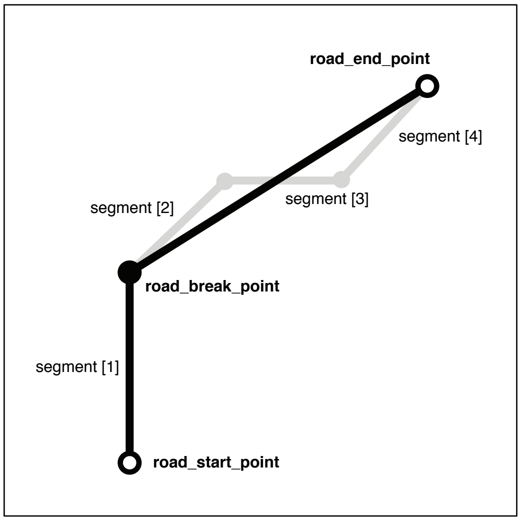


Figure 4.14 Establishing curvature breakpoints

4.4 Road Layout

Road Layout is a process that decides how to place a route within the space of the screen display. This process is directly related to *Simplification/Smoothing* and *Relative Scaling*. The goal of this process is to generate the entire route as simply as possible while making the important portions of the route segment salient. In the changing driving context, the system would also dynamically assign different saliency values to each segment.

The LineDrive system (Agrawala & Stolte, 2001) has demonstrated a very useful method for road layout. The LineDrive system generates a simplified route map through basic numerical optimization using simulated annealing (Černý, 1985; Kirkpatrick, Gelatt, & Vecchi, 1983). It selects a final route layout by performing three generalizations: *Length Generalization*, *Angle Generalization*, and *Shape Generalization* (Agrawala & Stolte, 2001). For the *Length Generalization*, the LineDrive system distorts the length of each route segment in order to make the entire route fit within a screen boundary while maintaining the constraint that shorter roads remain perceptually shorter than longer roads. *Angle Generalization* alters the angle of each road segment to improve the clarity of the turning points, ensure a minimum length for shorter roads, and to make room for labels. Finally, *Shape Generalization* simplifies the road shape by removing extraneous information and places.

Addition to the generalization processes of the LineDrive system, it handles errors that could happen when the original route is distorted, such as missing intersections and false intersections. These errors can appear quite often during the distortion process, and could disrupt navigation significantly.

Many basic layout methods used in the LineDrive system are valid for use in the MOVE system. However, additional layout methods are needed because the LineDrive system only focuses on static route maps, while the MOVE system addresses dynamic information.

For example, the LineDrive system consistently maintains the ratio of each road segment's perceptual length. In the MOVE system, if a segment is more important than other segments, that segment is enlarged (despite its original length) in order to ensure higher salience and more space for contextual information related to the segment. Therefore, we need to develop different road layout methods for the MOVE system.

The goal of the road layout optimization process is to display the route within a given screen boundary, emphasizing the segment of interest without losing the entire context of the route. Two major sub-goals will be introduced here: First, the route segment of interest should occupy most of the screen. Second, the entire route should be displayed within the display boundary.

4.4.1 Segment of Interest

The definition of *segment of interest* could vary depending on the driver's situation. In most cases, it could be defined as "the route segment containing the car." This coincides with our earlier findings from the navigation study. When navigating, people divide the entire route into small chunks and create sub-goals based on each turn, so a segment of interest is the road segment the driver is currently traversing. However, this idea may be incorrect in some instances. For example, if the road segment is very short, say 100m, then the driver may encounter very sudden changes on the route display. We usually experience this situation when we get close to a destination. In this case, we may want to combine two or more segments together to make a segment of interest. The optimization process will make this decision during route initialization of the road layout.

4.4.2 Internal Areas

To optimize road layout for each condition, we first assign two internal areas as Figure 4.15 depicts: *focus area* and *screen boundary*. Focus area is the main display area for the route segment of interest and takes up 80% of the entire screen display. Screen boundary is defined by a 20-pixel border of the entire screen display; the boundary is used to prevent any part of the route from exceeding the boundary of the screen.

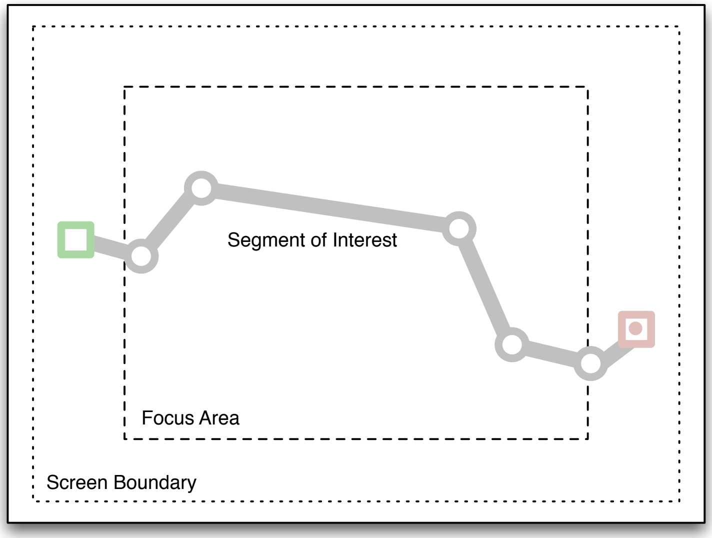


Figure 4.15 Internal Areas: focus area and screen boundary

4.4.3 Overall Optimization Process

As discussed earlier, simulated annealing is used for basic numerical optimization of the Road Layout. This is parameterized by perturbation functions and score functions. First, perturbation functions change the energy level of the currently selected state, and create a new candidate state (in our case, a new map design) by modifying the state's configurations. Afterwards, score functions evaluate the candidate state with given evaluation criteria and return a penalty score.

4.4.4 Perturbation functions

To create a candidate state by modifying the current configuration, we implemented the following three perturbation functions for the Road Layout Optimization:

1. *Randomly modify length of the segment of interest.*

The first perturbation function is *Randomly modify length of the segment of interest*. As discussed earlier, the segment of interest is where the vehicle is currently traversing. After an original route is placed on the screen, the Road Layout Optimization process selects a segment of interest from the original route map. In Figure 4.16, the fourth road in the route is the segment of interest. This perturbation function will randomly increase or decrease the length of the segment of interest by given value (e.g., ±5 pixels). The purpose of this function is to make the length of the segment of interest as long as possible, without exceeding the boundary of focus area.

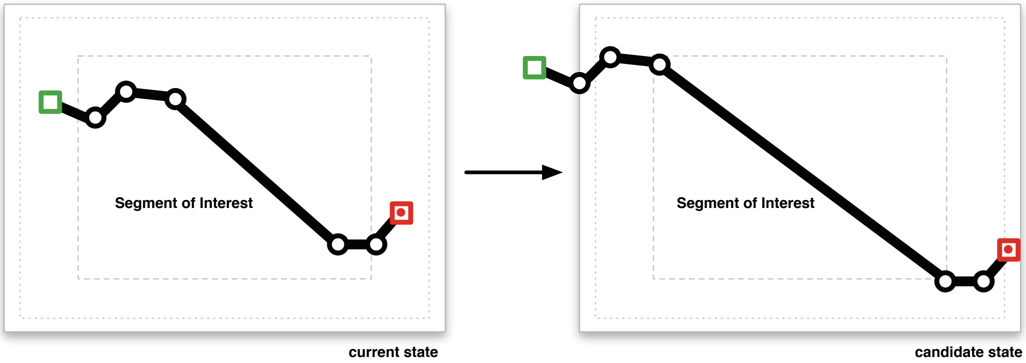


Figure 4.16 Modify length of the segment of interest

2. *Randomly modify angle of the segment of interest.*

Similar to the previous perturbation function, this function will randomly increase or decrease the angle of the segment of interest by given value (e.g., ±2°). Again, the purpose of this function is to make the segment of interest as long as possible within a boundary of focus area. Ideally, the longest line in the focus area would be the diagonal line that crosses the two corner points of the area Figure 4.17. As a result, this function will change the angle of the current state and try to make it equivalent to the angle of the diagonal line. In this case, however, we may experience serious distortion of the original route's road angle. To prevent this distortion, we implemented two constraints for angle modification.

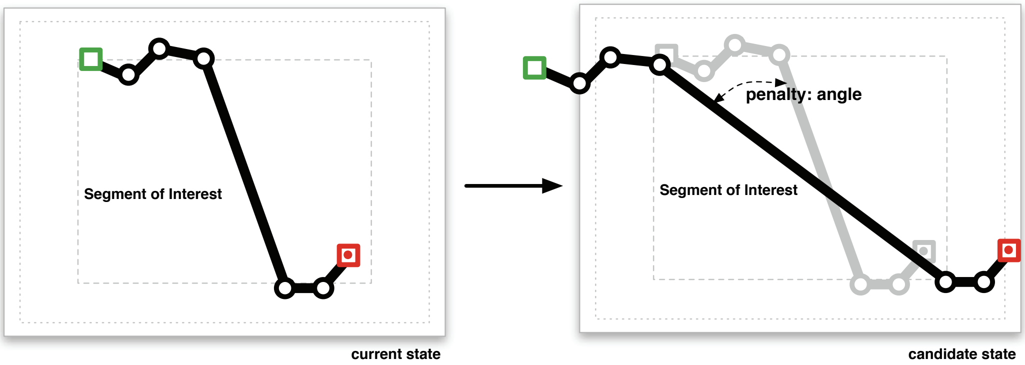


Figure 4.17 Modify angle of the segment of interest

3. Randomly modify length of the remaining route segments.

This function will randomly increase or decrease the length of the remaining route segments other than the segment of interest. The goal of this function is to make the entire route fit in the screen boundary. In Figure 4.18, without adjusting the length of remaining route segments, the entire route may exceed the boundary of the screen even though we successfully lay out the segment of interest within the focus area. In some cases, if an entire route is too small for the screen boundary, this function will increase the size of entire route to fit in the screen.

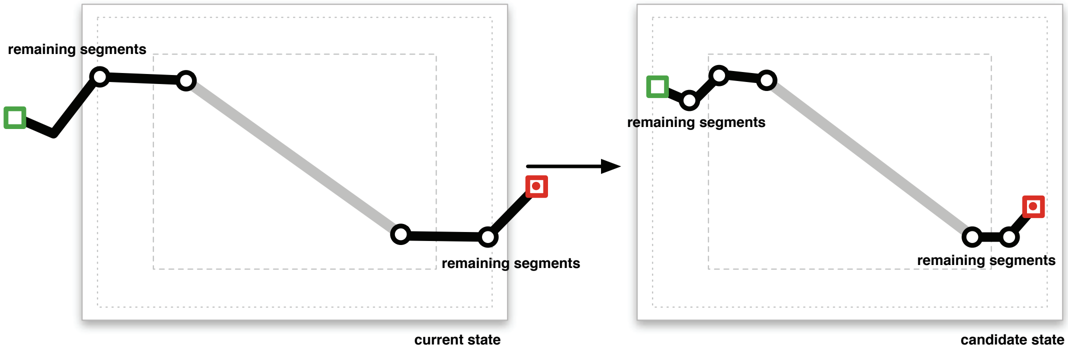


Figure 4.18 Modify length of the remaining route segments

4.4.5 Scoring functions

Scoring functions will evaluate each candidate iteration and calculate penalty scores for the candidate. The following three functions were implemented to evaluate each iteration:

1. *Minimize the difference between the boundary size of the segment of interest and the boundary size of focus area*

As discussed earlier in brief, our primary goal of the *Road Layout Optimization* is to make the important segment of a route (e.g., segment of interest) salient in the display by making it occupy the majority of the screen. To achieve this, we introduced the Focus Area, where the most important renditions are being placed. Our sub-goal for this evaluation function is to make the segment of interest as long as possible within the focus area. To do this, first we calculate the boundary of the segment interest and then calculate the difference of the boundary and the boundary of the focus area Figure 4.19; the difference is used as a penalty score. If the difference is big, then the segment of interest is probably too small or too big for the focus area. To correct, the optimizer will move forward by minimizing the score.

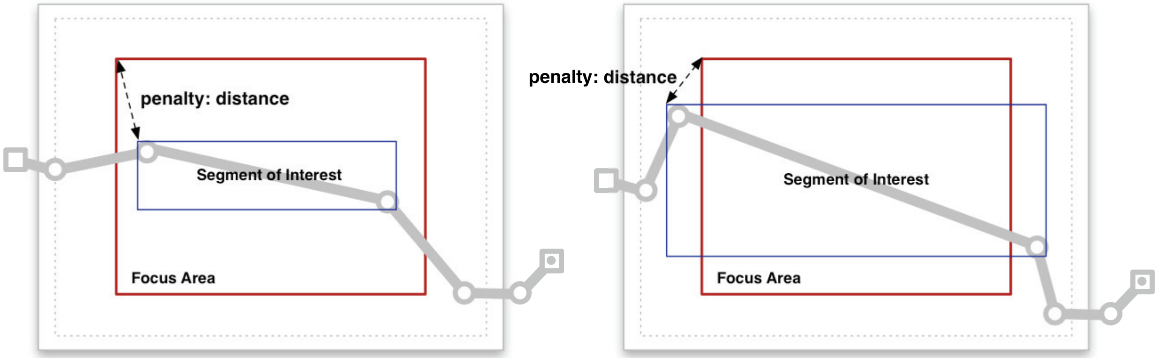


Figure 4.19 Boundary comparison of the focus area and the segment of interest

2. *Keep in original angle of segment of interest.*

If we rotate the segment of interest and make it a diagonal line in the focus area, then we will have the longest line in the focus area. However, if we just do this, we will have serious angle distortion of the segment. While the precise angle of a segment is not very important for navigation, we still need to keep the original angle since sudden changes of angle may cause a discordance issue to the driver — for example, if a road is heading west, but the distorted road is heading northwest or even northeast, then it will be a big problem for the driver (Figure 4.20).

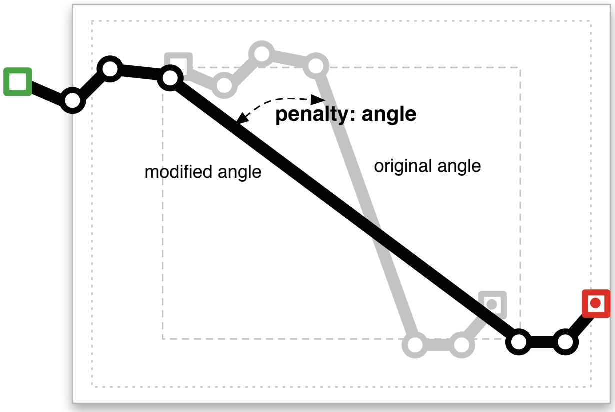


Figure 4.20 Angle difference of the original segment and the modified segment

For this reason, this function calculates the difference between the current state's angle and the original route's angle and returns the value as a penalty score. If the score is big, then the current state's angle is quite different from the original one, and it is not likely to be selected by the optimizer, so the optimizer will move forward to minimize this value. However, if the new angle is less or more than 10° from the original angle, then we don't penalize it. Most conditions can be handled using ±10° deviations from the original angle.

3. Keep entire route in screen boundary

The purpose of this function is to place the entire route within a screen boundary since we don't want any part of the route to go out of the screen boundary. This is somewhat similar to the *Minimize the difference of the boundary size of segment of interest in the boundary size of focus area* function. First, we calculate a boundary of the entire route and calculate the difference of the boundary and the screen boundary (Figure 4.21). The difference will be used to penalize the iteration. If the score is big, then the entire route might too big or too small for the screen boundary. The optimization process is likely to choose the one with minimum penalty score.

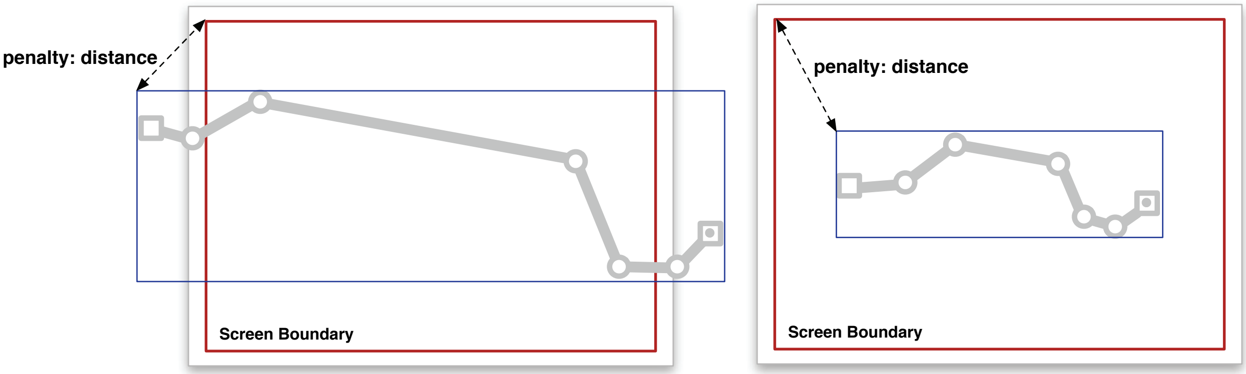


Figure 4.21 Comparison of the screen boundary and the boundary of the entire route

Figure 4.22 shows an example of our road layout optimization process. The perturbation functions and scoring functions discussed above will work together and choose the final solution that satisfies the all evaluation criteria.

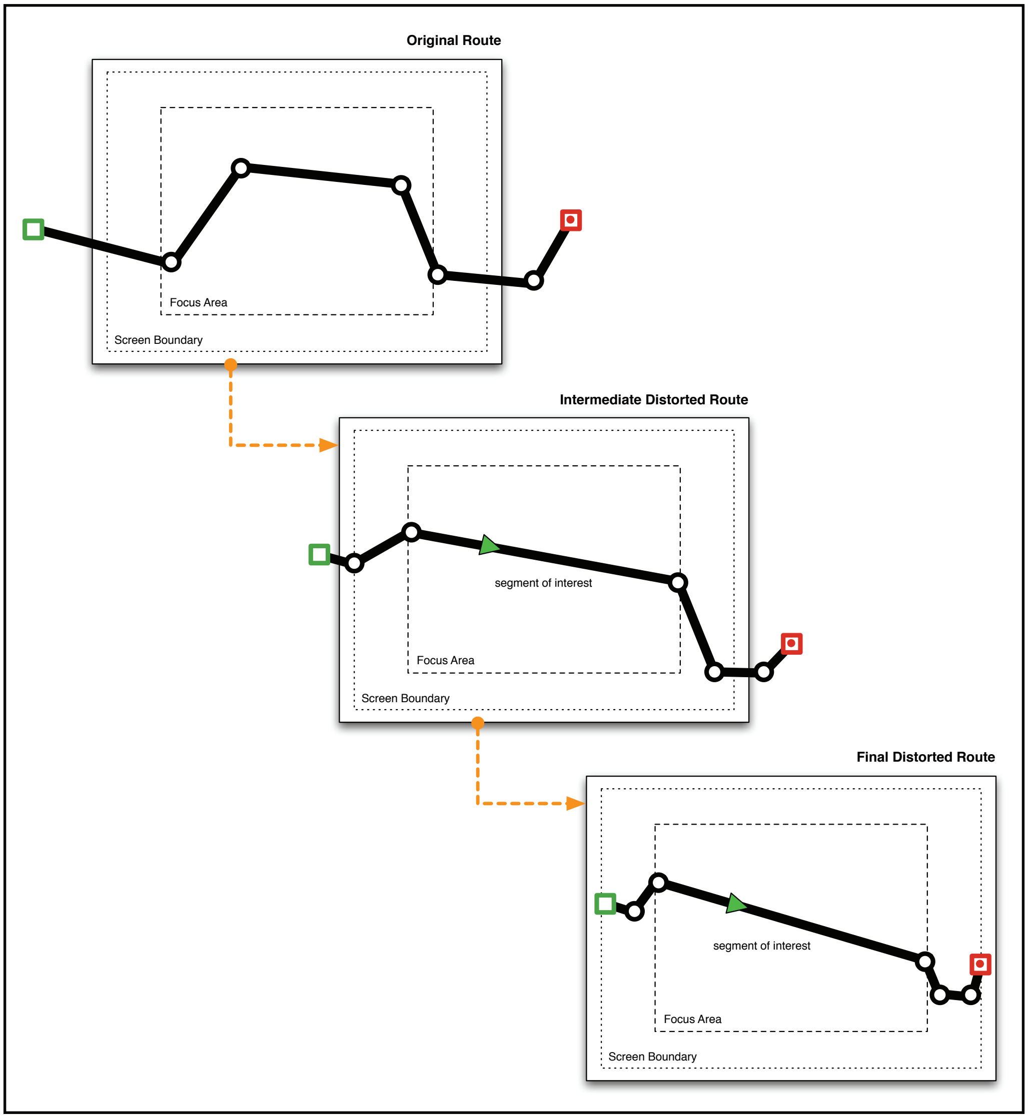


Figure 4.22 Example of road layout optimization process

4.5 Overall Process of Rendition Selection

When designing a map display, various types of map elements — what we call 'renditions' — are placed on the display. Since not every part of the display is equally important, and a user of this map display (driver) cannot read every bit of information on the map while driving, we want to bring various abstraction techniques to bear on the information. As a result, a map display shows various levels of detail — for example, the upcoming crossroads and landmarks are considered important to the driver, and are presented with the most detailed map elements. For the same reason, the crossroads and landmarks around the next turn are treated as equally important as upcoming ones. On the contrary, the crossroads and landmarks behind the vehicle, or the one that are far from the current vehicle's location, will be regarded as less important and treated as less attentive manner or even omitted from the display (Lee, Forlizzi, & Hudson, 2008).

When making this kind of design decision, the designer will consider which form of a rendition to use for the display in any given situation. For example, if a designer wants to put a McDonald's symbol in the map display, he or she will think of possible alternatives for the symbol as Figure 4.23 shows.

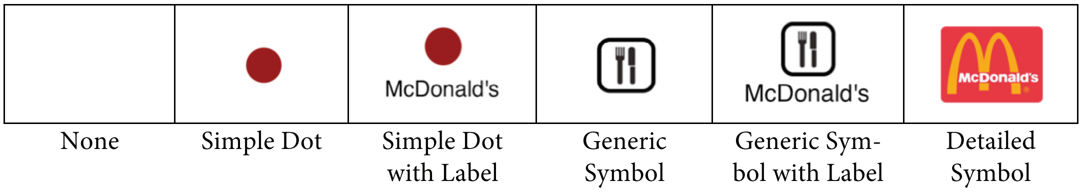
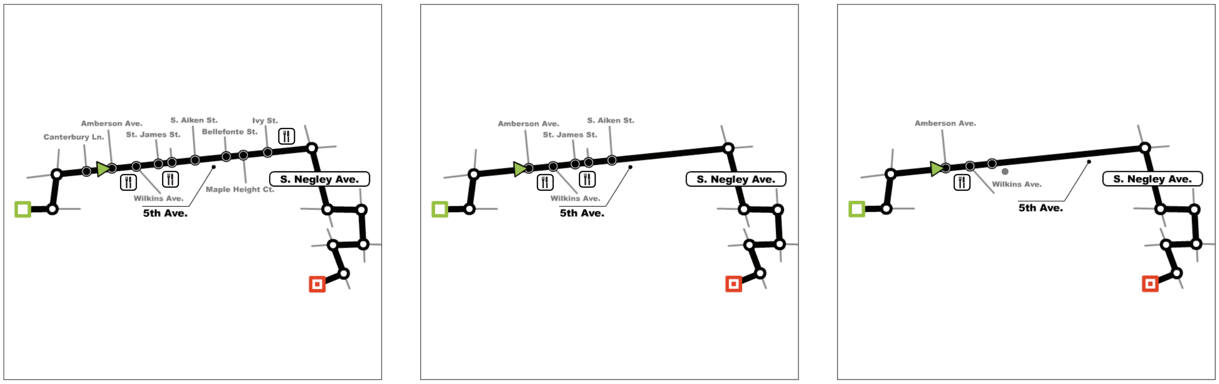


Figure 4.23 Alternative symbols for representing McDonald's restaurants



(a) (b) (c)

Figure 4.24 Searching optimal rendition alternatives

If the symbol is very important to a driver in a certain situation, then the designer will choose the most salient symbol — in this case, the McDonald's logotype — for the display. If it is less important, then a simple dot (or maybe a dot with label) will be selected. If it is not important at all, then none of the symbols will be selected for display.

However, the selection process isn't performed just by considering the importance of the symbol in a given situation; it also needs to consider the relationship with other elements. For example, even though the McDonald's symbol is very important in a certain situation, the designer will not use the most salient symbol (a McDonald's logo) if it conflicts with other information. In this case, the designer will try to use an alternative for the McDonald's symbol or even try to choose an alternative map element to resolve the conflicts. Simon sees this process as finding optimum solutions through the search for alternatives (Simon, 1996). Figure 4.24 depicts an example of the process of searching optimal rendition alternatives. The first route map (a) in Figure 4.24 is the default rendition set of a route. As we can see, it looks complicated because there are too many intersections and landmarks, and they are all treated with the same importance level.

In general, when driving, the details of a route such as the curvature of a road, or every crossroad and landmark within the route, are relatively unimportant. Our earlier study on navigation indicated that abstracted, flattened, and simplified representations were consistently favorable for navigation, except at critical junctions such as turns, upcoming intersections and upcoming landmarks. In these cases more details were needed (Lee, Forlizzi, & Hudson, 2005). For those critical junctions, we may want to use the most salient renditions in order to catch the driver's attention easily. Renditions at other junctions considered unimportant could be eliminated or de-saturated to decrease the driver's total attentional cost to the display. However, the selection in (b) still looks complicated because there are too many renditions that have the highest saliency level. As we are well aware, it is very dangerous if a driver's attention is taken away from the roadway for a task other than driving for too long a time. Rockwell's 2-seconds rule indicates that drivers are reluctant to go without roadway information for more than 2 seconds (Rockwell, 1988). It is generally recommended that the smallest amount of information that drivers need should be presented in order to prevent a driver's perceptual overload. By considering this, designers should eliminate more information from the display and select an alternative for each rendition to minimize the total amount of information conveyed to the driver. The last rendition selection example (c) in Figure 4.24 might be the most optimum rendition selection for the situation.

4.6 Types of Score

The described process of the human designer has been applied to create our rendition selection algorithm for perceptually optimized map display. The algorithm takes the large information set of the original map and presents it in a less information-demanding manner. However, in order to perform numerical optimization of rendition selections, every design alternative of each rendition has to be scored. The scores can be divided into two different categories: *fixed score* and *fluctuating score*. The *fluctuating score* will be changed by considering a given situation, while the *fixed score* wouldn't.

4.6.1 Fixed Score

The fixed score doesn't change its value over time as the surrounding situation is changed; it is assigned to each rendition at the time it is designed. The communicative score and the attentional cost score will also act this way. The communicative score can be described as how easily the meaning of a rendition is conveyed to a user. Every rendition (including its alternatives) on a map display will have different level of salience. When a user of the system reads map information on the screen, each map element can induce both positive and negative effect based on the saliency level of each element and the context in which they are being used. As we can see from the earlier example of a McDonald's symbol (Figure 4.23), it can be represented as one of the several different forms. Among the various forms of the McDonald's symbol, the most communicative form might be the red McDonald's logotype (Figure 4.23). If we choose the generic restaurant symbol, then we can still understand the landmark is 'restaurant,' but we are not sure what kind of restaurant it is. From the user's point of view, it is considered that higher salient information can convey its meaning much better than lower salient information. When the driver glances at the display for a short time, it is very likely that the driver's attention will be drawn to the higher salient symbol immediately — the saliency works positively when information is conveyed. As a result, the communicative score is increased as the saliency level increases.

However, raising the saliency level of information is not always better. The reason why it is difficult to find "Waldo" is there are so many visual elements in a picture, which have indistinguishable levels of saliency. Visual elements with similar level of saliency can distract from each other, so it isn't easy to find target information from the screen. In visual search process, *pop-out* plays an important role. Prior work from Goldstein (2002) has found that if a clear *pop-out* occurs in a search task, reaction time is consistently fast no matter how many distracters are present (Goldstein, 2002). On the contrary, if every element tries to induce *pop-out*, then the search task will be severely hampered. We can think about the case where the renditions work as distracters, distracting the driver's attention from other renditions. In this case, the saliency could work negatively and we regard this as the attentional cost score. Similar to the communicative score, the attentional cost score will be increased as the saliency level increases.

4.6.2 Fluctuating Score

Alternatively, we can think about a fluctuating rendition score that changes over the time as a vehicle traverses a route. Since the score is changed based on the importance of a rendition at a certain situation, we call it the *importance score*. For example, as we can see from Figure 4.24, crossroads and landmarks that are close to the current vehicle's location will be more important than the ones behind the vehicle, or the ones far from the current vehicle position. We can decide the importance score based on the distance between current vehicle position and a rendition. The importance score of a rendition will be increased as the distance to the vehicle decreases.

4.7 Scoring the Renditions

To assign actual values for each rendition, we conducted a visual search study. The result of this study has been already discussed in the previous chapter, so here we summarize the results briefly. Throughout the study, we grouped the renditions into *symbolic* and *semantic* categories. A symbolic rendition conveys its meaning through shape, while semantic renditions contain information conveyed through text and/or numbers (Table 3.2). The more detailed road signs in our experiment (renditions G–K in Table 3.1) are *semantic*, while the remaining renditions (A–F, L, and M in Table 3.1) are *symbolic*. We also grouped them into more detailed set of categories: *semantic text* (J, K), *semantic numbers* (G–I), *complex symbols* (B, D, F, M), *simple symbols* (A, C, E, L), *colored* (G, L, M), *black and white* (A–F, H, J, J, K), and finally with respect to the size of each rendition: *large* (B, D, F, J, K), *medium* (G, H, I, L, M) and *small* (A, C, E). (Table 3.2)

4.7.1 Scoring Fixed Score

In this study, we found that participants had faster reaction times when searching for semantic renditions. This result indicates that semantic renditions would be more communicative than symbolic renditions. In addition, text shows faster reaction times than numbers, and labels with shape show faster reaction times than labels with line. As we expected, renditions with color show faster reaction times than black and white. By compiling these study results, we grouped the renditions again for the purpose of scoring them.

Group 1a: Intersections

Shape	None	○	—○—
Score	0	1	2

Group 1b: Landmarks

Shape	None	Markup 1	Generic 2	Specific 3
shape example		●	🍴	McDonald's
Score	0	1	2	3

Group 2a: Labels

Shape	None	Number	Text
Score	0	1	2

Group 2a: Label Supports

Shape	None	Line	Shape
Score	0	1	2

Multipliers:
Type: Symbolic (1), Semantic (2)
Color: B/W (1), Color (2)

CommunicativeScore = {(Group1 * Type) * Color} + {(Label + LabelSupport) * Color}
AttentiveCostScore = {(Group1 * Color} + {(Label + LabelSupport) * Color}

Figure 4.25 Rendition Grouping for Scoring

As we can see from Figure 4.25, the renditions are divided into two groups. Representations of intersection marks and landmarks are categorized as Group 1, and labels and their supporting shapes are categorized as Group 2. Each group has subcategories based on the rendition's type — for example, intersection marks can be distinguished from landmarks since they don't convey the meaning through their shapes, so they can be placed into a symbolic rendition category, similar to our previous study analysis. Conversely, landmarks can be categorized as semantic renditions.

However, in the case of Group 2, sub-categorization is somewhat different from Group 1. When presenting labels on a map display, the labels can accompany other shapes such as callout lines, or border shapes. They are usually used to support labels, making the labels salient in a given context, so we separated the supporting shapes from labels since they are additional features of labels.

Each rendition in a group has been assigned a different score. For example, the renditions in Group 1a have scores from 0 to 2. The score assigned here is basically a communicative score, which is increased by its salience. If no rendition is displayed on the screen, the communicative score will be set to zero since no information is being conveyed. An intersection mark with a line will be more informative than an intersection mark without a line. So the score was set to 2 and 1, respectively. This scoring has been supported by our previous study (Lee, Forlizzi, & Hudson, 2008). Renditions in Group 1b, landmarks, have 4 different scores. A markup-style landmark, which is a simple dot representation of a landmark, will be treated similar to an intersection mark without a line and will have 1 as its score. A generic-style landmark, usually a simple icon of a landmark (e.g., restaurant, gas station etc.), can convey more information than the markup-style landmark so its score was increased by 1. A specific landmark, which is a logotype symbol of the landmark such as McDonald's or BP gas station, is the most salient among this category, so it will take the highest score. However, the study result also shows that semantic renditions are more communicative than symbolic renditions. It would be fair to apply this finding in the scoring since the intersection mark with line (score is 2) would never be the same with the generic-type landmark (score is 2) in terms of conveying information. For this reason, we created a type multiplier to make semantic renditions more higher scoring than symbolic renditions. By following this, the score of Group 1 would be calculated as follows:

```
Score1 = Group1 * Type
Where Type: Symbolic = 1, Semantic = 2
```

In Group 1b, a markup-style landmark is a symbolic rendition. So, if we apply the above formula to calculate its score, the score would be still 1 since its original score and the multiplier number of symbolic rendition are both 1. But for a generic-type landmark, the score after the calculation will be 4 (= 2 x 2), since it is a semantic rendition (multiplier number is 2) and its original score is 2.

The scores of renditions in Group 2 were determined by our visual search study results. According to the results, a text-type label was more informative than a number-type rendition. Also, a border line style of label supporting shape was more salient than a line style (Lee, Forlizzi, & Hudson, 2008). By following these results, the score of each rendition was given as Figure 4.25 presents. Usually, a label is defined by a combination of a label and its supporting shape, and the score of a label also can be calculated by the sum of each score. So, the final score of a label will be calculated as follows:

```
Score2 = Label + LabelSupport
```

The study also shows that using color for a rendition induces *pop-out*, making the rendition more salient than others. If a rendition is accompanied by color, then we need to consider the pop-out effect caused by color through the compensation of the score at some degree. For this reason, we have defined another multiplier — color. If a rendition is just composed of black and white, then we multiply 1 by the original rendition score. If it is a colored rendition, then we multiply 2 by its original score. The final score of Group 1 and Group 2 that is described above can be modified as such after considering color effect:

```
Score1 = (Group1 * Type) * Color
Score2 = (Label + LabelSupport) * Color
```

Even though we categorized renditions into two groups, they are often presented as a combined form — for example, a landmark can be presented along with a label if it is needed, so it would be reasonable to define the final score of a rendition as a combination of the two scores: Score1 + Score2. If a rendition is just a landmark without a label, then the Score2 will be simply zero since no rendition is associated with it. Conversely, if a rendition is just a label, then the Score1 will be zero. By this definition, the final communicative score of a rendition can be described as follows:

```
CommunicativeScore = [(Group1 * Type) * Color] +
[(Label + LabelSupport) * Color]
```

As we mentioned earlier in this section, there is another type of score for each rendition, which can be described as negative score — the attentional cost score. According to our study result, when a rendition works as a distracter, directing the driver's attention away, then the saliency of this rendition will work negatively. Similar to the communicative score, the attentional cost score will also be increased as the saliency level increases. However, our study result indicated that the type of renditions — semantic and symbolic — were not effective when they're used as distracters; instead, color made the difference. As a result, we eliminated the type multiplier in order to calculate the attentional cost score. By this definition, the final attentional cost score of a rendition can be described as follows:

```
AttentiveCostScore = (Group1 * Color) + [(Label +
LabelSupport) * Color]
```

4.7.2 Scoring Importance Score

Unlike fixed scores, the Importance Score is established through a heuristic. Two parameters are used: *distance* and *context*. Usually, intersections or landmarks right in front of current vehicle's location are more important than those behind or far from the current location. Renditions that are close to a turn (another type of intersection) are also important. In order to assign an importance score, we use the distance between a rendition and a critical point. The current vehicle position, next turn, or destination can be regarded as a critical point. Figure 4.26 depicts how we apply the importance score to a rendition using distance from a critical point: the importance score increases as the distance from the critical point to a certain rendition gets closer.

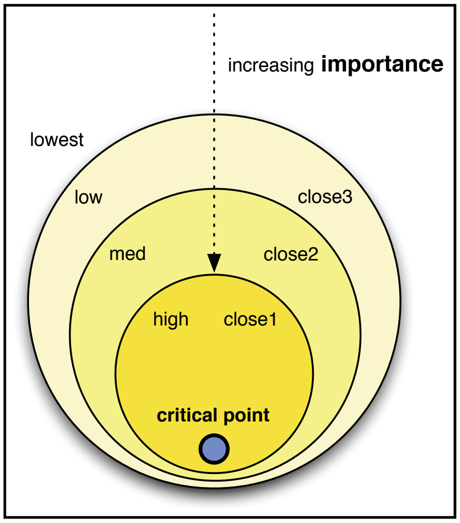


Figure 4.26 Importance Circle

Another parameter used to determine the importance score is context. When we travel a long route and the vehicle's gas gauge shows a near-empty tank, then we look for a gas station. In this situation, information about upcoming gas stations is more important than any other information — in other words, the gas station becomes the critical point. Likewise, within a certain context, a certain landmark may need to be more important than others and presented as salient.

However, not every critical point is considered equally important. Usually the destination would be the most important, followed by an upcoming turn and the vehicle's current position, leading us to apply a different scale of importance circle for those critical points. We used 10 scales for destination, 7 scales for upcoming turns, and 5 scales for current vehicle's position. For a critical point that is determined by a certain context, we also use a 5 scale importance circle. Each scale is decreased every 100m — if the scale factor is 5, then the renditions within 500m are covered by an importance circle. For example, the renditions within 100m importance circle will have higher score than the ones in 200m circle. The importance score is continuous number, so even the renditions within 100m circle will have different score based on the distance to the critical point.

As an aside, the importance circles may overlap for each critical point. In this case, the importance score of the renditions laying in the overlapping area will be calculated by the sum of the scores which are defined by each importance circle (Figure 4.27).

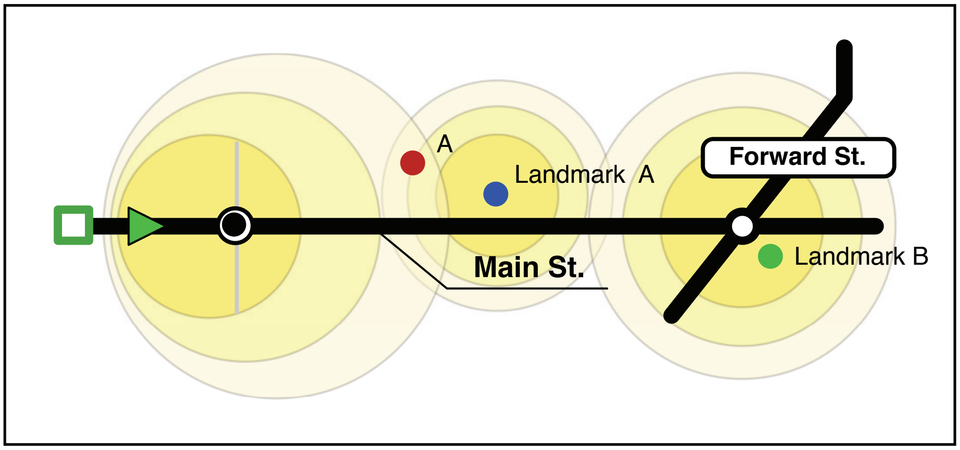


Figure 4.27 Applying importance circle to a route

4.8 Optimization Framework (CIA Framework)

The previous section described three types of scores, which are associated with each rendition. In this section, we will discuss how the scores are used to define characteristics of each rendition and also how the scores are used for rendition selection optimization.

When using renditions for the map display, the most important criteria will be the communicative potential of the renditions. Each rendition has to convey its meaning through its form, so the baseline score for the rendition selection ought to be the communicative score. Thus, when selecting an alternative of a rendition, it is likely to choose the one with higher saliency among the various forms of the rendition initially, because it can convey the information better than others.

However, if many map renditions need to be considered for the rendition selection process, then we probably want to make some of them more prominent than others. In this case, usually a search algorithm or other analysis uses a weight function to give some elements more weight than other. Similarly, we can give more "weight" to certain renditions to make them have a higher saliency than others. This "weight" is what we called the importance score in the earlier section, and it will give "weight" to renditions based on the distance to the critical point.

After giving "weight" to a rendition, then we need to consider the negative effect of the rendition in the map display. In the earlier section, we talked about the attentional cost score, which works as a negative effect of the saliency. As a result, the attentional cost score will subtract some amount of value from the total score of a rendition. If a rendition's importance score (weight) is high, then the effect of this subtraction might be insignificant, but if the importance score of the rendition is low, then the effect will be significant and the rendition's total score is decreased. This attentional cost score prevents the most salient symbol (e.g., McDonald's symbol) from being placed in an area where it is not important.

The relationship of three scores of each rendition can be formulated as follows:

```
C(Rs) * I(S) - A(Rs)
```

And the total score of every rendition in the route at a given situation should be formulated as follows:

$$\sum_{S \in Route} C(Rs) \times I(S) - A(Rs)$$

where S is a route segment or feature
Rs is a rendition choice for segment S
$C(Rs)$ is communicative potential score for rendition choice Rs
$I(S)$ is importance score for route segment S
$A(Rs)$ is attention cost (distraction) for rendition choice Rs

We will call this sum the ***CIA Score***.

As discussed earlier, the overall process of rendition selection is that the most important information in the current context remains highly salient, while reducing the distraction of surrounding information. However, we still need to manage the overall amount of information that is displayed on the screen so that the driver isn't distracted by unnecessary information. Driving usually requires a lot of concentration and it is easy to be distracted by other activities. We already see distractions caused by chatting with passengers, talking on cell phones, and manipulating other devices such as instrumental panels or music players (Lee, Forlizzi, & Hudson, 2008). The navigation system should carefully consider a driver's cognitive load and attentional state by reducing the amount of information that is conveyed to the driver. This is somewhat related to the budget system.

If we have enough money, we can buy as many items as we want. But, if the budget is very limited, then we need to decrease the number of items we buy by considering the priority of the items. If an item is useful for a given purpose but expensive, then we still want to buy this item and then adjust the number and cost of other items to fit in the given budget. Similar to this, we know the "budget" for the cognitive load of a driver is very limited, and we need to minimize the total score of information presented on the screen. However, if we just minimize the score of renditions, then the score may converge on zero, which can be interpreted as no information on the screen. To prevent this, we also need to maximize the score of local renditions that are important to given situation by weighing them.

Similar to the Road Layout optimization, Rendition Selection is also achieved through optimization with simulated annealing (Černý, 1985; Kirkpatrick, Gelatt, & Vecchi, 1983) which use perturbation functions and score functions to find a final solution for the rendition selection.

4.8.1 Perturbation Functions

To create a candidate state by modifying the current configuration, we implemented following function for the Rendition Selection Optimization.

1. Randomly modify rendition selection choice

This function randomly selects a rendition out of the whole set of renditions in a route, and makes a candidate state by raising or lowering the current state's rendition choice to the one which is next higher or lower in salience. Figure 4.28 is an example of this process. In this example, a selected rendition is a landmark and its current rendition choice is 'simple dot.' The perturbation function randomly decides whether to raise or lower its current selection. If the function lowers the rendition choice, then we will see no rendition displayed on the screen. If the function raises the rendition choice, then we will see generic symbol of the rendition as shown in Figure 4.28.

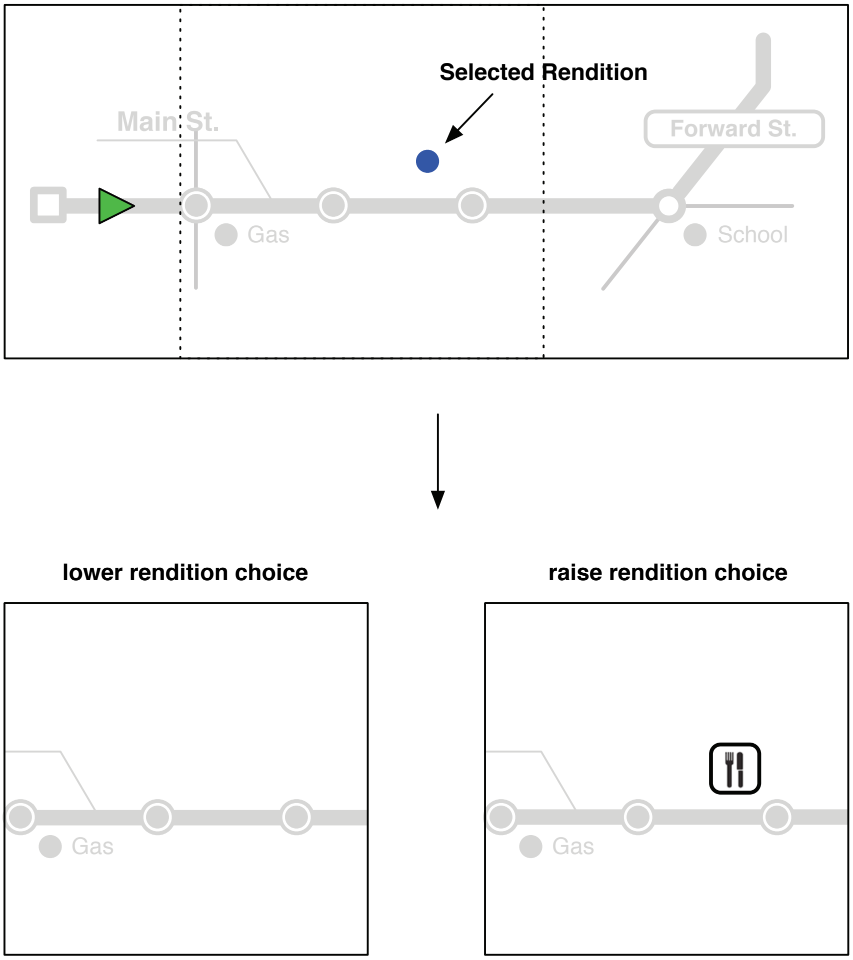


Figure 4.28 Modify rendition choice

4.8.2 Score Functions

The score functions evaluate each iteration and eventually choose a final solution. If an iteration's overall score is not improved, which means it is not suitable for the current situation and has not been improved from the previous iteration, it will be discarded and the rendition selection process will generate another iteration. To do this, following two functions have been implemented:

1. *Minimize the sum of CIA score*

The first scoring function minimizes the sum of the CIA score. As discussed earlier, we want to minimize the driver's visual attention to the display. By minimizing the sum of the CIA score, we can expect the amount of renditions presented on the display and their saliency will be decreased. To calculate each rendition's individual score, we use the formula that was presented earlier in section *4.7*. However, even though we are trying to minimize the sum of the CIA score of all the renditions, the Importance Score will still try to increase the score of renditions in the important area; for instance around the current vehicle position, making the renditions in the important area salient.

2. *Maximize the individual CIA score of important area*

While the previous function also tries to maintain the renditions in the important area salient, we want to do this job without fail, so this function has been implemented to maximize the score of the renditions in the important area. As a result, we can get the most salient rendition choices for them. In the important area, the Importance Score works as a fixed score — since all the renditions in the same importance score will have the same importance score — the optimizer will try to raise the *Communicative Score* and lower the *Attentional Cost Score* to maximize the score of the renditions.

Figure 4.29 is an example of final rendition selection. Even though the original route map displays many intersections and landmarks, the final display may show only two intersection marks: one with a crossing line and one without a crossing line. Also, the restaurant landmark and school landmark have not been selected for the final selection because they are not important in the current context of navigation.

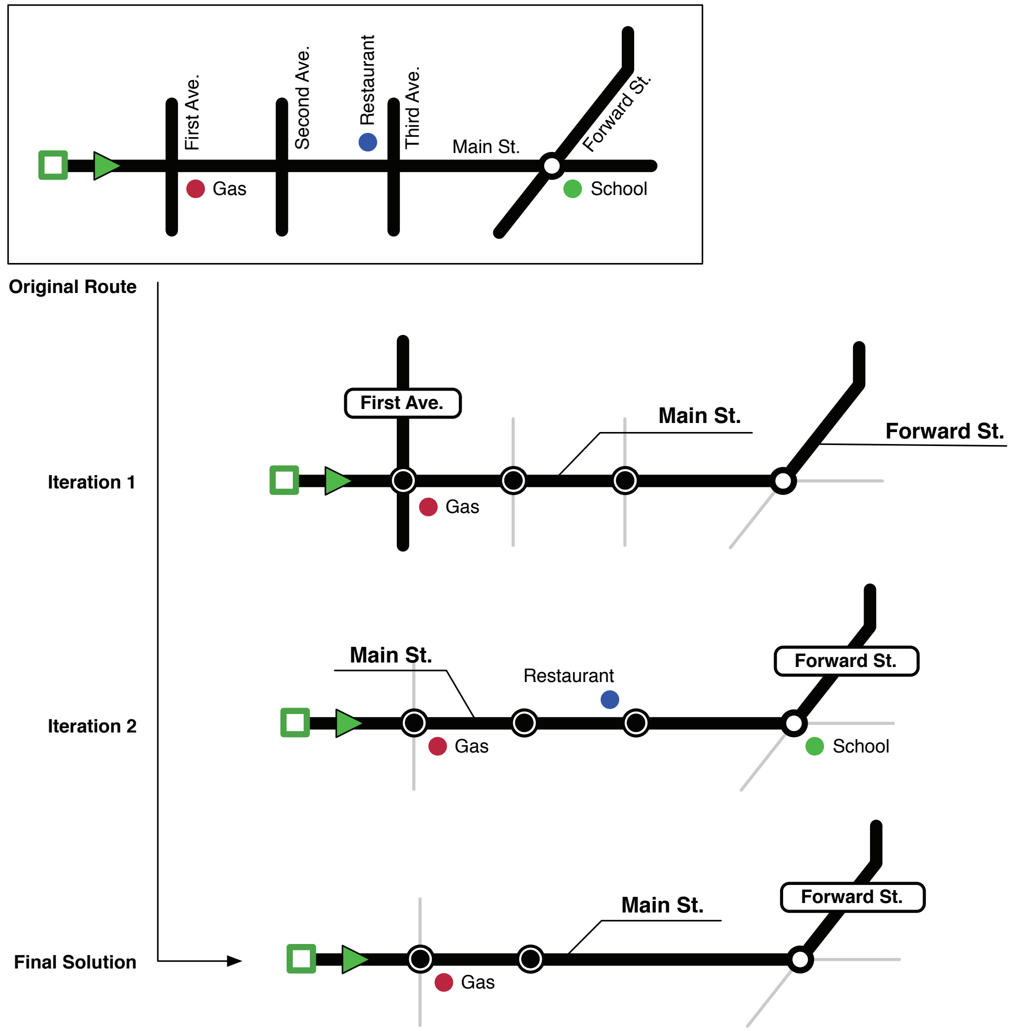


Figure 4.29 Example of rendition selection process

4.9 Final Placement Tuning

In previous chapters, we discussed the human designer's decision-making process of rendition selection and layout design. We also investigated ways to simulate the process computationally by using numerical optimization. In this section, we will discuss the final placement tuning process, which is the final map generation process.

Final placement tuning is the process of adjusting various properties of elements to be laid out on the screen. For example, in the case of a route map that we are designing, we may often see clutter or overlap of the renditions on the screen. Since a driver has to retrieve necessary information from the navigational display within a short amount of time, a complicated and cluttered screen may prevent him or her from getting the necessary information. In order to avoid this sort of unexpected problem, the designer adjusts the properties of a rendition such as location or size.

Actually, in a human design process, this is not a process performed in a vacuum. Instead, it is performed during the previous two design processes — road layout and rendition selection. However, in our implementation, we separated the final design tuning process from the other two processes since dealing with a lot of constraints at the same time would place a burden on the computer and create performance issues. As we discussed earlier, when a problem space is big, it is much easier to find a solution by narrowing down the problem and breaking it up into several sub-problems. To finalize the route map layout problem, we will perform a design tuning process after we have finished the road layout and rendition selection processes. During the placement tuning process, we will focus on the resolving the overlapping of renditions, which will address our map generalization principle — *Displacement*.

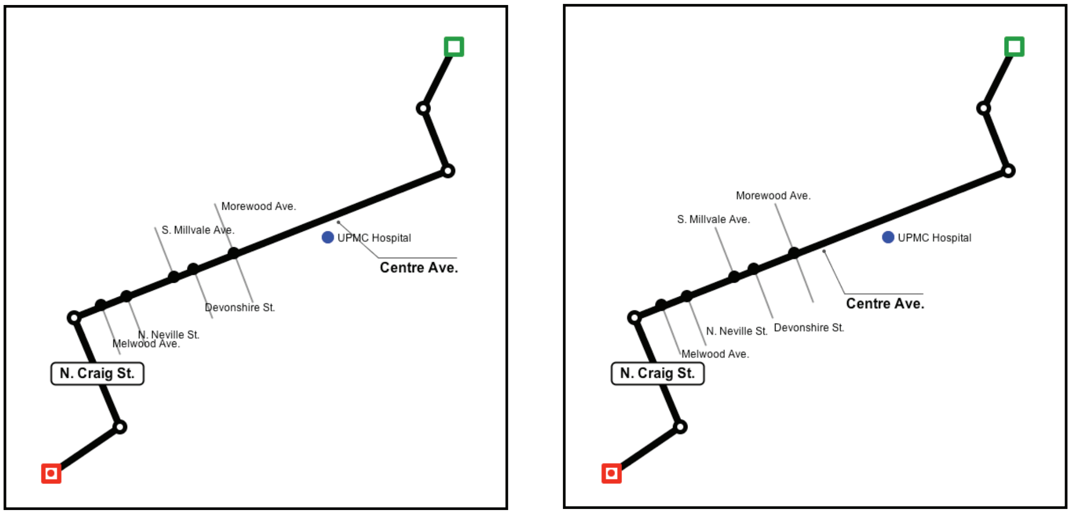
Related work explores point-feature label placement (PFLP) (Christensen, Marks, & Shieber, 1994; Christensen, Marks, & Shieber, 1995), which attempts to resolve overlapping issues when placing multiple labels on a 2-dimensional space. Overlapping of labels is common in cartographic design, due to limited space and abundant information. Prior research initially prioritized preferred positions for point-feature labels, and then placed labels using an optimization algorithm such as simulated annealing to avoid overlapping of each label.

Other researchers have also investigated placement of labels in the appropriate position on the visual display. Agrawala (2001) examined a way to place road labels for the route map and Fogarty (2003) has presented a system that can be used for solving many layout problems through numerical based optimization. Later, Vollick (2007) presented a way to automatically extract design properties from human-designed labeling visualization and then apply it using an automatic labeling system (Agrawala & Stolte, 2001; Fogarty, Forlizzi, & Hudson, 2001; Vollick, Vogel, Agrawala, & Hertzmann, 2007).

The MOVE system was greatly inspired by those works. However, since they are mostly focused on the static visual system, we developed an algorithm that can be applied dynamically.

4.9.1 Overview of Final Placement Tuning

The following figures show an example of the final placement tuning process. As seen in Figure 4.30a, road labels overlap crossroads, the main road, and other labels. After finishing the rendition selection process, the MOVE system places labels of renditions in their default positions, without considering other rendition's placement. As a result, we will experience overlapping, cluttered information elements in the display. The expected result layout should more like Figure 4.30b, which reduces overlapping areas of renditions, while maintaining the preferred position of label placement. Human designers will try to keep the preferred position of each label first, and then switch to alternative positions when the first choice is not possible.



(a) (b)

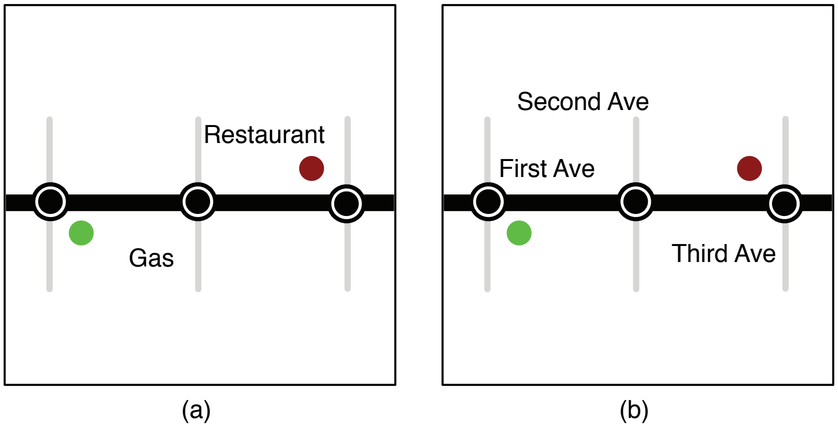
Figure 4.30 Final Placement Tuning example

The goal of the final placement tuning process is to minimize the overlapping and cluttered area of the labels and renditions through the adjustment of their position on the screen while trying to maintain their preferred position. To accomplish this, we first need to define following two attributes: *Label Placement Preference* and *Label Anchor Point Preference*.

4.9.2 Label Placement Preference

Every rendition on a map has its own name. However, not every rendition on a map is displayed with a name label. As we discussed from the *Rendition Selection Optimization* process, the label can be either displayed or omitted based on the importance of the rendition in a given context.

If a label accompanies a rendition, usually there are preferable positions for the label. For example, a designer may follow design rules, such as a label cannot be placed far apart from a rendition, or a label could be easily tied to a rendition when it is placed to the right side (or left side) of a rendition. Figure 4.31 shows examples of bad label placement. Figure 4.31a shows labels for a landmark, but they have been placed too far from the landmark. Moreover, the labels are close to the next crossroad, so they can be mistaken for next crossroad labels. In the case of the crossroad labels in Figure 4.31b, since they are placed very randomly, they are inconsistent and visually inappropriate and also could cause confusion to the user. It might be a good idea to use pre-established locations for rendition labels and their preference order, in order to prevent inconsistency of the label positions. In the MOVE system, we have three different rendition types — Road, Crossroad, and Landmark — and we have prepared different label placement preference based on their types.



(a) (b)

Figure 4.31 Examples of bad label placement

4.9.3 Crossroad Label Placement Preference

There are two types of crossroad — a crossroad with one side, and a crossroad with two sides. For the crossroad with one side, we have prepared three possible placements for the road label as described in Figure 4.32a. The label can be placed on the right side (#1) or left side (#3) based on the situation, and if there is a need to secure more space for the label, it might be placed on top of the crossroad line (#2). Usually, we can expect that another rendition such as a crossroad or a landmark will be placed beside the crossroad, the placement position #1 and #3 are not likely the best choice for the road label. As a result, position #2 might be a reasonable placement for most cases even in if the crossroad is being placed horizontally (Figure 4.32b).

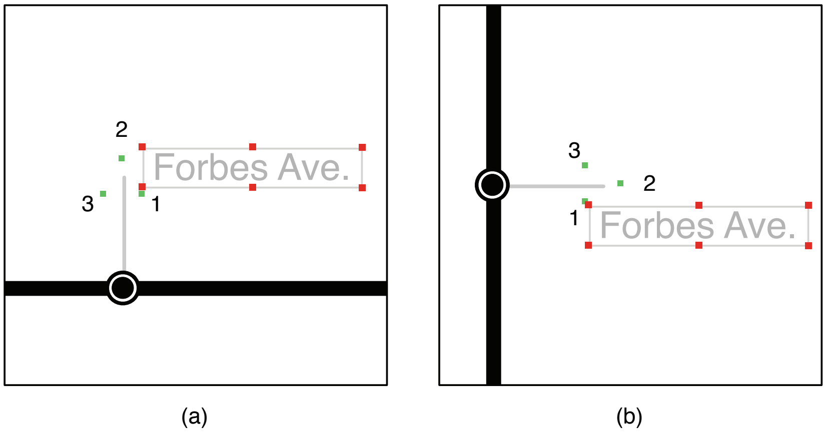


Figure 4.32 Crossroad label placement preference

When a crossroad has two sides, the possible placement positions for a label can be doubled (Figure 4.33). Similar to the crossroad with one side, label placement position #2 and #5 have an advantage over the other positions in terms of securing space for the label. However, it is not likely to be important whether to choose the up side (#2) or the down side (#5) for the label position.

The system will place the label either up or down by considering the other rendition's placement and also avoiding possible clutter and overlaps.

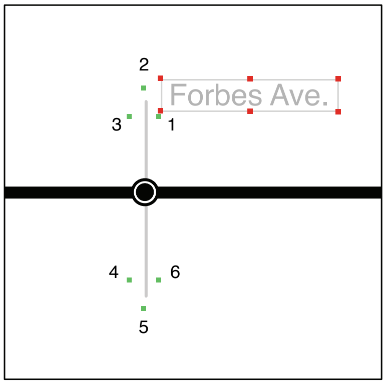


Figure 4.33 Label placements for crossroad with both sides

4.9.4 Landmark Label Placement Preference

As discussed earlier in the *Rendition Selection Optimization* chapter, a landmark can be represented as a simple dot, simple icon or detailed icon. Even though each of the three types has different size, color, and the level of detail, all of them have a rectangular boundary. To place a label around the landmark, we may consider at least 8 positions — left, right, top, bottom, left-top, left-bottom, right-top, right-bottom and so on. However, in designing the MOVE system, we would like to have the positions be as consistent as possible, since more choices would reduce optimization performance, so we reduced the number of the label placement positions to four, as Figure 4.34 depicts.

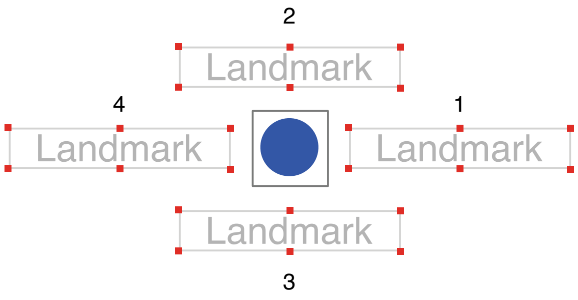


Figure 4.34 POI label placement preference

The priority of the four positions has a close relationship with the placement of landmark itself. For example, when a main road crosses horizontally, if a landmark is placed under the road (Figure 4.35a), then the label placement position #3 would have more priority order because a label in the position #2 would overlap with the main road. And in case of position #1 and #4, the label with these positions may overlap with other renditions. For the same reason, if a main road crosses vertically and a landmark is placed on the left side of the road (Figure 4.35b), the most preferable placement position of the label would be #4.

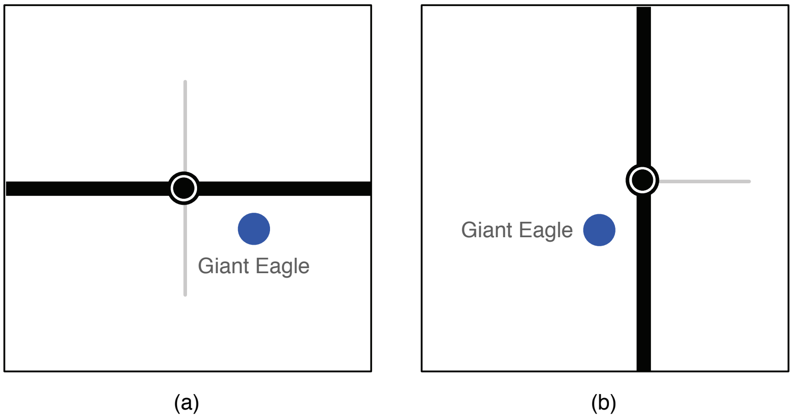


Figure 4.35 POI placement (a: below a route, b: left of a route)

4.9.5 Road Label Placement

A route is a collection of a number of roads. However, what we usually care about during driving are the current road and the next road. Our prior user study and literature review also indicated that usually information far ahead or behind the current driver's location isn't very important to a driver for navigation. Most drivers only care about information such as next intersection or next turn while maneuvering the vehicle (Lee, Forlizzi, & Hudson, 2005).

The current road contains most of the rendition presented on the display and those renditions will be cluttered at some locations. In order to avoid overlapping of the current road label and the other renditions, we need to find available space for the label. For this, we prepared six possible road label placement points as Figure 4.36 describes. During the optimization process, the system will look at those points and will choose the one of them that has enough space for labeling. After determining the label placement position, a callout line will be added to make visual connection of the current road and it's label. The callout line is thinner than crossroad line and has dot-shaped arrowhead to be distinguished from crossroad.

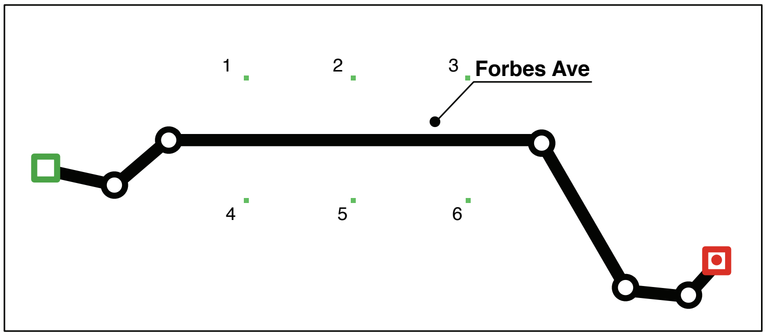


Figure 4.36 Current road's label placement choices

In the case of the ‘next road,’ we don’t usually note every crossroad or landmark. Instead, we only place a road label. However, in terms of importance on the route, the next road’s label should be much more important than the current road. Instead of placing it off from the road and connecting it with a callout line as we did for the current road, we want to place the label on the road as seen in Figure 4.37. To do this, we prepared three points for the label placement. In some situations, the label may overlap with renditions of the current road. If this happens, the system will find an alternative location for label placement among those three points.

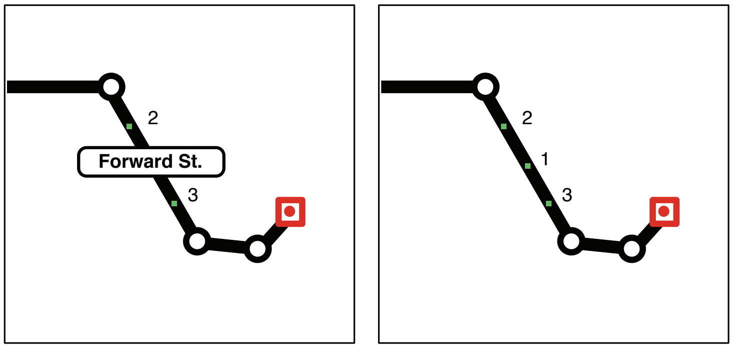


Figure 4.37 Next road's label placement choices

4.9.6 Label Anchor Point Preference

Until now, we have discussed the label placement position, which is the position where a label is placed. However, we also need a position on the label itself that will anchor it to the placement position. Without the anchor point, we will see overlap with a label; Figure 4.38 is a good example of this. Without a label anchor point, the system could only consider the label’s start point as left-bottom corner of a label. In this case, if a crossroad’s label placement choice is #1, a label will be placed without having any overlap problem (Figure 4.38a). If for some reason, the label placement choice is set to position #3, as seen in Figure 4.38b, we will see unwanted overlap of the rendition and the label. We could avoid the overlap by selecting the anchor point as the right-bottom corner of the label (Figure 4.38c).

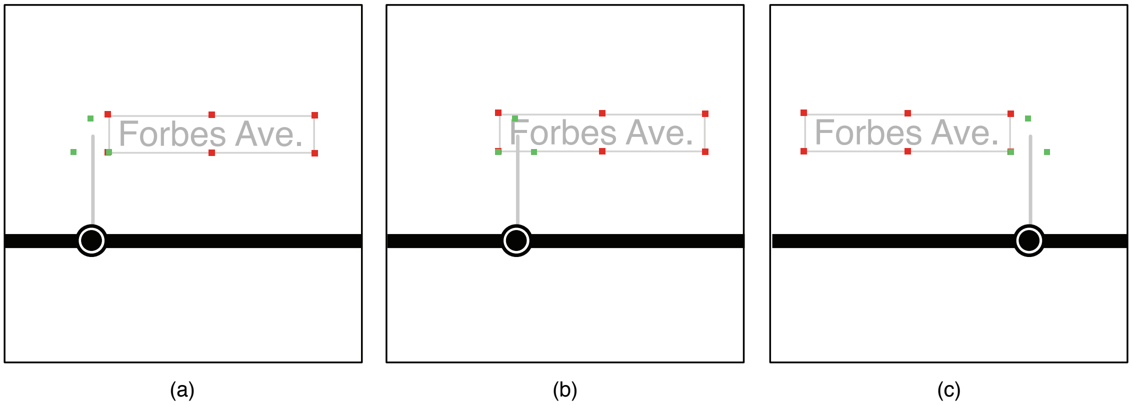


Figure 4.38 Label placement example with and without label anchor point

For this reason each label should have anchor points. In the MOVE system, we assign six anchor points to each label as Figure 4.39 shows. The selection priority of the anchor points would be determined by the label placement point choices, as we already discussed. In the previous example, if the label placement point choice is #1, which is the right side of the crossroad, then the most preferable anchor points are #1 and #4. If the label placement point choice is #2, then the system likely chooses #1, #2 and #3 for possible anchor point since #4, #5, and #6 would result in overlapping.

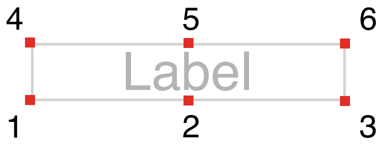


Figure 4.39 Label anchor point preference

4.9.7 Perturbation Functions

The perturbation functions change the energy level of the currently selected state by modifying the state's configuration. The following two perturbation functions are used in the *Final Placement Tuning Optimization* process.

1. Randomly modify label placement preference.

The first perturbation function is *Randomly modify label placement preference*. This function will randomly select a rendition and modify its label placement preference by increasing or decreasing its current value. For example, if a landmark is selected at random, and the landmark's current label placement choice is #2, then the new choice of the state would be #1 or #3. Increasing or decreasing the value is determined randomly. One important point in the process of modifying the value is that placement choice values wrap from #4 to #1 and vice versa as shown in Figure 4.40.

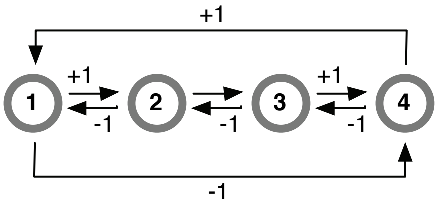


Figure 4.40 Selection wrapping for landmarks

2. Randomly modify label anchor point preference

Similar to the *Randomly modify label placement preference*, this perturbation function modifies a label's current anchor point preference to new one. It will first select a rendition randomly and modify its preference of the label anchor point by increasing or decreasing the current value by 1 wrapping as needed.

4.9.8 Evaluation functions

To evaluate the current state and move to a better state, following functions are used:

1. Minimize overlapping area

The *minimize overlapping area* function will collect every area that intersects with others and then will calculate a score with the areas that overlap each other. The green (shaded) areas in Figure 4.41 are the overlapping areas. This function penalizes the overlapping areas.

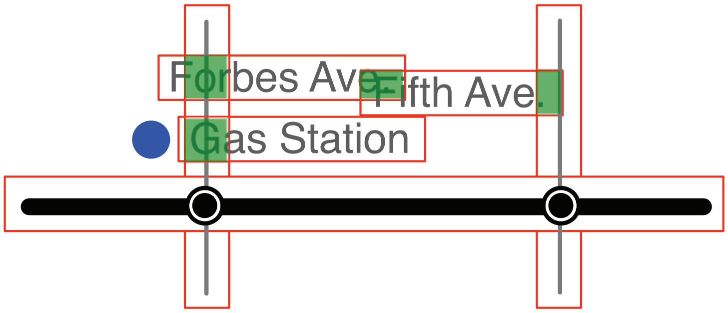
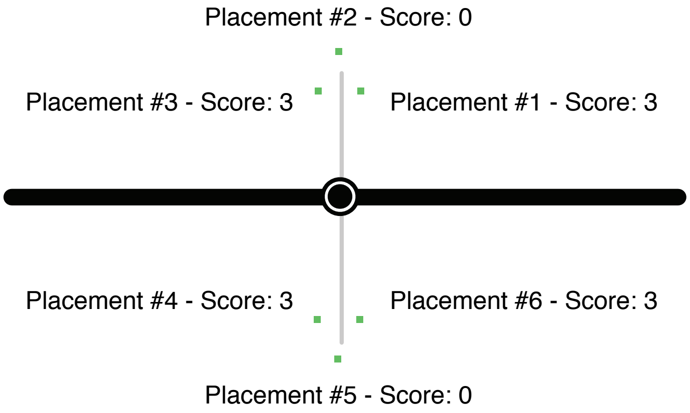


Figure 4.41 Overlapping area

2. Crossroad label placement priority

This function calculates a score based on the choice of label placement points. As discussed earlier, the placement numbers #2 and #5 are the most preferable choices since they could have more space for labeling, so we give them a 0 penalty score giving them a better chance to be selected. For the other placement points, we set 3 as the penalty score. The function adds up the score of each placement point choice, and selects to the better solution via the optimization process (Figure 4.42).



```
CASE label_placement_choice OF
        1       : penalty = 3;
        2       : penalty = 0;
        3       : penalty = 3;
        4       : penalty = 3;
        5       : penalty = 0;
        6       : penalty = 5;
ENDCASE
```

Figure 4.42 Penalty scores for crossroad label placements

3. Crossroad label anchor choice priority

The scoring of crossroad label anchor choice is different and a bit more complex than *crossroad label placement priority* because we need to think about various cases where a label may be placed. For example, if the current state's label placement choice is #1 and the label's anchor point choice is #1 or #4, we wouldn't be worried that the label overlaps the crossroad. However, if the label placement choice is #3, and the current label's anchor point choice is still #1 or #4, then we probably will observe an overlapping of the label and the crossroad. To prevent this, we give different penalty score for the label anchor choice based on the current label placement choice.

```
CASE label_placement_choice OF
     1   :
         IF     label_anchor_choice is 1 or 4 THEN penalty = 0;
         ELSE   penalty = 5;
         ENDIF
     2   :
         IF     label_anchor_choice is 2 THEN penalty = 0;
         ELSEIF label_anchor_choice is 1 or 3 THEN penalty = 3;
         ELSE   penalty = 5;
         ENDIF
     3   :
         IF     label_anchor_choice is 3 or 6 THEN penalty = 0;
         ELSE   penalty = 5;
         ENDIF
     4   :
         IF     label_anchor_choice is 3 or 6 THEN penalty = 0;
         ELSE   penalty = 5;
         ENDIF
     5   :
         IF     label_anchor_choice is 5 THEN penalty = 0;
         ELSEIF label_anchor_choice is 4 or 6 THEN penalty = 3;
         ELSE   penalty = 5;
         ENDIF
     6   :
         IF     label_anchor_choice is 1 or 4 THEN penalty = 0;
         ELSE   penalty = 5;
         ENDIF
ENDCASE
```

Figure 4.43 Penalty scores for crossroad label anchor choices

Pseudo code in Figure 4.43 depicts this scoring algorithm. If a label overlaps with the crossroad, we give it the highest penalty score (=5) for the label anchor choice, and, if it is not preferable choice even though it doesn't overlap with the crossroad, we give it a medium penalty score (=3). This is the case where the *label placement choice* is #2 or #5 but the *label anchor choice* is the left or right end point of the label, not the center point.

4. Minimize POI label placement priority

This function calculates the score of the POI label placement point choice. As discussed earlier, a POI has 4 possible label placement points. However, the score of each point may differ based on the placement of POI in the route map. For example, if a POI is placed below the route, the label placement point #2 would not be appropriate since there is not enough space for a label, so we want to penalize this choice with a high penalty score in order to lower the chance it will be selected. In contrast, #4 would be the most preferable position, so its penalty score should be much lower than #2 — we set 0 for this. The same thing happens when a POI is placed to the right or left side of a route. If a POI is placed on the right side, then #1 would be most preferable place. This scoring algorithm can be described as in Figure 4.44.

```
CASE poi_placement OF
     UP       :
         IF     label_placement_choice is 1 THEN penalty = 3;
         ELSEIF label_placement_choice is 2 THEN penalty = 0;
         ELSEIF label_placement_choice is 3 THEN penalty = 3;
         ELSEIF label_placement_choice is 4 THEN penalty = 5;
         ENDIF
     DOWN     :
         IF     label_placement_choice is 1 THEN penalty = 3;
         ELSEIF label_placement_choice is 2 THEN penalty = 5;
         ELSEIF label_placement_choice is 3 THEN penalty = 3;
         ELSEIF label_placement_choice is 4 THEN penalty = 0;
         ENDIF
     LEFT     :
         IF     label_placement_choice is 1 THEN penalty = 5;
         ELSEIF label_placement_choice is 2 THEN penalty = 3;
         ELSEIF label_placement_choice is 3 THEN penalty = 0;
         ELSEIF label_placement_choice is 4 THEN penalty = 3;
         ENDIF
     RIGHT    :
         IF     label_placement_choice is 1 THEN penalty = 0;
         ELSEIF label_placement_choice is 2 THEN penalty = 3;
         ELSEIF label_placement_choice is 3 THEN penalty = 5;
         ELSEIF label_placement_choice is 4 THEN penalty = 3;
         ENDIF
ENDCASE
```

Figure 4.44 Penalty scores for POI label placements

5. Minimize POI label anchor point priority

As described in Figure 4.39, a POI label has six anchor points, similar to *Crossroad Label Anchor Point Priority*. Their penalty score will be different based on the label placement choice of a POI. Figure 4.45 is pseudo code used to calculate penalty score.

```
CASE label_placement_choice OF
     1   :
         IF     label_anchor_choice is 1 or 4 THEN penalty = 0;
         ELSE   penalty = 5;
         ENDIF
     2   :
         IF     label_anchor_choice is 2 THEN penalty = 0;
         ELSEIF label_anchor_choice is 1 or 3 THEN penalty = 3;
         ELSE   penalty = 5;
         ENDIF
     3   :
         IF     label_anchor_choice is 3 or 6 THEN penalty = 0;
         ELSE   penalty = 5;
         ENDIF
     4   :
         IF     label_anchor_choice is 5 THEN penalty = 0;
         ELSEIF label_anchor_choice is 4 or 6 THEN penalty = 3;
         ELSE   penalty = 5;
         ENDIF
ENDCASE
```

Figure 4.45 Penalty scores for POI anchor point choices

5_EVALUATING THE MOVE DISPLAY

The final step of this research is to understand how an optimized map can reduce the driver's attention to a navigation display when it is compared to a non-optimized information display (e.g., current in-vehicle navigation systems, or paper maps) or other forms of information such as turn-by-turn directions.

In our previous experiments, we have shown that optimized information can dramatically decrease the subject's attention by reducing fixation time and number of glances per task when searching for information on the display. At the same time, subjects were able to increase the performance of the primary driving task (Lee, Forlizzi, & Hudson, 2008). One limitation of these studies is that they were conducted in a lab with a simulated driving context. As a result, we have yet to understand how optimized navigation information will affect the driver's attention and navigation in an actual driving context, so in our final evaluation study, we wanted to investigate the effectiveness of our perceptually optimized display in a more realistic driving context.

5.1 Study Overview

This experiment was performed in the context of a moving vehicle traversing a real route. The experimenter's vehicle was used for the study, and the subjects helped a driver by providing navigational information. Similar to our earlier study, this study also used a dual task attention saturating framework, where subjects were performing a primary task demanding high levels of attention while performing a secondary task at the same time (Wickens & Hollands, 2000). For this, the study made use of two displays in a vehicle setting. The first one, in front of a subject, is a simulated driving game task display; the other one is the dynamic navigation display.

During the study, the subjects were seated beside the driver and were asked to play the driving game during the session, while the experimenter was driving. The driving game is a simple tracking task that saturates the subject's attention. Meanwhile, subjects were also asked to read navigational information from the route display and the road, and tell the driver directions to navigate the route. A second experimenter in the back seat recorded any mistakes in the directions made by the subjects. The subjects navigated three different routes within the Pittsburgh area.

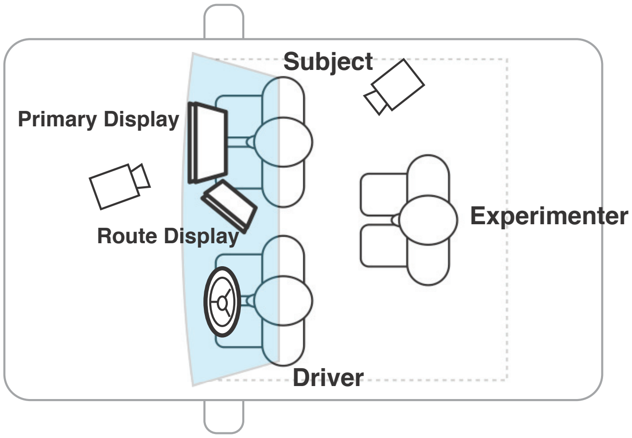


Figure 5.1 Experiment layout in a vehicle

5.2 Study process

To start, each subject practiced the primary task without the navigation display. Their baseline performance was then measured.

The main experiment consisted of three sessions. During the each session, participants were given a route map display to navigate and a driving game. Once the session started, the driver moved the vehicle forward, following the route. As each crossroad approached, subjects gave directions to the driver with a simple sentence such as "go straight," "turn right," or "turn left." If directions were given incorrectly, the driver followed the correct route anyway, and the second experimenter marked it as an error. Sessions were videotaped for *post hoc* analysis.

5.2.1 Primary task

Subjects performed a simple driving game as a primary attention saturating task (Figure 5.2). In this game, they used Nintendo's Wiimote controller in a simple steering wheel enclosure to move the vehicle icon on the screen to left or right. Meanwhile, the road on the screen scrolled down from the top of the screen, giving the appearance that the vehicle is moving forward. The road contained a dashed center line and number of coins (small blue dots) as shown in Figure 5.2. Subjects were asked to follow the center line of the road and collect as many coins as possible while playing this game. The number of collected coins was counted to measure the subject's performance of the primary task. Along with the number of coins, we also calculated the distance of the vehicle from the center of the road. This data was also used as our performance measure.

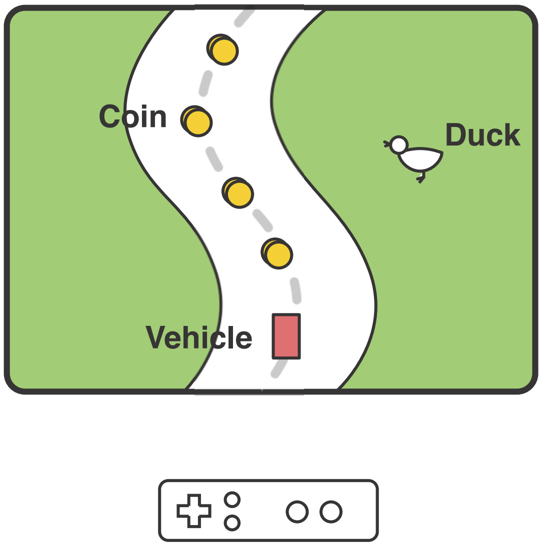
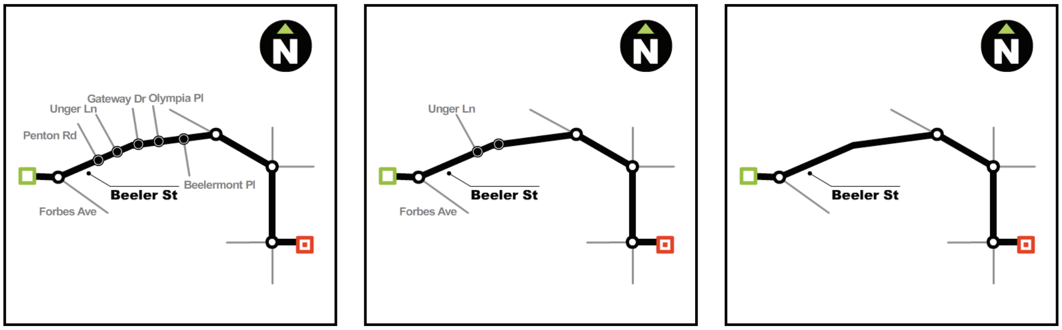


Figure 5.2 Primary task overview

5.2.2 Navigational displays

During the main study, each participant was provided with three different route maps. One was a full-context map that shows very detailed navigation information, including every crossroad and intersection and their labels (Figure 5.3a). One was a selected-context map that only presents selected map information relative to the driver's current context (Figure 5.3b). Finally, the last one is a no context-map that only provides next turn information analogous to turn-by-turn directions, as provided by many internet-based map sites (Figure 5.3c).



(a) (b) (c)

Figure 5.3 Maps used in the study (a: full context, b: selected context, c: no context)

Based on results from a pilot study, we manipulated the map stimuli slightly removing vehicle's location cursor, and making the next road information available just two crossroads before the turn. First, if we use a vehicle's location cursor on the map, the participants wouldn't look outside to find a road sign information — instead, they just looked at the display and tried to find the cursor to position the vehicle's current location on the road. Second, when we displayed the next turn information from the beginning, the subjects tended to retrieve the next turn information at the beginning of the route segment, and never look at the display to find information, instead just looking outside to find the road name for the next turn. Since the purpose of this study is to measure perceptual load in finding navigational information in a driving context, we couldn't get enough data without these manipulations.

5.2.3 Measurements

The measurements used for data analysis are as follows: first, we measured the performance of the main task (driving game). Second, we measured subject's perceptual load when performing the secondary task (finding information from navigation display and the road). Here we used number of glances and total fixation time as we used in our earlier study. Last, we measured error rate in the navigation task.

5.2.3.1 *Performance Measures*

The two performance measures were the number of coins collected and the distance from the center of the road. The number of coins collected was displayed on the game screen, allowing subjects to see their performance. It also helped to make them focus on the primary task. While motivating the subjects to keep collecting coins on the center of the road, we did not convey distance from the center of the road. With these measures, we calculated *average distance off from the road* and *average collected coin rate*.

```
average_off_from_road = SUM(off_from_road)/count
average_collected_coin_rate = collected_coins/total_displayed_coins
```

5.2.3.2 *Driver's perceptual measures for secondary task*

To measure driver's perceptual load for the secondary task, we installed a video camera in the dashboard to record the eye movement of the participants. To analyze the video taken during the study we extracted the number of glances and total fixation time. These measures are collected both for the navigational display and outside the vehicle to find contextual information. The measures were then sub-categorized as follows:

```
a: Number of glances to navigational display for each route
b: Number of glances to outside for each route
c: Total number of glances for each route (= a + b)
d: Total fixation time on navigational display for each route
e: Average fixation time (Fixation time per glance) to navigational dis-
   play (= d / a)
f: Total fixation time to outside for each route for each route
```

g: Average fixation time (Fixation time per glance) to outside (= f / b)

h: Total fixation time for each route (= d + f)

i: Average fixation time (Fixation time per glance) (= h / c)

j: Number of glances to navigational display per crossroad (= a / NUM_OF_CROSSROAD)

k: Number of glances to outside per crossroad (= b / NUM_OF_CROSSROAD)

l: Total number of glances per crossroad (= c / NUM_OF_CROSSROAD)

m: Total fixation time to navigational display per crossroad (= d / NUM_OF_CROSSROAD)

n: Total fixation time to outside per crossroad (= f / NUM_OF_CROSSROAD)

o: Total fixation time to navigational display per crossroad (= h / NUM_OF_CROSSROAD)

5.2.3.3 Error rate

Error rate was recorded as crossroad-based, when the subjects gave wrong directions. Error rate for each route can be calculated as follows:

```
error_rate = NUM_OF_ERRORS / NUM_OF_CROSSROAD
```

5.3 Results and discussion

Eighteen subjects from the university community, aged 19-54, 9 male and 9 female, completed the study. For data analysis, we first compared the number of glances (a, b, c) of each route type. Table 5.1 shows the mean of each route map style.

As the comparison table shows, we have slightly better results (low number of glances) with the selected-context map but the result is not statistically significant. The comparison of the number of glances per crossroad also shows similar result (Table 5.2). Although the selected context map shows better result, the ANOVA test result didn’t show the mean comparison as statically significant.

	Full Context	Selected Context	No Context	
NavDisplay (a)	75.83 (*SD* = 16.06)	69.72 (*SD* = 15.75)	77.67 (*SD* = 21.83)	F(2, 51) = 0.95, *p* = 0.39
Outside (b)	82.11 (*SD* = 19.07)	69.61 (*SD* = 17.41)	81.83 (*SD* = 24.50)	F(2, 15) = 2.17, *p* = 0.12
Total (c)	157.94 (*SD* = 29.10)	139.33 (*SD* = 29.45)	159.50 (*SD* = 35.49)	F(2, 51) = 2.29, *p* = 0.11

Table 5.1 Number of glances (mean, ms)

	Full Context	Selected Context	No Context	
NavDisplay (j)	3.53 (SD = 0.96)	3.17 (SD = 0.50)	3.53 (SD = 0.77)	F(2, 51) = 1.32, p = 0.28
Outside (k)	3.78 (SD = 0.87)	3.17 (SD = 0.65)	3.75 (SD = 1.12)	F(2, 51) = 2.61, p = 0.08
Total (l)	7.30 (SD = 1.61)	6.34 (SD = 0.92)	7.28 (SD = 1.33)	F(2, 51) = 3.13. p = 0.05

Table 5.2 Number of glances per crossroad (mean, ms)

However, when we compare the fixation time of each route style, we found that the route map with selected context shows much better results and they are all statically significant (Table 5.3).

As Table 5.3 shows, subject's fixation time to the navigational display with the selected context map was decreased by nearly half when comparing it to the full-context map. The fixation time is also decreased even when watching outside, checking road sign for navigation. Overall, the fixation time of the no-context map is shorter than the full-context map, but if we just compare the cases when the participants look outside, the difference between no-context map and full-context map becomes nominal. This could be because the subjects had ambiguity with the no-context map during the navigation since they didn't know where they are in the route, and hoped to derive that information from the display. A post-survey response from one of the subjects in this study clarified this issue. She said she didn't like the no-context map because it made her pay attention to every intersection until she got to the street where she needed to make a turn. So, contrary to the our initial assumption that subjects will spend less time watching navigation display and outside with a no-context map, they actually spent more time with this display, although the difference was nominal.

	Full Context	**Selected Context**	**No Context**	
NavDisplay (e)	980.24 (*SD* = 144.75)	478.97 (*SD* = 73.22)	773.74 (*SD* = 242.52)	F(2, 51) = 40.26, $p < 0.01$
Outside (g)	956.87 (*SD* = 219.10)	555.54 (*SD* = 101.24)	902.07 (*SD* = 225.66)	F(2, 51) = 23.42, $p < 0.01$
Total (i)	965.76 (*SD* = 149.49)	515.55 (*SD* = 71.23)	830.71 (*SD* = 146.13)	F(2, 51) = 59.10, $p < 0.01$

Table 5.3 Average fixation time per glance

	Full Context	**Selected Context**	**No Context**	
NavDisplay (m)	3391.67 (*SD* = 796.56)	1512.61 (*SD* = 331.45)	2661.38 (*SD* = 737.22)	F(2, 51) = 37.62, $p < 0.01$
Outside (n)	3566.36 (*SD* = 907.60)	1727.75 (*SD* = 336.00)	3306.62 (*SD* = 999.37)	F(2, 51) = 27.63, $p < 0.01$
Total (o)	6958.02 (*SD* = 1297.54)	3240.35 (*SD* = 501.69)	5967.99 (*SD* = 1136.95)	F(2, 51) = 62.01, $p < 0.01$

Table 5.4 Total fixation time per crossroad

This result indicated that even though the number of glances to the display or outside didn't significantly change depending on the route map visualization style, the time spent reading information on the display could vary depending on the style. Among our three stimuli, time was considerably decreased with the selected-context map display.

We used an additional data analysis to verify this. We compared the mean total fixation time per crossroad to the navigational display or outside. Table 5.4

shows the statistically significant results. As the results clearly show, selected-context map decreased the fixation time by nearly half in every measure.

Next, we compared the error rate of the route styles. The analysis shows very interesting results. As Table 5.5 depicts, no context map shows the worst error rate and the selected context map shows the lowest error rate. This explains that the selected map increases navigational performance as well as decreases perceptual loads. As we expected, the participants had more errors with no context map. It is an understandable result since the no-context map doesn't provide enough route data. In case of the full context map, since it draws more attention than others, the participants may have problem in reading the map and matching it to the real world.

	Full Context	**Selected Context**	**No Context**	
Error rate	0.045 (*SD* = 0.038)	0.013 (*SD* = 0.028)	0.072 (*SD* = 0.064)	F(2, 51) = 7.59, $p < 0.01$

Table 5.5 Error rate for navigation task

However, we didn't find any significant difference in the first task performance measures (Table 5.6). Even though we could see slightly better results with the selected-context map in the *"distance off from the road"* measure, it is not statically significant. In case of *"number of collected coins"* measure, we didn't really see any difference between the route styles.

	Full Context	**Selected Context**	**No Context**	
Distance off from road	29.65 (*SD* = 18.85)	22.67 (*SD* = 11.24)	26.12 (*SD* = 14.87)	F(2, 51) = 0.94, $p = 0.40$
No. of collected coins	0.68 (*SD* = 0.16)	0.67 (*SD* = 0.16)	0.69 (*SD* = 0.16)	F(2, 51) = 0.08, $p = 0.93$

Table 5.6 Performance of the driving game task by route map style

When we compare the performance measures by session number, we could see clear performance gains with *"distance off road"* measure in sessions 2 and 3 as Table 5.7 depicted. This could be evidence that there was a learning effect on the primary task. However, we could see a similar pattern with the *"number of collected coins"* measure, but the results are not statistically significant. Interestingly in both measures, sessions 2 and 3 shows almost identical results, so we could see the subjects needed time to get accustomed to the primary task during the session 1. However, the order of route style was counter balanced, so the other result wouldn't be affected by the learning effect caused in session 1.

	Session 1	**Session 2**	**Session 3**	
Distance off from road	35.21 (*SD* = 15.27)	21.76 (*SD* = 13.37)	21.47 (*SD* = 13.63)	F(2, 51) = 5.57, $p < 0.01$
No. of collected coins	0.61 (*SD* = 0.14)	0.71 (*SD* = 0.16)	0.71 (*SD* = 0.16)	F(2, 51) = 2.37, $p = 0.10$

Table 5.7 Performance of the driving game task by session number

6 _ CONCLUSION

6.1 Summary of work

In this dissertation, we explored the domain of situationally appropriate interaction. Within this problem area, we chose to focus on perceptually optimized displays. Most current user interfaces do not carefully consider particular "situations" or contexts of use, thus providing information to the user with the same demands of attention no matter what the user's attentional state is. This can result in serious breakdowns in communication between the user and the system, and is witnessed very often in our daily lives.

The driving context is a good example of a need for situationally appropriate interaction. Many people are now using navigation systems in their vehicles. However, displays created by location-based software, such as GPS mapping applications, are often not straightforward when used in the context of driving. Information is crowded and overloaded on the display. Critical information is designed and presented in a way that slows down the rate of uptake, interfering with the process of learning and remembering the route, encoding the information in memory, and making decisions at critical points.

In response to this, we designed and developed the MOVE system, a perceptually optimized map display. This system presents optimized geographic information, and works on the principle that different information has different importance within a given situation, and the driver's attention should be used on the more important information.

This research set out to examine how visualizing complex mapping information might be useful, by displaying optimized information to the user. We theorized that the information the user sees will change based on the user's prior familiarity with a route; whether the user prefers navigating by using landmarks, route information, a highly schematized survey information or current position and proximity to critical points. To accomplish this goal, the following research activities were undertaken:

1. Ethnographic research and a literature review of behavioral theory were performed to model the overall mechanism of the system.

At the beginning of this research, a study on navigation was conducted to achieve general understanding about how people read, draw and use maps for navigation (Lee, Forlizzi, & Hudson, 2008). In this study, participants generated route maps from given resources and then navigated the route using the map they generated. The study results indicated that people use landmarks, nodes, and paths as the primary form of representation, and divide the route into several chunks and setup sub-goals for navigation. Also, abstracted forms of a route were usually preferred over versions with full visual detail.

2. Iterative design and evaluation were used to develop the system.

We derived design principles from the analysis of the literature review and ethnographic study. These principles were used to design and prototype a system. Design and evaluation were iteratively performed until a desirable prototype solution was achieved.

The used important design principles that we learned from the preliminary studies were *abstraction* and *dynamic information interaction*. As our previous work and our preliminary studies on navigation indicated, an abstracted form of navigational information can reduce the driver's perceptual load.

In order to achieve *abstraction*, the first principle, we defined the five map generalization principles, which include: *feature selection*, *simplification/smoothing*, *relative scaling*, *displacement*, and *enhancement* (Lee, Forlizzi, & Hudson, 2005). They were derived from the long history of cartography principles, and also from the visualization literature.

The second overarching design principle is *dynamic information interaction*. Considerable work on dynamic information visualization has explored how to present detailed information within a limited screen display without losing its entire context (Bier, Stone, Pier, Buxton, & DeRose, 1993; Furnas, 1986). To present dynamic navigation information, MOVE reserves the most detail for the road segment that the driver is currently passing over, relative to the user's goal within the route. Four different presentation methods have been developed as potential candidates for the MOVE system: *Zoom in Context*, *Route Scrolling*, *Zoom in Context + Route Scrolling*, and *Zoom in Context + Overview* (Lee, Forlizzi, & Hudson, 2005).

After designing an initial prototype of the MOVE system, we performed a set of user studies. The first study we conducted was a visual search study. The purpose of this study was to obtain a detailed understanding of the perceptual effects of the renditions we had devised in our initial sketches. In this study, we investigated how particular renditions affect visual search, both when they are the targets of the search (providing positive communicative benefit), and when they serve as distraction from the target (inducing a negative effect). As a result of this study, we found that semantic renditions show better search results than symbolic renditions. The result of this study was later used to create a scoring for rendition selection.

The second study we conducted was an evaluation of design prototypes. The purpose of this study was to evaluate the relative merits of our design alternatives and to compare their effectiveness with that of high quality current practices, and to determine whether our prototype design might satisfy previously developed safety guidelines (Green, Levison, Paelke, & Serafin, 1993).

This study used a dual task attention-saturating framework where participants performed a primary task demanding high levels of attention (using a desktop application reminiscent of driving) while performing a secondary task (interacting with the navigation display) whose effects on the first task could be measured. LineDrive (an existing abstract display) was used for a baseline comparison, and the four presentation methods mentioned above were included (Agrawala & Stolte, 2001).

We measured the total number of glances, total fixation time and the average distance off the road in the desktop driving task. Overall, the MOVE system showed great improvement over LineDrive (Lee, Forlizzi, & Hudson, 2005). The total number of glances was decreased three times, total fixation time was decreased six times, and *average distance off the road* decreased five times.

3. Implementing a situationally appropriate, perceptually optimized system.

The implementation of the system was based on the five map generalization principles and our design principles of abstract, dynamic information presentation.

There are four steps in the implementation process. First, the Road Layout Optimization process works on the principles of *Simplification/Smoothing* and *Relative Scaling*. It generates the entire route as simply as possible, while making the important portions of the route segment salient. A numerical optimization process is used to maximize the length of important portions within the effective screen boundary while minimizing less important portions. Second, the Rendition Selection Optimization process works on the principle of *Map Feature Selection*, presenting map features selectively to decrease the driver's attention to the display by reducing the overall amount of information presented. Third, the Rendition Scoring process determines how to assign scores to potential renditions, and a numerical optimization process selects the renditions which maximize the score of the overall display — maximizing the communicative ability of important information while reducing distraction from less important elements. Last, the Final Placement Tuning process uses an intervention technique to prevent possible conflicts and clutter within the selected renditions when presented on the display. This works on the principle of *Displacement*.

4. Evaluation of the perceptually optimized display.

As a final step of this research, a study to evaluate the effectiveness of the perceptually optimized display was conducted. In this study, we wanted to clarify if an optimized route map display can reduce driver's attentional cost when retrieving navigational information from the display while driving.

The study was conducted in real driving context with a dual task attention-saturating framework; participants performed a primary task demanding high levels of attention while performing a secondary task at the same time (Wickens & Hollands, 2000). The primary task was a simple driving game, and secondary task was to navigate three routes using at three different route map displays. For safety reasons, instead of driving a vehicle by themselves, the participants gave directions to the driver, one of our experimenters.

The result of this study supported our theory that optimized displays can decrease attentional cost when retrieving information from the display. For analysis, we compared number of glances and fixation time to the display and to the outside searching for road signs and their context information. We found that the number of glances did not change significantly, but the fixation time of the perceptually optimized display has decreased greatly in every measure.

6.2 Contributions

The main contribution of this work is a demonstration of a new method for designing and implementing situationally appropriate user interaction. First, this work presents a way to construct generalizable measures for visual renditions to be used to select optimized renditions for certain conditions. Second, this work presents algorithms to build an automatic design system that considers user's perceptual load.

To accomplish these goals, the work presented in this thesis has successfully embodied interdisciplinary research methods from design, cognitive psychology and computer science, demonstrating how those three different approaches can be successfully used together in an HCI project.

In Chapter 3, we first present results from the ethnographic research method. From the results, we derived principles of the design of route map display. The principles were later used to design the system. Then we demonstrate how we combined design method and psychology methods. First, we created a principle for designing a route map display and applied it to creating prototypes. Second, a visual search study was followed by a presentation to measure visual element's attentional cost and benefit. Usually designers estimate these values through their insight and design experience, but the method presented in this study is generalizable and applicable to many other design projects. Third, the evaluation study demonstrated a way to compare design alternatives. For this, we designed a dual task study by modifying Wickens' dual task framework (Wickens & Hollands, 2000). Two measurements — number of glances and fixation time — that were devised for the comparison could be used for measuring the design evaluation where user's attention is the main concern. Through this study, we also show that a perceptually optimized display can decrease user's attention by three to six times.

In Chapter 4, we demonstrate algorithms that build a perceptually optimized display. The first contribution in this chapter is a demonstration of using our design principles in the implementation of the system. For this, we discussed the human designer's design process and presented a way to simulate the process for automatic design layout. This will be beneficial to both the design and computer science communities in many ways: For the design community, it will be more clear how to generalize the design process to be used in the automatic system design. For the computer science community, this work demonstrates how to use design activities in building human-centered system.

We also demonstrate how to build a scoring table for rendition selection process using the result of our visual search study. The specific scoring table created in this process may not be applicable to other domains; however the methodology used in this work to gather human-centric data and to build an algorithm for computation could be generalizable and applicable to other domains.

In Chapter 5, we presented a new evaluation study method for an in-vehicle user interfaces. Generally, various types of driving simulators are used to evaluate a user interface for vehicle, but they don't usually provide the rich context of a real driving experience. In our experiment, we demonstrate a way to conduct an evaluation study in a real driving context while minimizing possible danger. This method can be applied to the evaluation of various in-vehicle user interface projects.

6.3 Future Work

Moving forward, we are interested in extending the work on designing situationally appropriate user interfaces to the ubiquitous computing environment. As pervasive computing will be more popular in the near future, users will be exposed to more informational displays in diverse situations. Also, more advanced sensor technology will enable us to gather more information about users and their situations. From the interaction designer's perspective, the central issues will no longer be retrieving, generating, and delivering information. Instead, the emergence of increasing needs for understanding the user's situation and the costs and limitations facing the user in making use of that information will be important issues.

Since it is not possible to consider every situation that users may encounter in a pervasive computing environment, it is not likely that a designer can create a single user interface that suits every situation. Instead, by using the designer's experience and process, we can automatically generate a user interface that is appropriate to the user's certain situation. The work presented in this thesis is an example of how technology can be used to imitate the design process and create a situationally appropriate display through its iterative optimization process.

From my personal experience as an industrial and interaction designer, I understand that every design process involves an optimization process. When designing, designers have to deal with lots of variables and constraints. For example, when a designer lays out a page, he or she considers the target reader of the page, the place where the page is being presented, colors, themes, typeface styles, and so on. Even though an experienced designer would have built up his/her own design rules and disciplines through the design practice, there are always conflicts caused by constraints. When this happens, an experienced designer assesses conflicts by weighing the problem, and considering the priority of the condition through an iterative design process. During this process, several design alternatives are created, and then finally one of the alternatives is selected for the most optimized design for the situation. As we discussed earlier in this thesis, the process is very similar to a numerical optimization process, which is an iterative method to find the best solution for multiple conditions. As the work presented in this thesis shows, a numerical optimization process can be used to create a user interface design automatically when a human designer cannot be involved.

In conclusion, we believe if we carefully work on generalizing the designer's design process, then we can apply the resulting theory to 'situationally appropriate user interfaces.' Our future research will focus on this theory, and we hope to develop a system that generates adaptive user interaction while taking into consideration the user's attentional states, preferences and other variables.

7_ APPENDIX:
DESIGN GUIDELINES AND RECOMMENDATIONS

7.1 Introduction

The purpose of this appendix is to provide design guidelines for navigational interfaces to be used by drivers. This is not a list of strict design requirements to be followed during the design process. Instead, these guidelines try to provide recommendations to those designing navigational information displays. These guidelines are based on research from the disciplines of human factors, cognitive science, human-computer interaction, and information design. By providing the major findings from related areas, we expect designers can build their own consistent rules when designing future systems.

Our guidelines focus specifically on visual information. While many modern navigation devices are equipped with auditory information, and some research has shown that auditory information can help reducing perceptual load of visual displays (Walker, Alicandri, Sedney, & Roberts, 1991; Burnett, 2000; Liu, 2001; Gröhn, Lokki, & Takala, 2005), auditory information is out of scope of our present research. Also, this appendix does not consider conventional vehicle controls and instrument panels such as the speedometer, tachometer, fuel gauge, turn signal, audio device buttons, and so on.

This work is presented in two sections: design principles and design recommendations. In the design principles section, high-level principles are presented to give an overall of goals for designing navigational information displays. In the design recommendations section, we described more detailed rules that need to be considered to achieve the goals described in the previous section. The recommendations were generated by considering the treatment of visual elements and their properties such as typeface, size, and color.

7.2 Design Principles

Design principles presented in this section provide high-level goals to increase usability of systems and to decrease search time for specific information.

7.2.1 Predictability

Guideline: Systems should be designed with predictable alerts and warnings so that drivers can construct a mental model of how the system behaves.

Predictability supports the user by determining the effect of future action based on past interaction history (Dix, Finlay, Abowd, & Beale, 2003). For example, many current in-vehicle navigation systems provide auditory or visual feedback to the driver a few miles before the next turn, so that the driver can have enough time to prepare. Once the driver has been exposed to the system, the feedback is predictable, because the driver can predict what will happen in the future.

7.2.2 Familiarity

Guideline: Utilize appropriate affordances to enhance the driver's perception of the system. For example, use familiar road symbols as featured in the national highway system to make the system more understandable.

Familiarity extends and applies the user's knowledge and experience in other real-world situations to the interactions with a new system. Familiarity has to do with a user's first impression of the system. In this case, we are interested in how the system is first perceived and whether the user can determine how to initiate any interaction (Dix, Finlay, Abowd, & Beale, 2003).

Familiarity often accompanies what psychologists call affordances (Gibson, 1979). This concept states that the shape and other attributes of things suggest how they can be manipulated. The appearance of the object stimulates a familiarity with its behavior (Dix, Finlay, Abowd, & Beale, 2003). In his book, *"The Psychology of Everyday Things (1998),"* Donald A. Norman described affordances as follows: (Norman, 1988)

> *You are approaching a door through which you eventually want to pass. The door, and the manner in which it is secured to the wall, permits opening by pushing it from its 'closed' position. We say that the door affords (or allows, or is for) opening by pushing. On approaching that door you observe a flat plate fixed to it at waist height on the 'non-hinge' side, and possibly some sticky finger marks on its otherwise polished surface. You deduce that the door is meant to be pushed open: you therefore push on the plate, whereupon the door opens and you pass through. Here, there is a perceived affordance, triggered by the sight of the plate and the finger marks, that is identical with the actual affordance. Note that the*

affordance we discuss is neither the door nor the plate: it is a property of the door (the door affords opening by pushing).

7.2.3 Consistency

One of the most important and commonly cited principles in designing interactive systems is consistency, when behavior is similarly defined for similar situations or similar task objectives (Dix, Finlay, Abowd, & Beale, 2003). Alvin Eisenman taught that "similar information should be presented in a similar form;" likewise Hugh Dubberly suggests "similar tasks should be accomplished in similar ways." (Dubberly, 2008)

The advantage of the consistently designed information system is that a user of the system can significantly reduce perceptual load when using the system. For example, if a navigation system uses a consistent location and style to show next turn information, the driver can save time searching for that same kind of information in the future. However, consistency can be difficult as it can take many forms. It is not just a single and fixed form of a property. Instead, consistency can be applied relative to something (Dix, Finlay, Abowd, & Beale, 2003). This concept will be discussed in the following section.

The consistency rules for designing an in-vehicle navigation system can be categorized as follows:

7.2.3.1 Location Consistency

Guideline: Visual features presented on a display should have consistent location rules. Alternative location rules should be provided in the event of a conflict.

The first rule is location consistency. It conveys that all information displayed on the screen should be placed using consistent rules. For example, a compass symbol should be always located on the top-right corner of the screen (Figure 7.1). Or, a road name label should be always placed beneath the rendition of the road. If the first location choice is not possible due to screen clutter or some other reason, then the compass symbol can be moved to the top-left corner of the screen and the road label can be placed over the road as an alternative. As these examples describe, the location consistency does not just enforce a single and fixed location of an element. Instead, it should carefully define any possible alternatives for the location just in case the first choice is not available. By doing this, the driver can reduce searching time for particular elements.

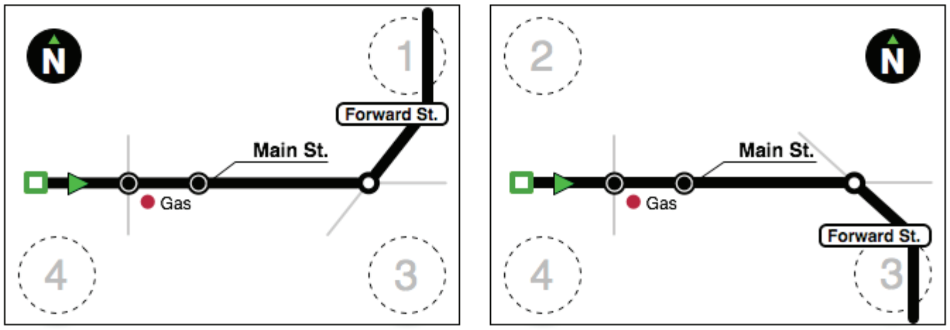


Figure 7.1 The preferred location and alternative location of the compass symbol

However, there are elements that always demand the same location consistency. Labels, such as speed of the vehicle, remaining time and distance to the destination, or heading direction (e.g., north, south, or north-east) of the vehicle should be placed in pre-assigned locations on the screen. In addition, the buttons for the destination input and the error message box should also have a fixed location.

7.2.3.2 Element Consistency

Guideline: Consistent properties should be maintained over the design of an entire system.

The second rule is element consistency. Every element on the screen has its own properties — size, color, typeface, weight or style. These properties make it easy to distinguish one element from another.

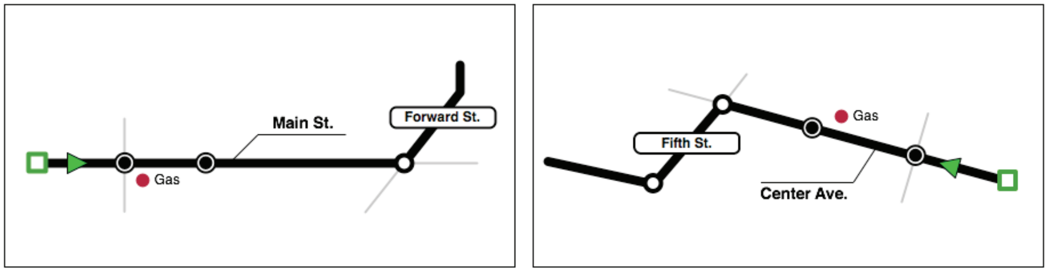


Figure 7.2 Element consistency. Drivers can stylistically differentiate the current road and the next road

Figure 7.2 is an example of this element consistency. In this example, the current road labels (e.g., Main St. and Center Ave.) are consistently rendered using the same typeface, the same font size and the same color. They are precisely distinguished from the next road labels (e.g., Forward St. and Fifth St.). Thus, consistency not only will enhance the driver's learnability, but also reduce the driver's attention to the display — the driver will easily notice the type of information with only minimal glances. Element consistency means that the same kind of information should be designed using the same properties.

Table 7.1 shows a list of elements and properties that should be used in an in-vehicle navigation system:

	Size	Weight	Color	Style	Pattern	Typeface
Line		+	+	+	+	
Shape	+	+	+	+	+	
Symbol	+		+			
Text	+	+	+	+		+
Number	+	+	+	+		+

Table 7.1 Types of visual elements and their properties

7.2.3.3 Terminology Consistency

Guideline: Messages, abbreviations, and other text outputs should be displayed using consistent rules.

The third rule is terminology consistency. The messages that are induced by the system should have consistent form and terminology so that a user can quickly interpret their meaning. For example, "Oops, you should have turned left at the previous street" or at other times, "Error, missed left turn for previous street" would be inconsistent (Green, Levison, Paelke, & Serafin, 1993).

In navigation systems, text is often abbreviated to save space. These abbreviations should take a consistent form. For example, for the road label "North Craig Street," "N Craig St." in one place and "N. Craig Str." in another place is inconsistent. Similar to this, "H" in one place and "hlp" in the other place for "help" would also be inconsistent.

Finally, units also need to be consistent. Mixed use of "km" and "miles" would confuse the driver. Even in the same unit system, for example metric, using "m" in one place and "km" in another place would be inconsistent.

7.2.3.4 Timing Consistency

Guideline: Notifications should be delivered at consistent intervals.

When the system delivers auditory or visual notifications to the user, the notifications should be presented at consistent intervals. For example, when a vehicle is approaching a turn, if the system sometimes gives notification of the turn 2 miles before the turn at one time, and 0.5 miles before the turn at another time, the notifications are not being delivered consistently.

7.2.3.5 Affordability

Guideline: Only an appropriate amount of information should be presented to reduce driver's attention demand when looking at the display.

The context of driving requires lots of attention. In such situations, an in-vehicle navigation system should exist to support the user's primary task rather than interrupting it. In his *Eight Golden Rules of Interface Design*, Ben Shneiderman suggested that the system should reduce user's short-term memory load by keeping displays simple and consolidating multiple page displays (Shneiderman, 1998).

Human short-term memory isn't a vast resource. Therefore, a navigation system should only deliver information that can be processed within this resource. In the driving context, most of the driver's cognitive resources are allocated to the driving task. In-vehicle navigation systems should be designed as simply as possible while providing understandable information to the driver.

7.3 Design Recommendations

Design recommendations in this section are based on a compilation of research findings from the fields of human factors, cognitive science, human-computer interaction, and information design.

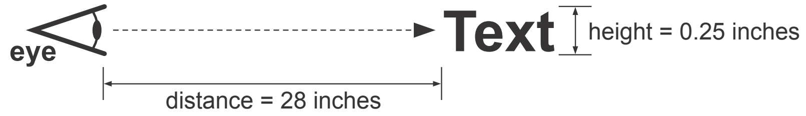
7.3.1 Legibility

When designing a paper map, contrast between the background and the labels and adequate text size are employed to enhance legibility. For example, low saturation colors may be used in the background to enable text to be more visible. In designing such features, attention should be given to the conditions in which the maps may need to be read. For example, poor illumination of the features will cause poor legibility (Wickens, Liu, & Gordon-Becker, 1998).

Legibility may sometimes be compromised because of the need for detail (Wickens, Liu, & Gordon-Becker, 1998). If a lot of information must be presented within a given space, legibility will be sacrificed at some level. Electronic maps can display detailed without sacrificing legibility. However, they may lose context. For example, we can maintain legibility by zooming in to a specific location of a map, or dynamically reducing legibility of features which are not important.

Guidelines for legibility can be sub-categorized as the following:

7.3.1.1 Character Size



Guideline: Character size should be 0.25 inch (6.4 mm) high or larger

Character size is an important aspect of legibility. Character size can determine if information can be read and how long it will take to read the information (Green, Levison, Paelke, & Serafin, 1993). For this reason, the legibility of text has been widely explored in human perception and vision studies. The literature shows that when measuring the legibility of a target visual stimulus, referring to its absolute size does not make any sense because its size can be different as the distance to the stimulus changes. For example, both a one-centimeter object at a distance of one meter and a two-centimeter object at a distance of two meters will be perceived as same size in the human retina. So, what really matters is visual angle, not absolute size.

Visual angle is the angle that a visual stimulus subtends at the eye (Figure 7.3). The visual angle of a stimulus on the retina can be calculated by taking the height of the stimulus divided by the distance between the stimulus and the retina (Figure 7.3). It is usually measured in degrees or minutes of arc (Sanders & McCormick, 1993).

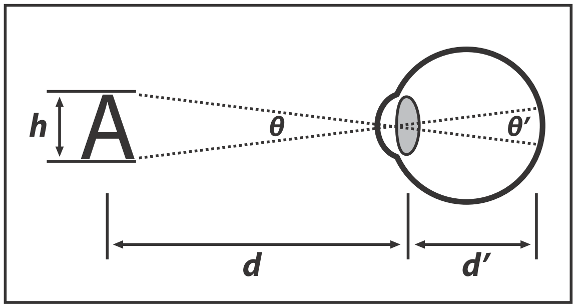


Figure 7.3 Visual angle

Calculation of the Visual Angle (after Sanders and McCormick, 1993)

va = visual angle (in minutes) = 3438 x h/d

where:
d = distance between the eye and the character
h = character height (total letter height)

Based on this theory, considerable research has presented legibility predictions that can be used to design a variety of information applications. Among them, one the most commonly referenced recommendations is the one from Peters and Adams (1959):

Letter Height (in) = H = .0022D + K1 + K2

where:
D = Viewing Distance (in)
K1 = Correction factor for illumination and reading situation
= 0.06 for illumination > 1.0 fc, favorable reading conditions
= 0.16 for illumination > 1.0 fc, unfavorable conditions or illumination < 1.0 fc, favorable conditions
= 0.26 for illumination < 1.0 fc, unfavorable conditions
K2 = Correction for Importance
= 0.075 for emergency labels, counters, scales, legend lights
= 0.0 for other (unimportant) panel markings

According to Peters and Adams (1959), a standard console's viewing distance is 28 inches, and K1 is 0.16 inches. So the recommended height of unimportant characters are about 0.22 inches high (K2 = 0.0), and important characters are about 0.30 inches high (K2 = 0.075). However, Green et al. (1988) showed that the recommendations from Peters and Adams (1959) were not supported by empirical data (Green, Goldstein, Zeltner, & Adams, 1988).

For this reason, Green et al. (1993) suggested that one of the most general expressions for determining required character height is Smith's Bond Rule (1979), which states that the visual angle of a character should be at least 0.007 radians (Green, Levison, Paelke, & Serafin, 1993). During his study, Smith tested the maximum reading distance legibility of 314 different sample test materials. In this study, 547 viewers walked up to the materials and stated when they could read them (Smith, 1979). The test material used in the study covered a wide variety of fonts, stroke widths, and spacing. The viewers participated in a study that also covered a wide range of visual acuity and age. The viewing conditions also varied.

As Figure 7.4 depicts, the distribution of 2007 viewers' responses showed that test materials were legible when the subtended viewing angle was 0.007 radians or less. With this result, Smith determined that for small visual angles less than seven degrees, the sine, tangent, and angle measure in radians are all equal to three significant figures, and the following formula to predict character height was developed (Smith, 1979):

Height = 0.007 x Viewing Distance (D, same units as height)

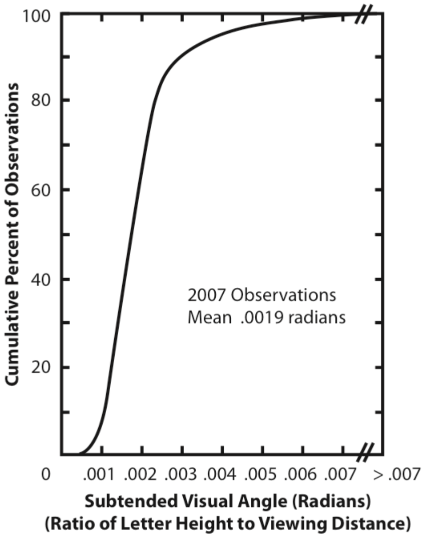
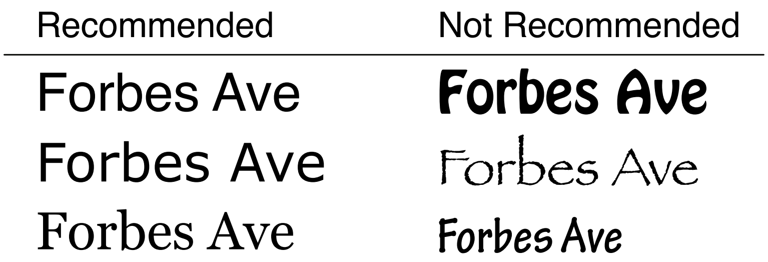


Figure 7.4 Ratio of Letter Height to Viewing Distance (Smith 1979)

By following Smith's rule, Green et al. (1993) found that the character size of the in-vehicle display that at the standard panel viewing distance, which is 28 inches (or 700 mm), characters should be 0.196 inches (0.007 x 29 in) high (4.9 mm). However, displays mounted on the center console of a vehicle are often at a slightly greater distance, requiring a larger character size. For displays mounted on top of or near the top of the center console, character height should be approximately 0.26 inches high (6.4 mm) (Green, Levison, Paelke, & Serafin, 1993).

However, the minimum legibility requirements tested under laboratory conditions can be generally too small for rapid reading under driving conditions. According to the research from Boreczky et al. (1988), the smallest character size tested in the driving conditions were about 5 mm, which is almost identical to the minimum requirement of Smith's Bond Rule. However, the research also found that when increasing the character size to 9 mm, reading time of the character was decreased by 15 to 20 percent, and increasing the size further to 12 mm to 16 mm resulted in further decreased reading time, although the gains were diminishing (Green, Levison, Paelke, & Serafin, 1993). So, it should be noted that the character size should be increased under the condition where the display needs to be read quickly.

7.3.1.2 Typeface



Guideline: Use a plain typeface designed for screen to maximize legibility.

In early human factors research, numerous studies examined the effect of fonts on reading performance. Many issues exist in applying these results to the design of navigational displays, because display technology has been changed greatly during recent years.

For example, Plauth (1970) compared reading performance of three fonts, which were generally used in aircraft displays at the time. According to the study result, the segmented fonts — what we still can see from many digital clocks — should not be used in applications where accuracy is critical and exposure time is severely limited (Plauth, 1970). Another study from Snyder and Maddox (1978) examined the design variation of dot matrix fonts concerned with finding optimal dot size-shape-spacing combinations for 5x7 dot matrix characters as a function of ambient illumination. The study compared three dot element shapes (square, horizontally elongated, vertically elongated), three element sizes (0.76, 1.14, 1.52 mm), and three between element spacing/element size ratios (0.5, 1, 1.5) (Snyder & Maddox, 1978). As we can see from these research examples, the early studies didn't really focus on the issue of typeface design. Many studies showed that differences among typefaces have less impact on legibility than physical characteristics such as size or contrast (Cornog & Rose, 1967).

Despite the advance of display technologies, the old argument that differences among typefaces have less impact on legibility seems still controversial. According to the study result from Boyarski et al. (1998), serif fonts were more legible compared to sans serif fonts (Boyarski, Neuwirth, Forlizzi, & Regli, 1998). The study also shows that fonts specially designed for screen display (e.g., Georgia and Verdana) are more legible than the ones designed for print materials (e.g., Times). However, following studies from Bernard et al. show that no typeface effects were found for perceptions of font legibility of attraction, particularly between the fonts designed for the computer screen (Bernard, Liao, & Mills, 2001; Bernard, Chaparro, Mills, & Halcomb, 2003). On the contrary, more recent studies from Subbaram et al. (2004) show that sans serif fonts have better legibility than serif fonts. This study also shows that heavier stroke widths were more legible than thin stroke widths (Subbaram, Sheedy, & Hayes, 2004). Interestingly, the first two studies were conducted under CRT display condition while the later one was conducted under LCD condition. Since most current in-vehicle navigational displays are equipped with LCD screens, it might be reasonable to rely on the LCD study results, but the work needs further validation. At this time, instead of providing specific guidelines for choosing typefaces, it may be better to for system designers to choose.

However, some rough guidelines can be presented. First, plain fonts are more preferable and more legible when compared to ornate typefaces. Previous research has found that older adults generally prefer sans serif fonts to serif fonts for printed material (Vanderplas & Vanderplas, 1980). Green et al. (1998) also suggested that plain typefaces (Geneva, Helvetica) are more legible than ornate ones (such as London). Additionally, fonts that are designed for screen display (e.g., Georgia and Verdana) are preferable, because they rely on larger x-heights than the ubiquitous Times Roman. These founts should probably be given more vertical breathing room with extra line-spacing (Boyarski, Neuwirth, Forlizzi, & Regli, 1998).

7.3.2 Readability (or Understandability)

Turn Right at Forbes Ave (o)
TURN RIGHT AT FORBES AVE (x)

Guideline 1: Use mixed case instead of all capital letters.

Abbreviation Rule:
Boulevard → Blvd

Baum Blvd (o)
Sunset Blvd (o)
Hollywood blvd (x)
Brookline Bld (x)

Guideline 2: Use consistent rules when creating abbreviations.

Common Abbreviation Rule:

Boulevard → Blvd
Highway → Hwy
Road → Rd
Freeway → Fwy

Guideline 3: Use common abbreviations.

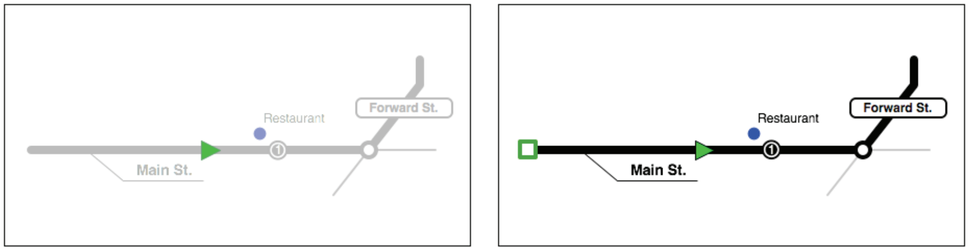
A message that consists of mixed case, for example "Right lane closed for next five miles," is much easier to read than upper case, "RIGHT LANE CLOSED FOR NEXT FIVE MILES" (Green, Levison, Paelke, & Serafin, 1993). Therefore, mixed case messages should be employed instead of all capital letters when presenting a message on the screen. If messages need to be displayed in all capital letters, then they should be consistent

Due to the limitations of screen real estate, words or sentences are often presented in abbreviated form. When creating abbreviations, it is recommended to use consistent rules so that people can reconstruct them (Green, Levison, Paelke, & Serafin, 1993). Green et al. (1998) recommended two commonly accepted abbreviation rules: vowel deletion and truncation. However, Department of Transportation made a list of commonly used abbreviations, so it is recommended to use the common abbreviations, if available (Green, Goldstein, Zeltner, & Adams, 1988). Following table is an example of well-understood abbreviations.

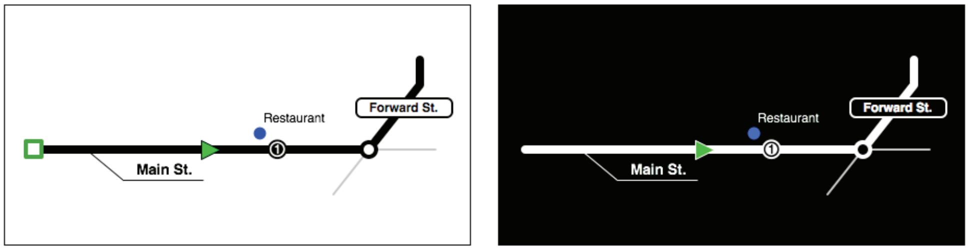
Word	Abbreviation	Strategy	% Agreement
Freeway	Frwy	vowel deletion	100
Highway	Hwy	vowel deletion	100
Left	Lft	vowel deletion	100
Parking	Pking	last syllable	100
Service	Serv	truncation	100
Traffic	Traf	truncation	100
Warning	Warn	truncation	100
Boulevard	Blvd	vowel deletion	96
Speed	Spd	vowel deletion	96
Center	Cntr	vowel deletion	92
Entrance	Ent	truncation	92
Freeway	Fwy	vowel deletion	92
Information	Info	truncation	92
Normal	Norm	truncation	92
Shoulder	Shldr	vowel deletion	92
Emergency	Emer	truncation	88
Expressway	Expwy	vowel deletion	88
Maintenance	Maint	truncation	88
Travelers	Trvlrs	vowel deletion	88
Road	Rd	vowel deletion	88
Slippery	Slip	truncation	88

Table 7.2 Well-understood abbreviations

7.3.3 Color Scheme and Contrast

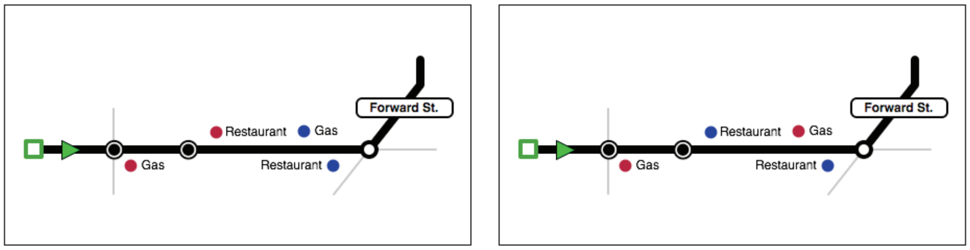


Guideline 1: Use high contrast.

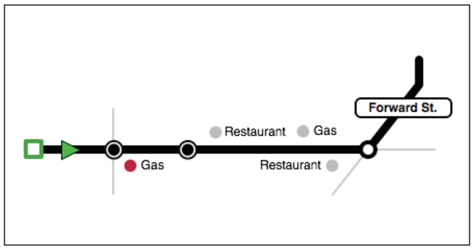


(daylight) (night)

Guideline 2: Color scheme should consider ambient lighting condition.



Guideline 3: Use color consistently. (e.g., same landmark with same color coding)



Guideline 4: Use color to draw attention, communicate organization, and indicate status.

Guideline 5: Limit color-coding to eight colors (four or less is preferable)

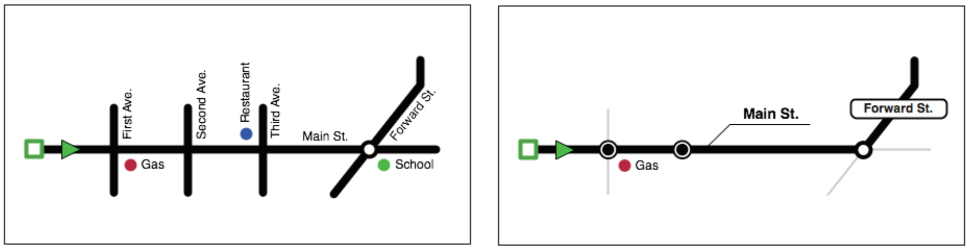
*note: these specific 8 colors are not necessarily a recommended color set.

Cobb and Moss (1928) examined the effect of four basic visual factors on legibility — these are target size, target luminance, background luminance, and exposure duration. Nine participants viewed a stimulus mounted on a disk that was spinning at high speed. The spinning disk then stopped for some variation of time for exposure. Target size was also varied and the contrast was adjusted by changing the background luminance and target luminance (Cobb & Moss, 1928). The study results show that for fixed visual angles, the primary factor that affects visual threshold is contrast ratio. This is followed by illumination level and exposure duration. Therefore, it is necessary to maintain high contrast ratio for important features when placed on the display.

When choosing the color scheme for a navigational display, some human factors guidelines recommend light characters on a dark background (known as a negative color scheme). Green et al. (1993) provided several reasons for this recommendation: since there are more pixels for the background than the text in the foreground, using a dark background will minimize the luminous output, and consequently minimize glare from the display (Green, Levison, Paelke, & Serafin, 1993). However, this recommendation is not always applicable, especially with new LCD technology. It is generally said that LCDs show lower luminance than CRT displays and are usually designed as "non-glare" screens. Instead, our recommendation is that the screen color scheme should change considering ambient lighting conditions — under a sunny day light condition, positive color scheme (dark characters on a light background) would be better for legibility, while a negative color scheme would be better under night vision condition.

Also, Mayhew (1992) pointed out that color should be used consistently for informational displays, with each color always used for the same purpose (Mayhew, 1992). To achieve this goal, it is recommended that the interface should first be designed in monochrome, and then color should be added to draw attention, communicate organization, and indicate status. Color-coding should be limited to eight colors, but four or less color-coding is preferable (Wickens, Liu, & Gordon-Becker, 1998).

7.3.4 Abstraction



Guideline 1: Minimize the amount of information to reduce search time.

Guideline 2: When abstracting map information, apply generalization rules consistently.

Map reading is primarily a search task (Lee, Forlizzi, & Hudson, 2008). When navigating, a driver keeps searching for interesting and relevant features from large sets of information. Thus, reducing the amount of information that is presented to a driver is recommended to reduce searching time. However, prior work (Goldstein, 2002) also found that if a pop out is provided, search time can be consistently fast no matter how many distracters exist. This means that considering saliency, a measure of relative importance, is another important factor when abstracting information.

When designing an abstracted map, not all of the information in the display will be of equal importance (or equally likely to be the target of a visual search) in any given situation. Lee, Forlizzi et al. (2008) has suggested that by using the most salient and attention demanding display elements only for the likely high importance items, while lowering the salience or even removing others, we can expect to achieve a perceptually efficient display (Lee, Forlizzi, & Hudson, 2008).

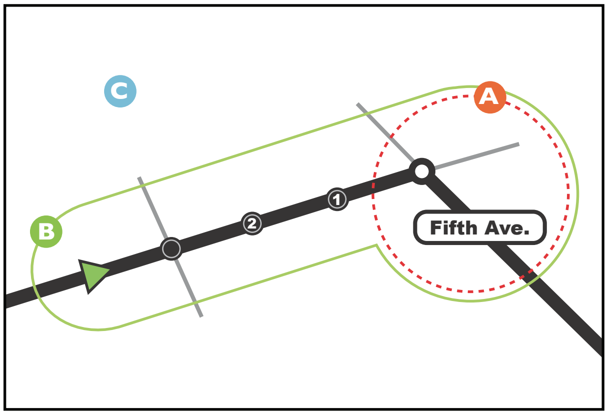


Figure 7.5 Areas of different importance

Figure 7.5 shows a depiction of how different areas of the display are assigned different importance. The display is divided into three regions. Region A is what is most important to the driver — the information about the next turn. Region B is the next most important information — the area surrounding the current position of the vehicle, working forward to the next turn once it is close enough. Region C encompasses the remaining surrounding area (where minimal or no renditions are used).

According to study results from Lee, Forlizzi et al. (2008), symbolic renditions show more searching time than semantic renditions. Thus, semantic renditions should be used primarily for important areas (region A, and sparingly in region B), while symbolic renditions should be used in areas that need less visual salience (region B and occasionally in region C). Finally, pop-out inducing renditions should be used very sparingly and only in locations of most likely current interest.

Prior work from Lee, Forlizzi et al. (2005) has also identified five map generalization principles when abstracting navigational information (Lee, Forlizzi, & Hudson, 2005). First, *Map Feature Selection* is used to guide selection and display important features among the large set of map elements since not all of them are needed. Feature selection should be done based on the current vehicle's location — for example, crossroads and landmarks in front of the current vehicle position become candidates for selection. Second, *Simplification/Smoothing* suggests that unnecessary road shape points can be removed. Generally, drivers are unaware of a road's actual shape or curvature while driving. Third, *Relative Scaling* suggests that the importance of different map features can also be reflected through scaling. The scaling factor of a road segment can be determined based on the importance of the segment in the route. Forth, *Displacement* suggests that labels and renditions that are displayed can be offset from their original positions to prevent clutter. Related to this, Green et al. (1993) suggested that all gaps between lines should be at least 0.6 mm (0.025 inch) wide so that people can discriminate each map feature (Green, Levison, Paelke, & Serafin, 1993). However, while abstraction generally increases searching time, detail can enhance navigation in some places. The final principle is *Enhancement*, which suggests using details when features are important to the current driving context — for example, at the final destination of the route, for features associated with the next or current turn, and for features associated with the road segments between the current position and the next turn.

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