A Design and Implementation for Effective Computer-Generated Route Maps

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Abstract

A route map depicting a path from one location to another is a powerful tool for visualizing and communicating directions. However, it can be difficult for a computer to automatically render route maps that meet the four design goals of effective route maps: readability, clarity, completeness, and convenience. Achieving all of these goals requires trade-offs. We survey the cartography, graphic design, and psychology literature for insight about these trade-offs. We then analyze several common route-mapping styles to demonstrate the variables in map design: what information is included, the precision of that information, and the rendering style. This analysis illustrates that hand-drawn route maps are particularly effective. Finally, we describe in detail a design and implementation for computer-generated maps that mimics the style of hand-drawn route maps.

1 Introduction

Route maps, when well designed, are an effective device for visualizing and communicating directions. Such maps have existed in various forms for centuries, and the recent availability of detailed geographic databases via the Internet has led to the widespread use of computer-generated route maps. Online mapping services typically provide directions as a set of maps complemented with text descriptions; while the text descriptions work well, it is our experience that the accompanying maps are often difficult and frustrating to use. We believe this is largely because these computer-generated route maps disregard many of the techniques and principles that guide human mapmakers.

We identify the following design goals for effective route maps: readability, clarity, completeness, and convenience. Simultaneously achieving all of these goals is difficult. The mapmaker must choose which information to include in the map and the precision with which to depict this information. To better understand the effects of these choices, we survey the literature in cartography, graphic design, and psychology. In this paper, we distill the results of this literature survey and analyze a number of existing route mapping styles in terms of how well they provide viewers with an understanding of the routes to be followed. Based on the analysis, we propose a new design for computer-generated route maps that meets all four of our design goals.

Following a route generally consists of switching between two activities: following a path until reaching a critical point, and then changing orientation to follow another path [3][4]. The most important information for route maps to communicate is the points of reorientation: where someone must consciously turn from one path to another. Until now, computer-generated route maps have uniformly scaled all the roads in the map by a constant scale factor. For routes of any reasonable length, uniform scaling causes some critical turning points to vanish because the roads are too small, particularly near the start and end of routes where many turns may be required.

The insight in our design is that precisely depicting the length, angle, and curvature of each path in the map is not necessary. The psychology literature shows that most people distort distances, angles, and curvature when they create route maps [15][16], and that they maintain these distortions in their own mental representations of the route [14]. By carefully distorting the map, it becomes possible to clearly communicate every reorientation point in a readable and convenient form.

Automatically generating route maps in our proposed style is a complex problem. Distorting aspects of the map can accentuate reorientation points, but it can also have detrimental effects such as introducing false intersections. Creating an effective route map requires searching the large space of possible map layouts for an optimal layout. We present an efficient multi-stage algorithm that couples a deterministic greedy search for road layout with a simulated annealing phase for label and annotation placement. The resulting map is rendered using subtle perceptual cues, such as a wavy hand-drawn style for drawing the paths, to communicate the distortion of scale and topography.

In the next section, we discuss the design goals for route maps and the results of our literature survey. Section 3 then analyzes a number of existing route mapping styles, and in Sections 4 and 5 we present our route map design and implementation.

2 Properties of Route Maps

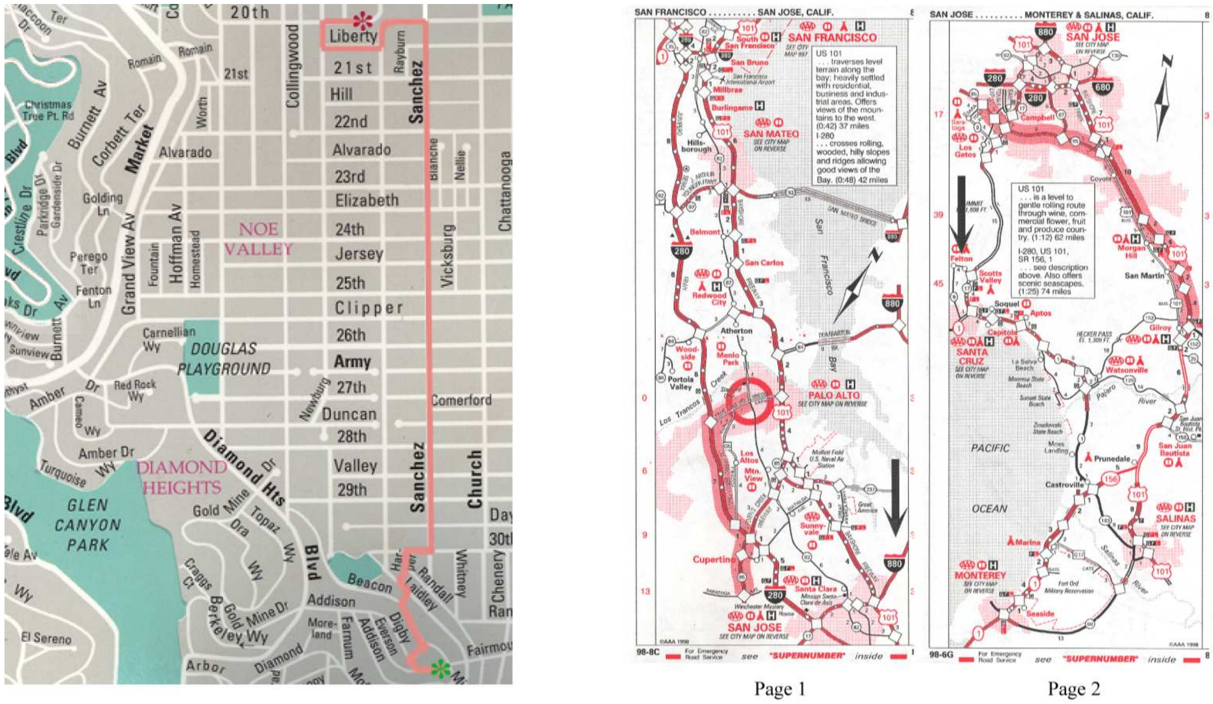
The existing literature provides extensive insight into the properties of effective route maps. In this section, we survey the literature to form a set of design goals for route maps and to understand the design variables available to the mapmaker.

2.1 Design Goals

In reviewing texts on graphic design [12][13] and mapmaking [9], we have identified four goals for route map design:

- **Readability:** All essential components of the route, especially the roads, should be visible and easily identifiable.
- **Clarity:** The route should be clearly marked and readily apparent even from a quick glance [13]. The map should contain only as much information as is necessary.
- **Completeness:** The map must provide all necessary information for navigation.
- **Convenience:** "A good design should take into account how, when, and where the information is used." [13] A route map is used while traveling – therefore, it should be easy to carry and manipulate.

Given this set of goals for our map design, we turn to understanding the variables in route map design.



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(a) (b)

Figure 1: (a) A Route Highlight Map depicting a route in downtown San Francisco (*courtesy of StreetWise Maps).* **(b)** A TripTik depicting the first portion of a route, highlighted in red, from Palo Alto to Los Angeles. (*map courtesy of CSAA).*

2.2 Variables

Mapmakers have three variables that they can manipulate when designing a map: the content, the precision, and the rendering style. We discuss each of these variables in detail.

2.2.1 Content

In his studies of verbal route descriptions, Denis identifies the most important components of a route description as the starting and ending points, and the reorientation points [3][4]. The reorientation points are the points along the route at which the navigator must change orientation and explicitly switch to a different road. Tversky and Lee [16] show that route descriptions and depictions have the same underlying structure, and therefore Denis' analysis is applicable to both route maps and route descriptions.

In addition to the information described above, mapmakers include context information. The amount of context information included in the map can greatly affect the utility of the map. There are two types of contextual information: local context that directly supports navigation, and overview context that helps the user locate the route in relation to the rest of the environment.

Local Context: The most common form of local context is a label or name for a path on the route. Other local context information includes landmarks along the route such as buildings, stoplights, or stop signs. People most commonly use landmarks to indicate the position of the reorientation points and, less frequently, to communicate progress along a road [3].

Overview Context: Overview context information provides a broad survey of the geography of the area surrounding the entire route and may show how the route topologically connects with other paths in the area. Including paths off the main route helps navigators find the main route if they accidentally stray from it.

Unlike some forms of local context, such as path labels or landmarks at reorientation points, overview context is not always necessary. In particular, for users that are somewhat familiar with the environment, little overview context is required.

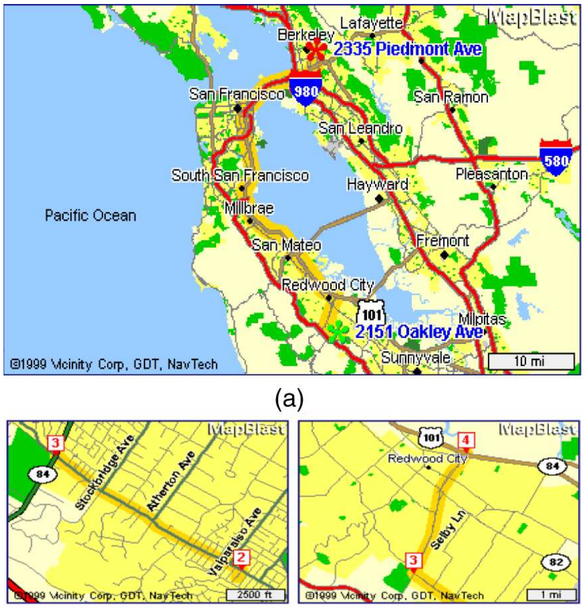
2.2.2 Precision

Studies in environmental psychology [3][14][16] have shown that human generated route maps usually contain distortion. There are three primary types of distortion: (1) inaccurate path lengths, (2) incorrect turning angles at intersections, and (3) simplified road shape. Tversky and Lee [16] asked a group of students to sketch a route map between two locations near the Stanford campus. Although they encouraged participants in their study to represent paths and intersections accurately, most did not. Most intersections were drawn at right angles regardless of their actual angle and 71% of the participants used simple generic curves and straight lines to represent the roads. Even when the participants intended to communicate the shape or length of the road accurately, they typically rendered these attributes incorrectly.

This distortion of the map is in fact beneficial. The design literature [12] shows that even well-planned route maps, particularly subway maps, contain similar distortions. These distortions increase the flexibility available to the mapmaker in designing and laying out the map. Variably scaling the length of each road allows the mapmaker to ensure all the reorientation points are visible, while flexibility in choosing turning angles and road curvature allows the mapmaker to simplify the map. Such distortions can simultaneously improve the readability and convenience of the route map with little adverse effect on its clarity and completeness.

2.2.3 Rendering Style

Although all maps are abstract representations of a route, there is a range of styles that can be used to render a map, with varying asso-



(a)

(b)

Figure 3: An Overview/Detail map of a route from a home near Stanford to a home in Berkeley. (a) shows an overview of the route and (b) shows detailed information about each turn. (*maps courtesy of MapBlast)*

ciations of accuracy and realism. An appropriate rendering style can greatly affect the readability and clarity of a map. Retinal properties such as color and line thickness can be used to draw attention to important features of the map [1][9]. Rendering style can also aid the user in interpreting how closely the map corresponds with the real world [11].

3 Analysis of Route Map Styles

We now analyze five of the major route mapping styles and consider the design choices made in each.

3.1 Route Highlight Maps

Route highlight maps simply highlight the route on a general road map of the region, as shown in Figure 1. Since the purpose of general road maps is to provide an understanding of the entire road system in a region, they typically employ constant scale factors and display extraneous detail throughout the map.

Constant scaling generally causes one of two problems. Either detailed turn information is lost because the scale factor is too large, or the scale factor is small enough to show the detail, but the map is very large. Since general road maps are not optimized to show any particular route, a route highlight map will often suffer from both a large scale factor and an inconvenient size.

The clarity of the route depends on the style of the highlighting since that is the only property differentiating the route from other roads. Usually the route is distinctively colored, but because general road maps provide context information over the entire map, extraneous information may clutter the map and make it difficult to perceive the route and the individual reorientation points.

3.2 TripTiks

TripTiks are similar to route highlight maps, but they are specifically designed for communicating a particular route. As shown in Figure 2, a TripTik usually stretches over multiple rectangular pages, and each page is oriented so that the route runs roughly down the center of the page. Each TripTik page employs constant scaling, but the scale factor can differ across pages. Changing the scale factor from page to page allows the TripTik to show more detailed turn information where needed. However, because the map stretches over many pages and the orientation and scale factor varies from page to page, forming a general understanding of the overall route can be difficult.

3.3 Overview/Detail Maps

Overview/Detail maps combine multiple maps rendered at different scales to present a single route, as shown in Figure 3. One of the maps is scaled by a large factor so that it provides an overview of the entire route. Since the large scale factor of this map reduces the readability of local turn details, maps showing turn-by-turn information are provided. A constant scale factor is used for each map, but the scale factor may differ across the maps.

While this may seem like an effective combination, in practice the two sets of maps can be extremely difficult to use. The overview map rarely presents more than the overall direction of the route. Although turn-by-turn maps provide detailed information for every turn, the use of distinct maps for each turn, often with different orientation and scale, makes it difficult to understand how the maps correspond to one another. Therefore, the navigator can have difficulty forming a cognitive model of the route, leading to frustration and confusion.

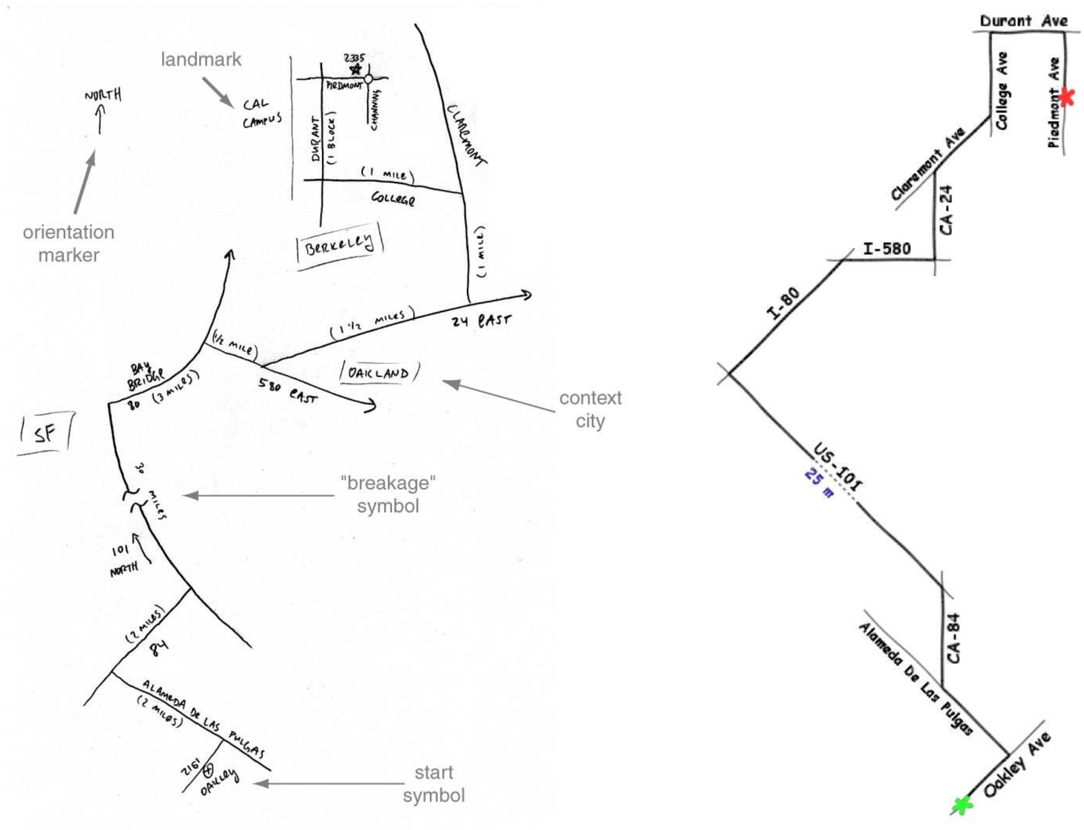
3.4 2-D Nonlinear Distortion Maps

To ensure clear communication of all of the reorientation points, some parts of a route's depiction may require a small scale factor while others require a large scale factor. Several papers [2][7] have described attempts to use 2D nonlinear image distortion techniques on general road maps to provide focus-plus-context viewing. These techniques allow users to choose regions of the map they want to focus on and then apply a nonlinear magnification, such as a spherical distortion, to enlarge these focus regions. Such 2D distortion allows detailed information to be displayed only where relevant and often produces general area maps that can be conveniently displayed on a single page. However, a major problem with nonlinear 2D distortion is that the regions at the edges between the magnified and non-magnified portions of the map undergo extreme distortion.

3.5 Hand-Drawn Maps

Hand-drawn route maps often present a good combination of readability, clarity, completeness and convenience, as shown in Figure 4(a). Instead of using a constant scale factor, hand-drawn maps only maintain the relative ordering of the roads by length. While this ensures that longer roads appear longer than shorter roads in the map, each road may be scaled by a different factor. Often the map designer does not know the exact length of the roads [14] and only knows their lengths relative to one another. The flexibility of relative scaling allows hand-drawn route maps to fit within a manageable size and remain readable.

Hand-drawn route maps typically remove most contextual information that does not lie directly along the route. This strategy reduces overall clutter and improves clarity. The intersection angles in hand-drawn maps are generally incorrect, the precise shape of roads is often misrepresented, and the roads are typically depicted as generically straight or curved. These distortions make the map simpler and only remove unnecessary information.



(a) Hand-Drawn Map

(b) System Generated Map

Figure 4: Two maps of a route from a home near Stanford to a home in Berkeley. The hand-drawn map (a) uses variable scaling to provide detail where it is necessary and to maintain a compact form factor. We have annotated the map in gray to show several features of hand-drawn route maps. (b) Our route map rendering system produces a similar map. *(map (a) courtesy of John Owens)*

Hand-drawn route maps are rendered in a "sketchy" style typical of quick pen-and-ink doodling. Many navigators are familiar with such hand-drawn maps and the sketchy style is a subtle indicator that the map may contain imprecision.

4 A Computer-Based Route Map Design

Measured against our goals for effective route maps, hand-drawn route maps are the most useful of the styles we have discussed. They convey the necessary information in a readable and clear manner, include little more information than is necessary, and easily fit on a single piece of paper.

Thus, we base our design for computer-generated route maps on the hand-drawn style. Figure 4(b) contains an example route map generated by our system. As can be seen in the figure, we closely mimic the aesthetics of the hand-drawn style, and we utilize distortion to produce an effective map.

Our current design is based on the following principles, derived from hand-drawn maps:

- Roads should be variably scaled so that all roads and reorientation points are clearly visible and easily labeled.
- If road A is longer than road B, then road A should be noticeably longer than road B in the map.
- The representation of a road only needs to convey general curvature and the significant changes in orientation.
- The precise angle of intersection is not important; instead it is sufficient to communicate clearly the action to be taken (turn left; turn right) and a generalized orientation.
- The start and end of the route should be clearly marked.
- Landmarks should be included where possible to denote the position of reorientation points and to communicate progression along the route.
- A "sketchy" style should be used to indicate an imprecision of scale and orientation.
- The resulting map should fit on a single sheet of paper.

Our current system, discussed in the next section, implements the majority of this design. We are not able to include as many landmarks, or as much information about road shape, as we would like, due to the lack of complete information in our data source. However, landmarks do present interesting challenges. Roads and intersections are effective landmarks for communicating the position of reorientation points, and information regarding the location and existence of these roads is easily obtained. However, human mapmakers often include other landmarks that are determined by perceptual or cultural saliency [3][16]. For a computer to automatically determine landmark saliency is a difficult task.

5 System Architecture

Generating a computer-based map in our style is more difficult than generating a map in the traditional computer-based styles.

Variable scaling gives us some flexibility in choosing the length of each road to produce a clear and readable map. However, we must ensure that the relative ordering of the roads by length remains fixed and that we do not introduce false intersections. The space of all possible route-map layouts is extremely large, and therefore it is not feasible to blindly search for a layout. We use a heuristic generate-and-test [10] approach to find a map meeting our design principles. The layout of the map occurs in multiple phases.

In the first phase, directions are read from a file and translated into a graph. Nodes in the graph represent intersections and edges represent the roads connecting the intersections. The current system does not contain a database of roads. Instead, we infer all the information about the map from text directions.

In the second phase of the algorithm, the roads are placed on the map. Initially, we use a constant scale factor for the entire map so that it will fit in the desired viewport. Such a uniformly scaled map often contains many roads that are too small to see or label. To remedy this, we begin by scaling all of the smaller roads until they are clearly visible. Since we only increase the length of roads in this step, we end up enlarging the size of the map beyond the size of the viewport. To resize the map, we search for long roads that can be shrunk. We iterate from the starting point of the route, examining each road until we identify one that extends outside of the viewport. We then build a list of candidate roads that can be shrunk while preserving relative scaling and avoiding false intersections. We greedily shrink the candidates as much as possible, in order from longest to shortest, until the offending road is pulled back inside the viewport.

The third phase of the algorithm places labels on each road in the map. The labeling of the individual roads is aided by the road scaling performed in the second phase, but optimal labeling remains an intractable problem [6]. Our labeling uses simulated annealing, based on the general cartographic labeling algorithm developed by Edmondson et al. [5]. Each labeling is scored according to principles derived from Monomier [9], Tufte [12][13] and Edmundson [5]. Unlike Edmundson, who uses a discrete set of label positions, we consider a continuous range of positions for label placement, and we consider label placements that are not directly above or below the road.

In the fourth phase, we add decoration such as road extensions and icons for the start and end points. Road extensions accentuate reorientation points, and allow us to extend the positions we can consider for a road label (effectively making the road longer). In this phase, we extend all roads by a small fixed amount and then further lengthen only those roads that need to be extended for the chosen labeling, as is done for Oakley Avenue in Figure 4(b).

The final phase of the algorithm is the rendering of the route map. In this phase, the "sketchy" pen-and-ink style and other rendering principles of Section 3.3 are applied. Instead of drawing roads as straight lines we introduce some variation in the bend and width of each stroke to generate the hand-drawn look. Based on the work of Markosian et al. [8], we break each line into small segments and slightly shift the position of each point both normal and tangent to the stroke direction. We then join these points with a NURB to create the final stroke. The thickness of the roads is adjusted to emphasize the route and de-emphasize the extensions.

6 Conclusions and Future Work

We have described a design style for effective computer-generated route maps, based on principles derived from cartography, graphic design and environmental psychology. We have also presented a system for automatically rendering route maps in this style. Our system is a work in progress, although it produces usable maps in almost all situations.

We have implemented a greedy depth-first search for road layout; this algorithm is not guaranteed to find the optimal road layout. We are considering other search strategies for road layout.

The current system contains little support for landmarks. We are currently implementing techniques for placing important landmarks along the route. This placement of landmarks would occur in a separate phase preceding label placement. We also intend to consider the task of selecting perceptually salient landmarks for denoting the position of intersections.

Finally, we are also investigating the use of insets as an alternative to variable scaling. However, as with Overview/Detail maps, insets can reduce the correspondence between the map and the navigator's cognitive model of the route.

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