

Referential scope and visual clutter in navigation tasks

Hans Westerbeek (h.g.w.westerbeek@tilburguniversity.edu)

Alfons Maes (maes@tilburguniversity.edu)

Tilburg centre for Creative Computing, Tilburg University
Warandelaan 2, 5037 AB, Tilburg, The Netherlands

Abstract

In a production task, we investigated the effect of *visual clutter* in route maps on the type of referential expressions used in route descriptions, and on the descriptive efficiency and accuracy of these descriptions. We show that cluttered maps tend to diminish the use of less robust, narrow scope *junction* expressions (e.g. *the next junction*), and promote the use of more robust, broad scope *landmark* expressions (e.g. *the post office*). Moreover, visual clutter results in the use of more redundant information elements, words, propositions, and incorrect landmarks.

Keywords: referential scope; visual detail, visual clutter; route descriptions, route maps.

Introduction

Navigation is a core component of cognition and daily life action. People can use route descriptions (RDs) to solve part of their navigation problems. RDs show a large variation depending on prior knowledge (e.g., Lovelace, Hegarty, & Montello, 1999), visuospatial abilities (e.g., Denis, Pazzaglia, Cornoldi, & Bertolo, 1999) and spatial perspectives of users (e.g., Brunyé & Taylor, 2008; Lee & Tversky, 2005; Mellet, et al., 2000; Taylor & Tversky, 1992). Also, RDs vary with the navigation task: route following is different from wayfinding (Hartley, Maguire, Spiers, & Burgess, 2003); actual navigation is different from learning routes for later use (Thorndyke & Hayes-Roth, 1982).

The core of RDs consists of the description of actions to be taken (e.g., *turn left*) and the identification of the location of these actions (e.g., *at the barber*). Different strategies can be used to successfully identify relevant locations in RDs. In this paper, two of these referential options will be studied in relation to visual characteristics of the route environment.

Reference maintenance and selection in RDs

RDs are referentially atypical in that they hardly show chains of different types of referring expressions used to establish and maintain the same referent over larger stretches of discourse. The protagonist in RDs is the navigator, who is easily maintained as the (implied) subject of route instruction imperative verbs (e.g., *[You] turn left*). Most of the discourse referents in RDs appear and disappear as the route develops: path and landmark referents are mentioned in the relevant route segment, and need not be maintained in the remaining discourse. This makes RDs hardly relevant for pronoun resolution algorithms or accessibility analyses of subsequent references.

Selecting relevant referents in RDs is less trivial, however. In describing each route segment, people have to

decide whether and what referents are helpful or necessary to identify relevant actions and locations, in order to ensure optimal navigation or remembering a route on a map. When asked to instruct someone how to go to the bank office (i.e., the depicted route in Figure 1), one can use “*Two times left*” as an adequate and unambiguous answer. There is a fair chance, however, that those instructions are enriched with different types of referential expressions: “*Walk one block straight up to the next junction. There, you see a barber on your left. Turn left. Walk one block straight up to the next junction. There, you see a pub in front of you. Turn left again and walk one block straight up again to the next junction. The bank office is on your right.*”

Different conditions make the selection of referents in maps and RDs challenging. The set of relevant referents changes over time as the route unfolds; the variety of environments, maps and routes makes the availability of salient referents unpredictable. Moreover, referents may not only be visible, but also hidden in users’ knowledge (e.g., *Go left where we met yesterday*), as common ground and prior knowledge are important sources of route relevant referents. Also, their conceptual range is varied (points, paths, regions), and the sum of all this is a holistic view of a naturalistic scene, rather than a clear set of target and distractor entities (Rosenholtz, Li, & Nakano, 2007). The unpredictability, definition and variation of relevant entities in navigation environments complicates the development of algorithms for the automatic production of RDs in different navigation situations (Dale, Geldof, & Prost, 2004; Koller, Striegnitz, Byron, Cassell, Dale, Moore & Oberlander, 2010; Paraboni, Van Deemter, & Masthoff, 2007).

Despite this variability, recent navigation studies show that one referential strategy is stable in producing RDs: the tendency to add referents at choice or decision points, i.e., locations in a real environment or on a map which afford pathway options, and thus require a decision on the part of the navigator (Allen, 2000; Daniel & Denis, 2004; Denis, et al., 1999). According to Allen (2000), adding references at decision points “is one way to achieve referential determinacy by making it clear exactly what environmental features will be encountered by the traveller at choice points and how he or she should respond.” (p. 335). Daniel & Denis (2004) asked respondents to describe well known routes as concise as possible, and concluded that landmarks at decision points underwent less reduction than other landmarks. This strategy aligns more or less with the preference for landmark descriptions over street descriptions (Tom & Denis, 2004), as landmarks mostly represent points on a map, and therefore, they may be better suited to mark decision points in routes.

For current purposes we define decision points (DPs) as route intersections where the navigator either has to continue (i.e., *go left, right, straight on*) or to stop. For example, the route depicted in Figure 1 has three DPs. The starting point (right) is given, the route turns left (DP1), left again (DP2) and ends one block ahead, at the destination point (DP3).



Figure 1: cluttered (top) and schematic (bottom) route map. The route is depicted with red dots, with a green starting point pointing in the initial direction (right) and a blue destination point (left).

Referential scope of landmarks and junctions

Decision points in routes can be uniquely identified by *route independent landmarks* (e.g., *Go left at the restaurant*) or by *route dependent descriptions* (e.g., *Go left at the next junction*). In the navigation literature the term landmark refers to salient objects along the route, which are referred to either by using a proper name (*Eiffel Tower*), a definite description (*the church with three towers*) or an indefinite description (*a large restaurant*). Route dependent references use definite or indefinite descriptions referring to parts of the route itself (*the next intersection, a T-junction*). For the sake of clarity, we will refer to these two reference types as *landmarks* vs. *junctions* respectively. Landmarks and junctions can be seen as part of what Denis et al. (1999: 150) call our “shared metacognitive knowledge” of routes.

In analytical studies of RDs, junctions are mostly implied as a subclass of landmarks (e.g. Klippel & Winter, 2005), but the two entities have never been distinguished systematically.

When someone chooses to describe DP1 in Figure 1 as “*Go left at the barber*” or as “*Go left at the first junction*”, what exactly makes this choice referentially different? The two definite descriptions result in a unique and unambiguous identification of DP1. The main difference is the visual and discourse scope within which their denotation holds. The denotation of *the first junction* only applies to the visual scope in between the starting point and DP1, and in the corresponding RD segment. The scope validity of *the barber* is wider and applies to the whole map, and to the whole RD. *The first junction* only makes sense in one spatial perspective taken on the map, i.e., the route (as opposed to the survey) perspective, whereas *the barber* is not dependent on spatial perspective. The wider scope makes landmarks more referentially robust than junctions.

However, junctions (more than landmarks) are directly related to the navigation task, as they are part of the route itself, and they are always there, while some decision points may lack obvious landmarks. This makes junctions more readily accessible in RDs.

These referential differences align with conceptual differences. Landmarks are more ‘what’ entities than ‘where’ entities, but junctions are the other way around (Landau & Jackendoff, 1993). Landmarks tend to activate conceptual knowledge which exceeds the realm of navigation. This makes them useful as anchor for memorizing routes. Junctions, on the other hand, do hardly evoke more than spatial and locational features as their core meaning. Finally, junctions are part of a larger whole (the map), whereas landmarks have a more independent conceptual status, which makes them more typical first order entities than junctions (Lyons, 1977).

These differences create an interesting strategic choice in RDs: either navigators can trust on narrow scope junction references, which are easily accessible and easy to resolve in the route perspective, while they are also easily losing their robustness, for example in the case of disorientation. Navigators can also opt for broader scope landmarks, with a higher production and resolution cost (because of the larger search space with more distractors), but also with a higher robustness gain.

The aim of our production study is to construct a task situation in which landmark and junction entities are equally available, and to explore whether people exploit them differently when the referential task is varied. In the next section, we will argue that varying the visual complexity of maps may elicit different preferences for the use of landmarks and junctions and their respective referential strategies.

Detail in maps and RDs

Maps and RDs can both be different in the level of detail and the types of features included. Detail in RDs affects the quality of navigation tasks. For example, Tom and Tversky (2011) systematically varied the vividness of street and landmark descriptions in a map learning task, and found that

vividly described elements were remembered better. An explanation of this effect is suggested by Holmes & Wolff (2011). They presented respondents with sentences containing adjectives or spatial prepositions, followed by visual objects, identical in information load, but different in visual detail (line drawings vs. photographs), and concluded that adjectives tend to result in more realistic mental simulation than prepositions. In turn, this realistic mental simulation may help people to remember.

Visual features of maps, like color or detail, may affect route learning as well. Mixed results can be found in the literature. For example, Devlin & Bernstein (1997) did not find a difference in search efficiency between detailed and less detailed maps, whereas Abu-Obeid (1998) reported more errors in map drawing tasks based on scenographic (as opposed to abstract) maps. Support for the idea that schematic maps are more effective than detailed comes from recent experiments by Holmes & Wolff (2010), which show that schematic depictions facilitate the processing of implied motion better than photorealistic depictions.

Visual detail also affects language production. For example, Coco & Keller (2009) concluded that the more detailed or 'cluttered' the visual environment was, the longer it took respondents to start typing their response. Moreover, realistic scenes tended to result in the production of more complex constructions. More recently, they also found that cluttered environments resulted in more complex eye tracking patterns (Coco & Keller, 2010).

Present Study

This paper investigates the effect of visual detail on the selection of referents in route descriptions. We define map detail as visual clutter, a measure of visual complexity composed of three physical variables in scenes (i.e., feature congestion, sub-band entropy and edge density, see Henderson, Chanceaux, & Smith, 2009; Rosenholtz, Li, Nakano, 2007) and used two map types to create different levels of clutter: satellite photographs (*cluttered*) and map views (*schematic*). Figure 1 illustrates the two types.

We expect the referential choice between landmarks and junctions to be mediated by the level of visual clutter of maps. In particular, we expect junctions to be used more in RDs based on schematic maps and landmarks more in RDs based on realistic, cluttered maps. Narrow scope junctions are an easy and safe choice when maps are visually simple (schematic), but they are less reliable as the scene becomes more cluttered and complex. Conversely, broad scope landmarks need not be used when maps are visually simple, but their robustness becomes more useful as visual complexity increases.

To test this expectation, we asked respondents to carry out simple route learning and production tasks. They were presented with either *cluttered* or *schematic* maps, and were asked to orally describe an adequate route description. The task stimulated respondents to produce RDs using a limited number of actions and referents.

Apart from looking at the choice between landmarks and junctions, we explored other differences in RDs that may relate to visual clutter as well. In line with Coco and Keller's (2009) finding that cluttered scenes tend to result in

longer and complex sentences, we looked at the descriptive efficiency of RDs in the two conditions. Note that cluttered maps did not provide our respondents with more task relevant information than schematic maps. As a result, different descriptive features were not expected, but the presence of irrelevant visual detail in the cluttered version may result in more verbal production (number of words or propositions), or in irrelevant information elements.

Finally, we also compared the accuracy of RDs in the two conditions. Following performance differences in other studies (e.g. longer response latencies in Coco and Keller, 2009) we may expect more route errors in cluttered map descriptions.

Method

Participants

Forty-five Tilburg University undergraduate students, 38 females and 7 males, participated in the experiment for course credits. Their mean age was 22 years, ranging from 18 to 35. All participants were unaware of the goal of the experiment, and had normal or corrected-to-normal vision. They were randomly assigned to either the cluttered or the schematic map condition.

Stimuli

Twenty-four different routes were set out on the same map, a section of a map of Upper East Side Manhattan (New York City, NY, USA). Eight routes were short, the other sixteen long. For current purposes, we only used the short routes.

The short routes consisted of three route segments each; each segment consisted of a path leading to a decision point. Each DP coincided with a four way junction and a landmark. The starting point and initial direction were given. Four short routes contained two left-right DPs and the destination DP (as in Figure 1), the other four contained one left-right DP, one straight decision point, and the destination DP.

The depicted routes aimed at offering respondents a limited set of elements per route segment. Applied to DP1 in Figure 1, the following elements were expected: a landmark referent (*the barber*), a junction element (*the next junction*), the action to be carried out at DP (*take left*), and the action leading up to the DP (*continue straight*). Landmark and junction referents were considered to be equally available and competing. The action at DP was considered the descriptive minimum of each segment, the action in between DPs was considered less crucial to the task. The relative importance of actions at in between DPs was confirmed in a small scale evaluation study, in which 20 respondents rated the relevance of these elements on a 10-point scale ($M_{\text{atDP-actions}}=9.72$; $M_{\text{betweenDP-actions}}=6.06$; $t(19)=7.30$, $p<.001$).

Each map was constructed in two versions. The cluttered maps were photorealistic real-world examples taken from Google Maps and were slightly modified to remove obvious landmarks (using Adobe Photoshop). The schematic versions were custom made by tracing the Google Maps satellite pictures (using Adobe Illustrator).

On both versions of the maps, landmarks were set out using a red icon of a house plus a name (e.g., *pizzeria*, *post*

office). The starting point was a green pointing circle with the word *start* in it. The route was depicted as a red, dashed line. The destination point was a blue circle. The maps, 700 by 700 pixel uncompressed colored bitmaps, were presented on a 22 inch, 60 Hertz, 32-bit color LCD screen, at a resolution of 1680 by 1050 pixels. The maps measured 20 by 20 centimeters on the screen.

The degree of data compression when a digital picture is converted from an uncompressed to a compressed format (such as JPEG) is indicative of the sub-band entropy of that picture (Donderi, 2006: 86; Rosenholtz, et al., 2007: 7). When a picture is more cluttered, it is lower in sub-band entropy and a conversion to JPEG will yield a lower degree of compression. Using a 5/12 JPEG-quality threshold, the compressed file size of cluttered maps is 11% of the uncompressed bitmap originals, compared to 5% for the schematic map compressions ($t(7)=2782.60$ $p<.001$), confirming that schematic maps are indeed visually less complex.

Procedure

Participants were placed in a sound proof and dimly lit cabin in front of a desktop computer with a tabletop stereo microphone. First, they read the instructions on the screen. They were told to carry out a self paced route description task based on routes depicted on the screen. They were not given any specific addressee perspective. Next, they carried out a practice trial (two 4-section maps). Then the twenty-four maps (8 short, 16 long) were presented in random order. Each stimulus trial started with the display of a 50 millisecond fixation cross on the center of the screen. Next, a map was presented for exactly 6500 milliseconds. Then the screen turned black, indicating that the participants could describe the route they had just seen. Speech was recorded with the microphone. After they produced a route description, participants pressed the space bar to start the next trial, until they completed all trials. Stimulus presentation time and audio recordings of the responses were controlled and registered using E-prime 2.0 software (Psychology software tools, Inc., 2007).

After completing the last trial, the participants filled out a pen and paper self-evaluation about the perceived difficulty of the task they had just completed (four seven-point Likert scale items, based on the NASA TLX; Hart & Staveland, 1988). The experiment took approximately fifteen minutes.

Coding and analysis

The speech data of two participants could not be analyzed due to technical problems. We analyzed the speech data of 43 participants (22 in the cluttered condition and 21 in the schematic condition).

The responses were transcribed, resulting in 344 RDs (43 participants \times 8 route maps). As expected, the task elicited exclusively descriptions consisting of actions at DP's. Only four RDs combined these with one or two propositions informing about the overall shape of the route (e.g. *You have to make an inverted U-turn*).

As the maps were identical in the two conditions (except for the level of clutter), we compared means per map in the two conditions using paired samples t-tests. The maximal

number of junctions, landmarks, actions at DPs and actions between DPs was $n=1032$ each (43 respondents \times 8 maps \times 3 route segments).

For the *reference type* analysis, the relative frequency of landmarks and junctions was calculated per route segment in one value: presence of a junction NP counted as +1, presence of a landmark NP as -1, so that a positive and negative value means a preference for junctions and landmarks, respectively.

Results

Reference type: Landmarks vs. junctions

Figure 2 presents the mean difference score for junctions ($n=454$) and landmarks ($n=401$) in the two conditions. The results show that junctions are more often used in the schematic map descriptions, while landmarks are more frequent in cluttered map descriptions ($t(7)=6.86$, $p<.001$). This confirms the basic expectation about reference type. The two versions did not differ in the number of cases where junctions and landmarks were combined within one route segment description ($n=80$, $t(7)=1.85$, $p=.11$).

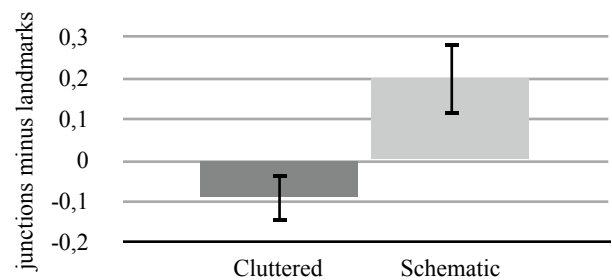


Figure 2: Mean (SD) difference score (junctions minus landmarks) per route description, as a function of map type (cluttered, schematic).

Descriptive efficiency

Table 1 shows per route description the mean frequency of actions at DPs, actions between DPs, words and propositions as a function of map type. The number of crucial actions (actions at DPs) was not affected by clutter ($t(7)=.18$, $p=.86$). However, less important actions (actions between DPs) were used more often in cluttered map descriptions ($t(7)=3.08$, $p<.05$). Also cluttered map descriptions used more words ($t(7)=4.07$, $p<.01$) and propositions ($t(7)=2.83$, $p<.05$) than descriptions from schematic maps.

Descriptive accuracy

Visual clutter did not result in respondents making more pattern errors in their RDs ($M_{cluttered}=.93$; $M_{schematic}=.91$; $t(7)=.59$, $p=.57$). In the two conditions, the number of route pattern errors was low (and mostly the result of left-right errors). Likewise, the number of correct landmarks did not differ significantly either ($M_{cluttered}=1.03$; $M_{schematic}=0.92$; $t(7)=1.69$, $p=.14$). However, respondents in the cluttered condition produced more incorrect landmarks ($M_{cluttered}=.29$; $M_{schematic}=.14$; $t(7)=3.42$, $p<.025$).

Table 1: *Mean (SD)* number of actions at DPs, actions in between DPs, words and propositions, per route description, as a function of map type (cluttered, schematic). Significantly different values are shaded.

	Cluttered	Schematic
actions at DPs	2.15 (.29)	2.16 (.16)
actions between DPs	1.05 (.13)	.80 (.19)
words	22.23 (2.27)	19.15 (.97)
propositions	3.65 (.37)	3.34 (.26)

Discussion

When people study and memorize routes (e.g. using Google Maps), they use map representations with different degrees of visual detail or clutter. When they have to describe these memorized routes, visual clutter tends to affect the preference for particular types of referential expressions. When they use visually simple maps they feel confident enough to largely rely on easily accessible junction NPs, with a narrow referential scope. When using visually cluttered maps, they rather opt for more robust expressions with a broader referential scope: landmark NPs. Landmarks are points of interest along the route, whose denotation is independent of perspective. As the perspective of the addressee was kept implicit in the task, the suggested preferences likely based on speaker oriented considerations (Arnold, 2008). As junctions and landmarks were considered equally available in the two map types, visual detail falls outside the scope of the variables which are currently assumed to determine the adequacy of referential expressions, and which mostly focus on features of target referents and distractors (as in most GRE algorithms). The results suggest the relevance of taking into account ‘non-countable’ visual aspects of the environment as well.

Apart from referential preferences, the increase of visual detail also resulted in a number of collateral effects on descriptive efficiency. Cluttered maps result in the same amount of crucial information. But cluttered map descriptions contain more information elements which are less crucial, and they use more words and propositions. This suggests an association between irrelevant visual detail on the input side and irrelevant verbal detail as output.

Because of the simplicity of the task, visual clutter was not expected to affect route description performance drastically: route patterns, the most crucial information, were described equally accurate in the two versions. Yet, cluttered maps resulted in more incorrect landmarks, which may suggest that irrelevant visual detail caused extra memory load resulting in more errors on second order information (landmarks).

Future work

The results of this production experiment suggest that task irrelevant visual features of maps may influence the choice of referring expressions in route descriptions. A few more experimental steps are needed, however, to corroborate these findings and exclude alternative explanations.

We need to make sure that the relative visual saliency of junctions and landmarks in the two map versions are comparable. For the current experiment, we only judged the visual saliency of the two map types using a saliency algorithm (Harel, Koch, & Perona, 2007). Although the resulting eye-tracking patterns were quite similar, with a focus on landmarks in the two map types, these simulations are unreliable as the simulation model was not informed about the route task perspective of the viewers. It is unlikely that landmarks in our maps were more salient in the cluttered version, but it may well be that the route patterns (including the junction locations) were less salient in the cluttered version. A better control of visual saliency is needed to exclude this possible bias.

Landmarks may be preferred in the cluttered map descriptions because they may be associated more naturally with realistic maps than with schematic maps. Therefore, systematic manipulation of landmarks (as is done e.g. in Roberts, Bonebright & Wischmeier, 2011) and junctions is needed to control this natural association.

Landmarks and junctions had to be completely competitive in this experiment, which may have created unnatural biases in favor of the use of junctions. For example, the simplicity and the generic nature of the route tasks may have promoted the producers’ confidence to use junctions (only). More complex tasks and natural routes are needed to replicate the findings.

Finally, we did not take into account relevant individual differences that are known to affect navigation. It is reasonable to assume that people with different visual abilities use landmarks and junctions differently, for example based on their different visual-object and visual-spatial abilities (e.g., Blazhenkova & Kozhevnikov, 2010).

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