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RESEARCH ARTICLE

This is the tricky part: When directions become difficult

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Abstract: Automated route guidance systems, both web-based systems and en-route systems, have become commonplace in recent years. These systems often replace human-generated directions, which are often incomplete, vague, or in error. However, human-generated directions have the ability to differentiate between easy and complex steps through language in a way that is more difficult in automated systems. This article examines a set of human-generated verbal directions to better understand why some parts of directions are perceived as being more difficult than the remaining steps. Insights from this analysis will lead to recommendations to improve the next generation of automated route guidance systems.

Keywords: navigation, route directions, road networks, granularity, wayfinding complexity

1 Introduction

When giving route directions, it is not unusual for people to use an expression like "this is the tricky part" when they expect that the recipient might have particular difficulty navigating a certain part of a route. Such expressions give insight into the direction givers' own experiences, their mental representation of the route, and the assumed information needs and capabilities of the recipient. This paper addresses issues of route complexity by considering when verbal route directions might alert the traveler to attend to a specific

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junction or segment. In doing so, both the reasons for identifying one leg of a journey as uniquely difficult and the strategies used to navigate that part of the route will be discussed. The analysis is supported by a case study of human generated directions, which include a *tricky part*, that have been collected from the web. Finally, the strategies to navigate through the difficult sections will be discussed in light of automated route guidance systems.

There is a large body of literature on how humans generate route directions for different kinds of travel including directions while driving, walking, cycling, hiking, using public transportation, and using multiple modes of transportation. A common framework was developed by Allen [3, 4], who posited that the act of giving route directions consists of four stages: 1) initiation phase, 2) route description, 3) securing phase, 4) closure phase. Allen goes on to argue that the most critical of these is the route description stage, as this provides a set of communicative statements that are meant to deliver sufficient information to reach the destination. While typically singular in voice with direction giver providing directions to the receiver, the route description stage can also include comprehension queries to confirm that the speaker is understood. In extending Allen's framework to written directions, one might argue that elaboration is the result of expected confusion, which would carry over to the securing stage in Allen's model.

In order to describe a route, people invoke a mental representation of the respective environment [8]. This mental representation is then used to plan a route from origin to destination. In this planning, direction givers account for description and navigation complexity, i.e., the described route may differ from the one they would travel themselves to get a route that is easier to describe and to navigate [45]. Based on this coarse plan, route directions are formulated that describe the way to take from origin to destination. These directions need to link the actions to be performed to the environment. The directions contain instructions in the same sequential order as the corresponding real-world situations, stating what to do when [11]. In that, they often refer to landmarks (see Section 1.2).

In general, direction givers favor concise instructions, as these are perceived to be easier to understand and to remember [9]. Still, the granularity used in these descriptions may vary. On one hand this may be related to the transportation modality addressed in the descriptions [37, 38]. For example, travelling in a train between two cities may require less detailed information compared to finding the train station or even finding the right platform in the station. On the other hand, more complex situations may require more detailed information. In their analysis of how people describe turning actions at intersections, Klippel, Tenbrink, and Montello [23] have pointed out different strategies people may employ to account for increased complexity: 1) a more verbose description that encompasses several options of describing the turn, 2) more variation in verbalizing instructions (other than simple projective terms), 3) more references to the structure of an intersection, 4) providing additional alternative instructions (redundancy), 5) references to competing directions that are not to be taken. The complexity of a wayfinding situation depends on different factors that are discussed next.

1.1 Complexity in route directions

The structure of an environment strongly influences people's wayfinding behavior. In complex environments, people have more difficulties building up a mental representation, i.e., learning the environment (e.g., [18]). Wayfinding itself is also more difficult. People take longer and make more mistakes [5, 12]. Different factors influence the complexity of an environment's structure. O'Neill [30] focused on the structure of the network underlying movement in an environment. His inter-connection density (ICD) value is the average number of nodes connected to every node. It captures the connectedness of an environment. With increasing ICD, wayfinding performance decreases [28]. This indicates that many possible ways through an environment can aggravate constructing mental representations of that environment (there is more to be stored) and may increase the chance of making errors (there are more options to choose a wrong turn).

Mark [25] characterized intersections of an environment according to the number of possible choices. For each type of intersection, different costs are assigned that reflect the difficulty of navigating it. The simplest action is going along a straight segment, followed by turning around a corner, which requires a mental update of one's heading. Intersections are weighted according to their number of branches. Coming to the dead end of a T-intersection, which forces a decision on how to continue, is treated as a special case with lower costs than other intersections.

For travelling in public transport, Heye and Timpf [15] combined several factors to form a complexity measure. In such a scenario, complexity mostly refers to the stations where changes occur from one mode of transport to another or from one line to another within the same mode of transit. The structure of the stations and the paths between places to be travelled there determine complexity. Influencing factors are number of path options (e.g., tracks), visibility, barriers (e.g., streets to cross), and distances between places (cf. also [38]).

More generally, structural complexity of built environments depends on architectural differentiation, the degree of visual access, and the complexity of the layout [43, 13]. In urban environments, the types and orientation of streets [27] or competing spatial reference systems [44], among others, determine a layout's complexity.

Complexity in route following and route directions does not depend on structural complexity alone. In fact, some routes may be easy to follow even in structurally complex environments. Klippel [19] discussed the difference between structure and function in wayfinding. While structure captures the physical layout (the configuration) of an environment, function demarcates those elements of the environment that are relevant for the wayfinding process. In terms of his theory of wayfinding choremes, an intersection's complexity increases if it offers several turns into the same (conceptual) direction. References to salient features—landmarks—may disambiguate these situations and, thus, lower the complexity. The role of landmarks in wayfinding and route directions is discussed next.

1.2 Landmarks

Landmarks serve as a fundamental construct in spatial cognition, both as an organizing concept of space and as a navigational tool in wayfinding [14]. As an organizing concept, landmarks help the navigator visualize the area and parse the space into segments. Of more direct interest to this project is the second concept identified by Golledge, in which landmarks are used to aid navigation. This can take the form of implicit orientation markers ("as you enter the parking lot, the school will be on your right") or as explicit navigational markers ("turn right just past the school").

In his seminal work in this area, Lynch [25] argued that local landmarks are often used in idiosyncratic ways by long-term residents to assist in navigation and that such landmarks could be as specific as "turn at the blue mailbox." It is in this context that Lynch argues that the use of landmarks can outlive the landmark itself, leading to the classic instruction of "turn left where the red house used to be." Passini [29] has argued that one aspect that makes a labyrinth difficult to navigate is the complete lack of landmarks or other marks of differentiation.

It has been shown that navigation by landmarks is more effective than navigation without the inclusion of landmarks, particularly when there are strong landmarks at decision points [10, 26, 31]. Following Lynch [24], Raubal and Winter [31] designated the landmarks used at decision points to be local landmarks and developed algorithms for automatically identifying the best local landmarks from a set of possible options. Their approach, based on previous work by Sorrows and Hirtle [35], rate landmark options in terms of their visual, structural, and semantic distinctiveness.

In terms of the current project, one might find that landmarks are useful in resolving the difficult parts of directions. However, a more likely scenario is that landmark-rich environments would rarely lead to confusion about directions. Rather it is the absence of landmarks, combined with unusual road geometries or missing signage, which would lead to difficult routes to traverse (cf. [26]).

1.3 Simplification

A wayfinding task can vary in its level of difficulty. The level of difficulty depends on factors such as the complexity of the environment, or the wayfinder's familiarity with the environment. Hence, the appropriate or necessary granularity of route directions, and the strategies that people use to describe these routes, may vary based on the varying conditions of the described route. This adaptive process of describing routes may be natural to humans, but is more challenging for route guidance systems. The challenge for wayfinding systems is to continuously tailor the output of the system in a manner that is *cognitively adequate*.

Route descriptions and depictions are deliberately simplified in order to achieve cognitive adequacy in a process known as *aspectualization* or *schematization*. Agrawala and Stolte [1], for example, developed a system where route depictions are automatically generated to mimic hand drawn sketch maps. Here, the lengths of the roads in the depictions are intentionally distorted. Shorter roads involve more turns and are hence more complex to navigate. In order to describe these complex sections in greater detail, the lengths of shorter roads are exaggerated. The lengths of longer roads are shortened because they include fewer turns, and are less complex to navigate. Klippel and colleagues introduced the notion of *schematic maps* to describe maps of this nature [21].

Another approach is to schematize the output of a system based on the prior knowledge of the wayfinder. Srinivas and Hirtle [36] introduced the concept of knowledge-based schematization to represent routes with known and unknown sections along the same route. They presented empirical evidence that suggested a preference of wayfinders for this kind of schematization. Knowledge-based schematization involves presenting more detail in unknown sections of routes, and less detail in known sections of a route. Research in this area has also focused on computational issues [31, 33, 34]. Using this approach, systems are being developed to generate output that is tailored to an individual's personal knowledge.

Route directions included in the case study reported in our work involve the presentation of route information based on the complexity of the route and the assumed prior knowledge of the wayfinder. These human generated route descriptions employ a combination of the two schematization methods described in this section—schematization based on complexity and schematization based on prior knowledge. This issue is discussed further in Section 3.3.

1.4 Structure of road networks

The difficulty of navigating road networks can be a function of both the microstructure of turns and angles [19] and the macrostructure of the network [40]. Traffic engineers use the term "expectancy" to describe the mental baggage motorists carry with them as to what they expect the road network to present to them. Consideration of expectancy is a major factor in the engineering standards for location and style of warning signs, which is termed positive guidance by Alexander and Lunenfeld [2]. Counter-expectancy occurs when visual cues are not in line with the network, such as when an exit ramp from a highway does not have a corresponding entrance ramp to undo the exit. Such counter-expectancy leads to "you can see it, but you can't get there from here" moments. Keeping motorists from taking an obvious but erroneous route is a challenge for direction giving and requires an appreciation of the counter-expectancy traps that the macro structure of the network is laying for them. Firth [12] used the term *configurational grasp mapping* for the process of articulating how the structure of a road network works at a macro level to both provide and restrict access to a given area. Tomko, Winter, and Claramunt [40] took a similar approach to defining what they call an experiential hierarchy of streets. Tomko et al. argue that it is the shared knowledge of this implicit hierarchy that allows for locals to communicate efficiently about routes and locations.

Another common source of road network confusion, where such an area articulation can be helpful, is at *phase changes* [12]. Road networks can be read like a geologist reads sediment layers. Over successive eras of highway building, one local grid can be bypassed by a new highway, which itself can be bypassed by a later super-highway. The problem arises in connecting the new with the old. Especially in dense urban areas, these connections can require a series of complicated maneuvers. Rarely is the object of travel in sight, as in the case of a by-passed main street business district.

Another kind of phase change occurs in the collision between local grids caused by topography or by a succession of property developments. Downtown Pittsburgh has one grid running in line with the Allegheny River and another in line with the Monongahela River, with Liberty Ave as the *continental divide* between them. One grid runs at an oblique angle with respect to the other, causing disorientation as motorists cross from one into the other. Market Street in San Francisco also serves as a *divide*, in this case between grids that run at a 45 degree angle with respect to one another. This results in similar disorientation issues for motorists. In Manhattan's West Village, the post-1811 avenues collide with the pre-1811 grid resulting in numerous opportunities for confusion. A much more common kind of collision is between the regional arteries radiating out from a city center and the grid at the center itself. How this center grid interconnects with the radiating arteries, especially with modern one-way streets and/or pattern-breaking developments, can be intricate and can require numerous counter-expectancy maneuvers.

What can be done about such phase change confusions in direction-giving? In configurational grasp mapping, arterial roads are grouped hierarchically by area and by phase and then packaged into a *geographical narrative* that accords with a common sense understanding of how a place is structured. For example, a narrative can consist of the bypassing highway and then the connecting sequence of roads and finally the primary target road, such as the main street of a business district. Such a narrative can thus treat macro structures of the road network as landmarks, serving to provide confirmation to the motorist of their sense of position on a given trip[1].

As for colliding radiating and central grids, a similar narrative solution presents itself. The case of colliding orthogonal grids at oblique angles is a difficult one. One solution is to use a landmark to restore a sense of overall orientation. For example, those in downtown San Francisco often use the direction to the Ferry Building or the axis towards the Bay versus the Pacific for orientation. When a trip crosses from one grid to the other, references can be made at decision points to these macro-orienting landmarks as a confirmation to the disoriented motorist that they are indeed on the right track. In fact, there is a mnemonic among locals in San Francisco: "Bush to the Bay, Pine to the Pacific," the insider's shortcut streets.

The flagging of a tricky part of directions is, thus, in part due to the structural expectations that a motorist brings to a decision point. It is important to reiterate that the cognitive load is independent of the actual geometry of the situation. For example, a winding road up the coast can be followed with the simple direction of "head up the coast," while the exact same geometry in an urban setting might be seen as difficult to follow. In the latter case, there is no simple rule or an understanding of why the road would continue to turn at seemingly random degrees of curvature. Thus, the absence of *local surprises* depends on an appreciation for the expectation that the road network itself builds with respect to the underlying geography.

1.5 Tricky parts of directions

While the previous literature has focused on the whole of wayfinding from 1) the mental representation of a space, to 2) generation of directions, and finally 3) the adequacy of those directions, this paper is focused on one particular aspect of direction giving. When do individuals who are writing directions for public consumption choose to isolate certain parts as being particularly difficult or requiring additional attention? Such a phenomenon is interesting as it goes against the grain of most automated systems, which present an undifferentiated set of steps (move p miles then turn in the q direction at location r). Furthermore, isolating the difficult sections can give insight into where the spatial representation of the traveler is in conflict with the physical structure of the space. In the following case study, a set of published directions that use the phrase tricky part at some point in the directions are analyzed in terms of the structural, visual, and semantic incongruities that lead to their identification.

2 Case study

A set of approximately 100 directions, each containing the phrase "tricky part," was retrieved from the web using a Google search. The hits from that search were filtered to exclude all web pages that obviously did not provide route directions (e.g., some referred to math problems or cooking recipes). In a second filtering pass, the coders (see below)

[1]In his work in traffic sign planning, Firth provides such narrative directions in the form of local guide signs. See http://www.informingdesign.com/ for more details.

restricted the set further to only those "tricky part" documents that describe difficulties in finding the way as a cognitive challenge. That is, directions that referred to physical difficulties (e.g., hiking trails over rocky terrain), or to seasonal or one-time conditions (e.g., icy conditions in winter) were excluded as well. This was done to analyze problems that occur due to persisting problems in understanding.

The remaining set of 45 directions created a corpus of naturally generated, verbal directions that were composed for readers of the website by small businesses, community organizations, individuals, educational, and government organizations. Often the locations were remote, such as a country inn or the trailhead to a hiking trail, but the list also included suburban locations, such as soccer fields, and driving through city centers. The full list of URLs, valid at the time of submission, is given in the Appendix. The examples were drawn to cover a variety of problems that might occur in generating handwritten directions.

2.1 Coding procedure

Following a similar procedure as used in [17], three independent coders (the first three authors of this paper) identified the reasons of pointing out complex parts in the directions. The initial coding scheme included a variety of judgment strategies and offered to establish a new code should none of the present fit the example. The coders had been asked to assign exactly one reason to every example route descriptions. Table 1 lists the final coding scheme that emerged from the three coders agreeing on a single code for every example.

While the coders could not visit the actual sites, they have used Google Maps and StreetView for validation purposes if that was needed for understanding the described situation. Additionally to the reasons for highlighting tricky parts, we also looked at the strategies employed in highlighting them, using those identified by [23] as a basis. This has been done only informally after the actual coding; it serves as evaluation whether these strategies may be used for communicating tricky parts in automated services (see Section 4).

2.2 Navigational difficulties

The results suggested that the most common reasons for flagging directions with the tricky part were a result of the geometry or signage, which together account for 26 of the 45 examples.

Geometry A common geometrical problem was sharp turns and other odd angles that could be hard to describe in one word. Many geometry problems had a time element, in that there was a rapid sequence of turns where one would not have time to refer back to the directions between turns. Time-based geometric problems included rotaries, which often require that one knows when to exit before entering the rotary. In one set of directions, the geometry of the road network was so confusing that the traveler was advised to "look at a map prior to taking the ride."

Y-intersections or forks in the road can lead to being flagged, particularly when the flow of traffic or angle of the Y-intersection might lead one to head in the wrong direction. An example of this kind of wording was:

Frequency	Code	Subcodes	Description
13	Geometry	Y-intersections rotaries sharp turns quick turns other	Geometry (layout) of the street network affords unusual maneuvers or contains unusual structures
13	Signage	missing ambiguous visibility	Navigation problems arise from missing or inappropriate signage
6	Naming	ASB ARA ALA	The naming scheme of streets does not match with the geometry of the network. See text for explanation of codes
5	Lanes		Move to a specific lane
3	Traffic regulations		Traffic regulations such as "no left turn" (turning left by turning right) or one-way streets
3	Endpoint		Finding a parking lot or entrance to final location; not directly related to finding destination itself
2	Other		Additional problems not covered by categories above

Table 1: Coding scheme used to identify the tricky parts of directions

> The only tricky part is at about the 13 mile point, where the road seems to turn left across a bridge. You want to go straight, rather than left across the bridge.

Another example of a Y-intersection comes from Upland, CA, where the map (and a user's expectation) imply that eastbound traffic can continue straight along E Arrow Hwy, when in fact the satellite image shows that the flow of traffic leads directly onto San Bernadino Rd, as seen in Figure 1.

Signage The second most common problems were with signage, which included unmarked roads, obfuscated signs, and signs that were not visible until after passing the signs. One set of directions warned that the sign was difficult to see at night, while another warned that the "road sign is hiding between a tree." Unmarked roads were often described with details of the terrain or surrounding landmarks.

Naming There were a half a dozen cases of naming problems, which resulted when the naming scheme does not match the geometry of the street network. Typical examples are shown in Figure 2. The most straightforward example, shown in Figure 2a, is where a Road A becomes Road B with no change in direction. This was labeled with ASB for *A straight B* and would rarely warrant the tricky part warning. Figure 2b shows another example of ASB, where the change occurs at an intersection. In this case, turning right keeps you on A, which is labeled as ARA. Returning along this same path would yield ALA. Road name changes at intersections, such as Figure 2b and 2c, are often flagged as tricky, but even an occasional ASB with no intersection was flagged as tricky in one set of instructions.

Figure 1: Map (Informing Design, Inc.) and aerial photo (USGS—The National Map Seamless Server) of mismatched Y-intersection

Another notable example of a naming problem occurred when the traveler was asked to turn on the second occurrence of passing a horseshoe shaped road on the right. In another case, the traveler was advised to turn the third time a particular road crossed the main road. In each case, responding simply to the name of the road would lead to a turning error.

Traffic regulations and lane restrictions Traffic restrictions, such as no left turn, led to several entries in our database. This was typically solved by using a special right turn spur or by a combination of several turns, such as "The tricky part is you have to go to the turn-around by Pasco and Heald Road since you cannot cross the median." The directions can get quite complicated such as the following example:

> Now the tricky part, there is no way to make a left turn into the restaurant parking lot from A street (at least legally). So you can either proceed to Hesperian Blvd and make a U-turn and come back up A street to the restaurant or right before Hesperian there is a strip mall with a Burger King in it. You can make a left into that strip mall and do a U-turn in the parking lot and come back onto A Street heading EAST and proceed to the restaurant. The distance between the

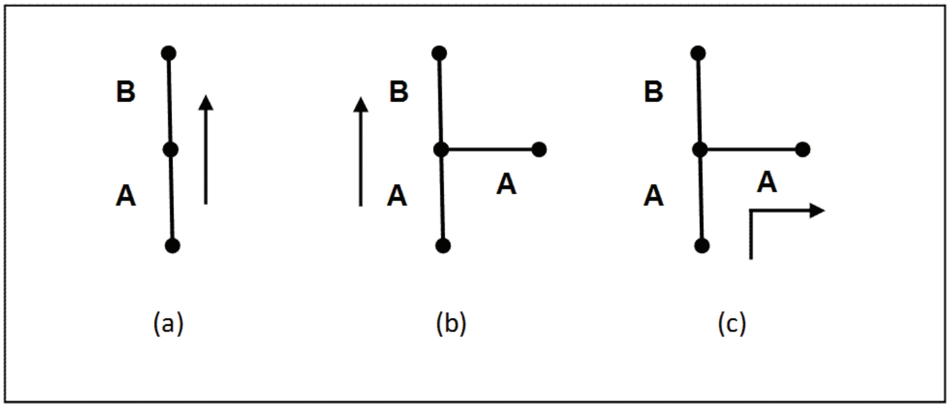

Figure 2: Three examples, where the naming of streets does not match the geometry of the network, are shown. In (a) and (b), the traveler goes straight. In (c), the traveler turns to the right. Examples (b) and (c) are commonly labeled as tricky.

> freeway and Hesperian is about 1 mile or so. If you get to the Hayward Airport you have gone too far.

Traffic regulations and lane restrictions often result in counter expectancy as seen in the examples above.

Endpoint Endpoint problems occurred when the traveler is close to completing the directions. Often the final steps required finding a parking lot or a specific entrance to a site, such as a driveway. This is the distinction between finding a landmark and finding a location near the landmark. A quintessential example of an endpoint problem was the phrase "The tricky part is that the left for parking is actually before the school."

While we identified three sets of directions as endpoint problems, these could also have been classified using the other codes, since there is often a geometry or signage problem associated with finding the endpoint. Given that most GPS systems will direct you to a building rather than a parking lot for the building (and virtually no system will direct you to a parking space), it was deemed worth keeping this a separate category.

Other Finally, there were two examples where the problem was related to the driving level rather than the procedural level, to use Timpf's terminology [39]. These involved following the actual roadbed along an unpaved segment and noting where to pullover along a one lane road, as noted in the following example:

> Only real tricky part of the road: Many sections are very narrow and there aren't too many places to pull off and/or pass oncoming vehicles. Backing up on these steep shelf roads isn't for the wary, but at least the road isn't too rocky up there. As you drive, try to remember the most recent pull off, and try to memorize the terrain in case you have to drive it in reverse. I had to back up more than 50 yards on multiple occasions.

3 Discussion

The case study points to the value of evaluating online route descriptions to understand when parts of directions are seen as difficult. The examples have external validity in that they were not produced in laboratory experiments, but rather published on a website, often with the goal of attracting more customers to a business location. It is worth noting that the data are certainly not an exhaustive set of tricky parts and we urge the reader not to make too much of the actual counts of each kind of problem type. The search term "tricky part" restricts hits to those directions that actually use this term verbatim, but there might be other ways of expressing expected wayfinding problems, for example, "pay attention" or "take care." The search term "miles" favors the USA as the location of the directions. The use of English search terms and search results excluded directions from non Anglo-Saxon countries. There might also be some problem types we have missed. At the same time, we can use the set of examples to begin to understand why certain steps in a long set of directions might seem difficult.

3.1 Level of the trickiness

At a general level there are two kinds of scenarios that lead to the tricky flag. First, there are somewhat trivial problems expected to show up in the analysis that include missing signs, obscured signs, construction, temporary bypasses, and related problems. While important to the navigator, these could be easily corrected.

A second kind of problem is both more serious and less obvious how to identify. It is a function of how the geometry of the street network violates the expectation of the navigator. There is an expectation that road names will not change arbitrarily and that intersections typically form a right angle. When expectations are not met, it is possible that the direction giver will add a flag to warn the traveler of the mismatch. Furthermore, expectations will often build on local knowledge. For example, directions in New Jersey might not flag a left turn from the right lane using a jug handle intersection as tricky, as it is a rather common occurrence. In other States, where it is relatively rare, it would most likely be a candidate for tagging as unusual.

The role of expectation is assumed to vary greatly from region to region and country to country. In a location where Y-intersections or rotaries are common, such geometry would not merit a special warning. The same is true for areas where the amount and content of signage varies. Directions in the fjord region of Norway rarely mention the need to take ferries, as they are just part of the standard road network, not unlike bridges elsewhere in the world.

3.2 Theoretical integration

The results are consistent with a number of previous theories. Most notably, the nature of intersections as discussed in detail by Klippel [19] accounts for many of the geometrical problems. As noted in Section 1.1, the structural complexity of networks has been addressed and quantified by a number of researchers (e.g., [13, 16, 26, 27, 38]). Mark [25] noted that the dead end of a T-intersection forces a decision of the traveler, but at a lower cost than other intersections. In fact, no such intersections were labeled as tricky, which is consistent with his cost function. Likewise, we found little evidence of landmarks in tricky parts. Instead, landmark-rich environments are seen as not tricky (cf. [26]).

The results are also consistent with Klippel, Tenbrink, and Montello [23], who found that redundancy was used at complex intersections at a much higher rate than at simple intersections when generating directions from annotated maps. While we did not explicitly measure redundancy in this study, the nature of flagging an intersection as tricky often results in additional details beyond simple commands. Furthermore, unlike the participants in Klippel et al. [23], the corpus in the present study was generated by those familiar with the landscape and could include references to visual details of the route.

One caveat that is worth mentioning is that some of the routes, even when viewed with Google Street View, did not seem to look particularly difficult to the coders. It is possible that some writers of directions might have a very conservative estimate of the skills of recipients of the directions. In Allen's notion of dialog [3, 4], one can consider the transmitter and recipient of written directions to be temporally isolated. Thus, the direction giver is indicating what might be a potential problem, without direct feedback from the traveler.

3.3 Prior knowledge and complexity

One can also view the tricky part of a route in terms of a combination of complexity and familiarity issues. In the theory of knowledge routes [36] as described in Section 1.3, the focus was on areas where part of the route is known (the K region) and part is new (the N region). Here, the direction giver has strong knowledge of the route, but the receiver has little knowledge. Furthermore, while the traveler might have taken part of the route before, by the very design of the instructions, the tricky part is perceived to be new to the traveler.

Finally, this implies a high level of knowledge exists within the direction giver's K region. The direction giver has—through prior knowledge or experience—reason to believe that certain sections of the route are "tricky" to traverse, and would require a focus of attention due to a possible increased demand for cognitive resources. Furthermore, the direction giver also has the extended knowledge necessary to clarify route descriptions—and eventual travel—through this complex section of a route.

4 Implications for automated route guidance

As discussed throughout the paper, the reasons for pointing out parts of route directions as tricky can be grouped into four main categories: geometry, signage, naming, and traffic regulations. Also, in the examples we have found all strategies listed in Klippel et al. [23] being used in communicating the tricky parts. Often, more than one strategy is used. Thus, for the implementation of references to tricky part statements in automated route guidance two challenges have to be solved: 1) automated identification of tricky parts; 2) automated adaptation of the description.

4.1 Identification of tricky parts

Tricky parts arising from the geometry of the street network may be handled automatically by navigation systems to some extent. For example, matching the configuration of an intersection's branches against patterns defining such special intersections can identify Y-intersections and other unusual configurations in the street network. Klippel, Richter, and Hansen [22] have argued that such intersections are salient entities along the route that may be used as landmarks. They are part of the urban knowledge data structure (UKDS) [20], which provides a specification of the knowledge required to follow a route. Automatically generating references to these structures has been implemented in [32] as a prototype. In the same line, matching the turning angle at an intersection to a qualitative direction model (e.g., [19]) will lead to an identification of the kind of turn (its geometry). Any direction that is not categorized as one of the basic relations "straight," "left," or "right" may be marked as special; those categorized as "sharp turns" as tricky. While this serves as a basic heuristic, it may need to be refined to account for situations where a sharp turn may not be seen as tricky—possibly because it is the only option or is according to travelers' expectancy (e.g., winding roads up a hill). Phase changes as discussed in Section 1.4, i.e., tricky parts arising from parts of a network connecting in complex ways may in part be identified by analysis methods of Space Syntax [16], namely integration (a centrality measure). These methods provide some insights about a network's structural complexity. While such an analysis allows identifying parts of an environment that can be expected to be more difficult to navigate and, thus, may require more detailed instructions, it does not (necessarily) identify local counter-expectancies.

Quick turns may be identifiable by relating the distance between two intersections to the assumed travel speed. If the distance is smaller than a given threshold, a warning needs to be issued. In fact, some car navigation systems take the succession of turns into account in scheduling the provision of instructions. Statements, such as "turn left and then immediately turn right again," are not uncommon in today's systems.

Likewise, being required to be in a specific lane at specific points along the route is already handled today by several car navigation systems. It is mostly a question of having the data needed for identifying which lane to take in order to (not) turn at the right spot and when lane shifts are necessary. Tricky parts arise if either something unusual has to be done (exit highway on the left) or there are many lanes and it is crucial to take the right one (e.g., of the seven lanes only the third from the right allows for going straight). Identification of these cases may turn out to be difficult. It may be captured by parameterized rules defined in the system, which again serve as heuristics to capture such cases. A more difficult problem is when a lane is not required, but recommended, due to traffic flows. For example, an instruction such as "stay in the middle lane to avoid the frequent stops by buses in the right lane" would be difficult to implement in an automatic system.

Signage provides a great challenge to be included in automated services. Information on signage is hardly present in geographic data sets. Given the range of different signs that can be addressed—from traffic regulations (e.g., stop signs, traffic lights) and signs of street names to signs for points of interests (put up by authorities or business owners)—collecting this data and making it available in data sets is unlikely to happen anytime soon. Even if it were, automated services would need to interpret them in order to be able to judge their visibility, ambiguity, or possible absence. Is the required sign well identifiable from the travel direction? Does it unambiguously identify a single way to take? Does the combination of all signs at an intersection lead to confusion? Is the intersection hard to navigate without (additional) signage? The challenges of enabling automated systems to consider signage in these respects are similar (and possibly greater) to the integration of landmarks as explained in [31, 46]. While it can be done at least partially in principle, it requires large amounts of data and, at least for visibility determination, complex algorithms, which are unlikely to find their way into commercial navigation systems.

As geographic data does contain information about street names, naming problems, i.e., those cases where the naming of a road does not match with the geometry of the underlying street network may be detected automatically. To this end, it needs to be checked at an intersection whether the street segment in the network that is in the straight continuation of the current travel direction has the same label as the segment the intersection is entered on. If this is not the case, an instance of ASB has been identified. If a turn is required at this intersection and the segment a wayfinder turns on has the same label as the current segment, an instance of ARA or ALA, respectively, has been identified. In combination with other factors, such as involved road categories and number of lanes for example, this then may constitute a tricky part. Again, heuristics need to be tuned to separate actual tricky occasions from those that are expected by the travelers.

Another part of the naming and signage problem is that there may be several alternatives for identifying a road, such as the street name or one of multiple highway numbers, of which one, and only one, option would lead to clear and simple directions. Automated systems by design will either focus on the street names, ignoring the highway numbers, or focus on the multiple highway numbers, leading to instructions such as "turn right from Rte 30/50/110 to Rte 30." In fact, one of the tricky directions in our case study warned drivers that "US-322 shares the road with many other highways, so always stick with 322 West." This kind of simple instruction might be the easiest to follow, as it limits the cognitive load on the driver. Unfortunately, most automated systems would fail to identify selectively the best label out of the set of all possible road labels for a given situation.

Traffic regulations require appropriate modeling of restrictions in the underlying data. Usually, this information is available. Given that the travel modality (car, bicycle, walking) is known, an automated service can appropriately account for them in path planning. Tricky parts here mostly arise from restrictions concerning left turns (in countries where traffic is on the right hand side of the road) and one-way streets. Any time such a restriction is encountered in path search, the respective node of the path could be flagged, since there would be a potentially easier maneuver, if it were not for the restriction. This holds especially if the destination is on the restricted segment. If the restricted segment eventually becomes part of the described route, a tricky part resulting from traffic regulations has been identified.

As stated above, the "endpoint" problem is orthogonal to the challenges just discussed. Finding the right entrance to a building or parking lot, for example, may result from any of the four categories. However, as pointed out by Tenbrink and Winter [37], often complexity arises due to information needs on a finer granularity level for finding the right sub-part of an endpoint than for getting to the endpoint. Capturing these problems in automated services is first of all a matter of availability of data describing a space on the required granularity level (cf. [7, 38, 41]) and then using this data for identifying tricky parts as explained above. However, mechanisms that allow for an automatic adaptation to the finer granularity level remain an issue for further research.

In principle, all these mechanisms for identifying tricky parts may be subject of personalization in an automated service. Based on user behavior and feedback (e.g., rating of received route directions) a service may learn which types of maneuvers and which situations along a route are truly tricky for an individual user.

4.2 Communication of tricky parts

The mechanisms described above aim at allowing automated services to cover the reasons for people pointing out tricky parts in route directions. This then needs to be reflected in the communication of route directions as well. A service needs to adapt its way of communication to adequately prepare a user for the tricky part. This also entails explaining the tricky part appropriately. Here, the strategies of Klippel et al. [23] come into play.

In general, the aim is to keep route directions concise as this eases understanding and memory [9, 33]. In automated systems as in human route directions, conciseness is achieved by spatial chunking [20], among others. Spatial chunking is the subsumption of several consecutive instructions into a single, higher instruction (e.g., “turn left at the third intersection” instead of “straight, straight, left”). Those parts of a route that have been identified as tricky may be excluded from chunking and, thus, become their own part in the route directions. This will automatically lead to more verbose instructions, which is one of the strategies listed in [23]. Wrapping them in explicit statements that announce them, such as “and here is the tricky part,” may further emphasize the instructions.

It can be expected that those tricky parts of a route that are based on geometry are hard to integrate into spatial chunks to begin with. Chunks reflect parts of a route that can be navigated with the same type of high-level maneuver (e.g., going straight until a landmark or following the flow of a major street). Tricky parts referring to the geometry break this flow; likely they will emerge in the directions as an individual instruction. For other tricky parts, this may not be the case. To ensure adequate coverage of tricky parts in route directions, an explicit mechanism to emphasize them in the communicated information should be implemented. All of them entail shifts in granularity of communicated information one way or the other (cf. [37]).

For sharp turns, for example, this granularity shift is in the preciseness of describing the kind of turn (from a general turning concept to a refined one using linguistic hedges). Pointing out specific lanes in the directions shifts instructions from the instruction level to the driving level [39]. Y-intersections and other unusual network structures may be explicitly referenced, thus, serving as a kind of landmark [22]. Ordering concepts may come into play to denote the entrance to take in case there are several alternatives (“take the 2nd highway ramp”), leading to variations in the verbalizations.

If tricky parts emerge due to ambiguity, it would also be possible to explicitly mention the alternatives that are not to be taken, following another of the strategies in [23] (e.g., taken from the sample directions: “FM 362 goes to the right at the ‘Y’ and FM 359 goes to the left. Take FM 362 to the right”). This way, the tricky parts will be clearly emphasized in the route directions, i.e., making their description more verbose. It also changes granularity in that instead of only making explicit the functionally relevant parts of an intersection, a more complete picture of the intersection is given. However, this requires careful selection of communicated information in order not to overload the traveler with information.

Finally, there may be situations where images can resolve the ambiguity of the situation. The use of Google Street View and related techniques are now available on GPS-enabled smartphones, such as Android. This allows one to view turns on a recent image of the intersection, regardless of the complexity. It is interesting to note that the idea of images for navigation was used as far back as 1907, when Chapin [6] published his Photo-Auto Maps, which showed “photographs of every turn, together with a topographical outline of the road showing railroad crossings, bridges, school houses and all landmarks, with accurate distances between.” The Photo-Map directions from New York City to Albany consisted of 58 images, one at each turn, with a clear photograph of the intersection and an arrow indicating the direction of the turn, as seen in Figure 3.

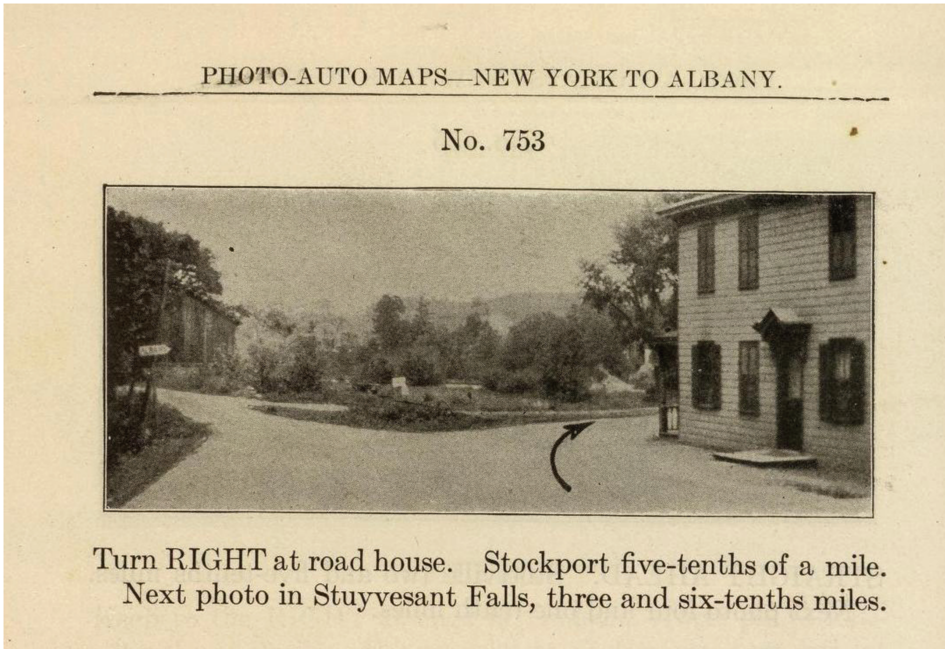

Figure 3: One of 58 photographs indicating the driving directions from New York City to Albany. Reprinted from http://www.davidrumsey.com/luna/servlet/detail/RUMSEY~8~1~34028~1170181 under the Creative Commons License.

The book by Chapin pre-dates the development of standardized route numbers in the United States, which began in the State of Wisconsin in 1918. By 1926, a national system of numbered routes was established in the United States to facilitate navigation [42]. It is interesting to observe that lack of integration of route labels, signage, and automated guidance systems makes navigation by Street View surprisingly similar to the state of affairs over 100 years ago.

4.3 Summary

The granularity of spatial information for navigation assistance remains an interesting and challenging problem. While useful directions in well-known areas can be notably vague, such as "head towards the airport," there are other situations where navigation requires great cognitive effort. By examining steps that were flagged as being particularly difficult in verbal route directions, we were able to determine when the granularity of the directions need to be increased, so that they are more detailed and even redundant. The steps that were judged to be the "tricky part" of the directions were due for the most part to ambiguous geometry within the road network, absence of appropriate signage or landmarks, the need for quick sequential decision, or unusual constraints on driving or turning.

It was shown that the different reasons for trickiness pose different challenges. Some of the challenges may be solved in actual implementations, while others are hard even on a theoretical level. In general, however, even with tricky parts being flagged, removing the securing phase from generating automated instructions and not providing any feedback mechanisms, as it is the case in today's navigation services, will result in some failures in the navigation process. The most problematic steps in a navigational sequence were generally related to a violation of expectations that the traveler brings to bear on the navigation task. Thus, while aspects of difficulty can be resolved in current and future automated route guidance systems, the problem of counter-expectancy will prove to be a particular challenge for designers of automated systems.

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Appendix

http://bahiadelfin.net/directions.htm
http://bahiadelfin.net/directions.htm

http://books.google.com/books?id=7MPh0ypi-oQC&lpg=PA76&ots=H_f0BUFP_k&pg=PA76#v=onepage

http://casadiablo.net/PI/documents/OZDIRCT.pdf

http://cneba.com/fields.php

http://csrc.nist.gov/archive/pki-twg/maps/NIST-BWI-backway.pdf

http://excitingny.com/ny-directionsyankee.shtml

http://heartbookseries.com/heart-of-a-mother/mother\%E2\%80\%99s-day-book-signing-borders-eastlake/

http://hellonormal.com/blog/somewhere-else-ish
http://homepage.mac.com/jeffmorrison/summer04/summer04trips.html
http://omahahomeschool.com/info-directions.html
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http://www.churchcreation.com/map.asp
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http://www.sabikerides.com/WillowCity.html
http://www.scorpionbay.net/forum_old/get_topic.asp
http://www.stonequarryhouse.com/directions.html
http://www.sunburyhospital.com/Directions/Pages/Directions.aspx
http://www.sweetgrassdairy.com/directions.php
http://www.thewritersroom.net/directions.htm
http://www.variationsdancestudio.com/htm/map.html
http://www.wimberleytourism.com/index.php?pid=169