Recursive Construction of Granular Route Directions

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Abstract

People give route directions to persons who are familiar with the environment typically by refering to elements of the city of varying granularity—what we call *granular route directions*. This is in contrast to current navigation services, which produce directions of constant granularity. In granular route directions the detail of the description is adapted to some relations between the start and target of the route. The references to elements of the city are aggregated to a referring expression respecting the conversation maxims formulated by Grice. We demonstrate how granular route directions can be automatically constructed by selecting appropriate elements of the city from a hierarchical city structure, and we further demonstrate that the process is based on a recursive application of a small set of topological rules.

INTRODUCTION

People naturally communicate about space by referring to familiar or easily identifiable objects in the environment, for example when providing route directions. Studying such route directions it emerges that people frequently vary the level of detail for different parts of the route. This characteristic is even more pronounced in conversations between people who are both familiar with the environment. In particular, the part of the route directions converging to the target commonly show references of increasing detail.

For example, imagine the following conversation between a taxi passenger and a driver:

Passenger: "*To Turnbull Alley, please.*"
Driver: "*??*"
Passenger: "*It is in the city, just opposite the Parliament.*"
Driver: "*Very well.*"
...
Driver: "*Here is the Parliament, where should I go now?*"
Passenger: "*It is the laneway before the theater. The house at the end, thank you.*"

The route described leads from the airport of Melbourne, Australia, to a location in the city center. It is evident that both people in the conversation are familiar with the environment, and share some knowledge of its basic structure. As the direction giver, the passenger presupposes the shared knowledge of the objects 'city' and 'Parliament', and of the categories 'theater', 'laneway' and 'at the end'. Strictly speaking, the passenger describes the *location* of the target, but not the *route* itself. In this situation, the passenger assumes that the taxi driver can fill in the route to the referred target. Furthermore, the passenger describes the location of the target in a *hierarchical manner*, becoming more and more detailed. We call such route directions *granular route directions*.

In contrast, current navigation services rely on turn-by-turn directions and path metrics. Such route directions are expected to be suitable for wayfinders with low familiarity with the environment, so called *naive* wayfinders. In the given situation, however, they appear to be inappropriate: the taxi driver would have to synchronize the route directions constantly with his cognitive map. Furthermore, turn-by-turn directions are longer (in this situation a Web-based route planner comes up with 14 instructions), typically exceeding the capacities of human short-term memory (Miller, 1956). For that reason turn-by-turn directions have to be communicated piecewise *in-situ*, which demands the presence of the direction giver and some concentration on the conversation by both partners during the whole travel. The taxi driver would be cognitively more occupied, and may feel patronized by the level of detail, without reaching better wayfinding results.

Hence, the ability to generate granular route directions will increase the usability of navigation services for wayfinders in familiar environments, i.e., for every-day wayfinding situations. This paper looks into the problem of automatically generating granular route directions. For that purpose we will build on a formal model determining the initial reference of granular route directions (Tomko and Winter, submitted). This model was derived from Grice's conversational maxims, and driven by the topological relations of the elements in a hierarchical city structure. What still needs to be explored is the identification and selection of the consecutive references in granular route directions. Our hypothesis is that the selection of the consecutive references can be determined by the same rules, applied recursively.

By that way we will propose a formal model for the selection of the references in granular route directions. We show that the principles of selection of consecutive references are identical with those applied for the selection of the initial reference. This leads to a recursive function, selecting elements of the city with a decreasing granularity level. In this manner, the initial reference of granular route directions is iteratively replaced by the references retrieved in the recursions, and ends when the target itself is referred to. The model is implemented and tested on a hierarchy of one type of element of the city, the districts (Lynch, 1960). The tests will demonstrate that route directions using this sequence of references form consistent route information. We expect that the guiding principles of the model are valid for references to the other elements of the city as well (landmarks, paths, nodes and edges, or their configurations), which will be tested in future work.

The remainder of the paper is structured as follows: we first introduce our previous work and the foundations on which we build our hypothesis and approach. The following section describes the theoretical foundations that drive the selection of consequent entities in granular route directions, and is followed by a section which demonstrates an implementation of the recurrent call of the rules identified. Afterwards, we demonstrate the behavior of the program on a set of test cases, by identifying elements referred to in granular route directions in a hierarchical structure of a city, consisting of districts. The paper ends with a discussion and conclusions.

PREVIOUS WORK

Route Directions Among People Familiar With the Environment

People living in a city learn its layout through continuous interaction. This leads to the creation of spatial mental models. Their quality increases with repeated interaction of the agent with the environment (Tversky, 1993). The need to communicate a description of a specific place to a wayfinder leads to a recall of this mental model, which is transformed into route directions. As previous research has shown, good route directions are organized in an order which reflects wayfinder's interaction with the environment (Allen, 2000). They include references to salient features along the route, mostly found at decision points, where turns occur in the route (Lovelace et al., 1999; Michon and Denis, 2001).

Approaches for adapting route descriptions to human conceptualization of space have been tested for different scenarios. Timpf et al. (1992), Timpf (2002), and Timpf and Kuhn (2003) developed a hierarchical model of route planning for wayfinders in a hierarchically structured road network (the US interstate highway network). It uses a single type of element of the city, roads, and builds on the traditional turn-by-turn approach to route directions. This approach is different from that of people familiar with the environment.

Cognitive scientists have proven the importance of two-dimensional regions for the human conceptualization of space, and have shown how it impacts wayfinders' route planning (Wiener and Mallot, 2003). In urban environments, these regions are represented by districts. Newman et al. (2005, in press) have shown the importance of the overall structure of the environment, as well as the position of landmarks, to the ability to learn the layout of the environment. Together, this shows that route directions for wayfinders familiar with the environment should incorporate references to multiple and different elements constituting the environment's structure. These elements should be included in the route directions in a manner enabling a description of the route that would characterize it best.

Granular route directions as referring expressions

A referring expression is defined by Dale (1992) as an expression uniquely identifying a specific object. Our approach to granular route directions represents a specific case of a referring expression: the final naming of the target alone would not necessarily form a unique identification of the target; instead, the whole set of consecutive references of increasing level of detail is unique.

Granular route directions represent a non-singular referring expression using superordinate objects of the target to unambiguously describe it. In this regard, granular route directions resemble Dale's *Full Brevity Algorithm*, defined as the shortest description of *r* that is still a distinguishing description of *r*. The idea of brevity goes back to the principle of simplicity as expressed in Ockham's razor. In our case, the length is measured by the number of references made in the granular route directions, not by the number of words. A selection algorithm for referring expressions that explicitly refers to aggregation hierarchies is presented by Bateman (1999). In contrast to his aggregation lattices, we will work on spatial hierarchies.

The philosopher Grice stated a set of four conversational maxims (1975; 1989), defining the rules for constructing good informational statements. The maxims of information quantity ("*Make your contribution to the conversation as informative as necessary. Do not make your contribution to the conversation more informative than necessary.*"), quality ("*Do not say what you believe to be false. Do not say that for which you lack adequate evidence.*"), relevance ("*Be relevant: say things related to the current topic of the conversation.*") and manner ("*Avoid obscurity of expression. Avoid ambiguity. Be brief: avoid unnecessary wordiness. Be orderly.*") are reflected in Dale's definition of referring expressions, and as such also apply to route direction statements.

Grice's maxims thus define the communication as a pragmatic endeavor. It occurs in context, and is undertaken in a cooperative manner. People engaged in communication tend to be cooperative, by making conversational contributions at the right time and in context of the purpose of the information exchange. This aspect is well reflected in our approach by taking a limited set of attributes of the wayfinders context into consideration: the start and target of the route and the functional structure of the city (defined primarily by the mode of transport). The choice of the mode of transport determines the classification of the city entities into Lynch's categories. Imagine wayfinders in Venice, Italy: depending whether they walk or travel by boat, the function of canals will change from barriers (edges) to paths.

The remainder of this paper builds mainly on the maxims of quantity and manner, and shows how these theoretical foundations can be used in conjunction with topological analysis to identify the entities from a hierarchically ordered set of districts to provide granular route directions.

IDENTIFICATION OF CONSECUTIVE REFERENCES

Structure of granular route directions

We tackle the problem of retrieving additional entities of granular route directions by testing the validity of the basic rules for retrieving the initial district of the granular route directions , exploiting the topological relation of the start and the target element. The topological controls performed ensure that the topological distance of the two inputs is sufficiently large to make the provision of granular route directions meaningful.

In human granular route directions references to elements of the city, such as districts, appear to be inserted in a manner respecting Grice's conversational maxims of quantity and manner, leading to a construction of a unique and ordered referring expression. Only references to elements necessary for a non-ambiguous description of the target are inserted. The insertion of these references in route directions is orderly, which is also in accordance with the principles of communicating route knowledge as explored by Allen (2000). Allen's experiments show that remembering and following routes directions was facilitated, among others, by a correct temporal-spatial order.

In granular route directions in a city structured only by districts, the target district of the route is necessarily an ancestor of the initial element of the granular route directions. The initial district completely covers the area where the target district is to be found. To narrow down the target's location, additional ancestors of the initial element can be specified. It is, however, necessary to verify that the amount of features referred to is kept to a minimum. Every new entity included in the route directions needs to add information value to the referring expression. As with the algorithm for identification of the initial reference, we consider the topological relations in the layout of the city structure to determine the inclusion of additional features in the granular route directions.

We define the topological distance of two elements s and t in the city structure as the number of elements of the same type and granularity level lying between s and t. Thus, this measure enables an assessment of the added information value provided by the inclusion of a reference to a specific element in the referring expression. The topological distance is a concept adhering to Grice's maxims of information quantity and manner. When identifying the initial element, we search for an entity (ancestor of t) with a topological distance from the start s, or its parent element, greater than one. In addition, it is necessary to verify that the overall distance covered (s–t) justifies the insertion of an additional reference. If found, the entity i represents the initial element of granular route directions.

The same principles have to apply to any consecutive references included in the granular route directions. The maxim of quantity states that a statement should provide all the information necessary, but no information unnecessary to the wayfinder. The maxim of manner enforces that the information is clear and non-ambiguous. Translated to granular route directions, this means that any entity appearing in the sequence must add value to the referring expression. The omission of a specific entity from the route directions would lead to an unclear or ambiguous statement, and thus will lead to an unsuccessful referring expression.

Assume a hierarchical structure of the environment that can be represented in a tree hierarchy as shown in Figure 2. This structure relates to the partition of space based on districts from Figure 3. Note that for figure clarity branches of the tree not related to the test case from Section *Model Testing* are suppressed. A schematic sequence of granular route directions from start s to target t should look as follows:

$$\text{route}(s,t) \;::\; i \rightarrow e_2 \rightarrow t$$

where i is the initial reference, and e_2 is a consecutive reference of the granular route directions. In our case the references are of the same type of element, districts, but of

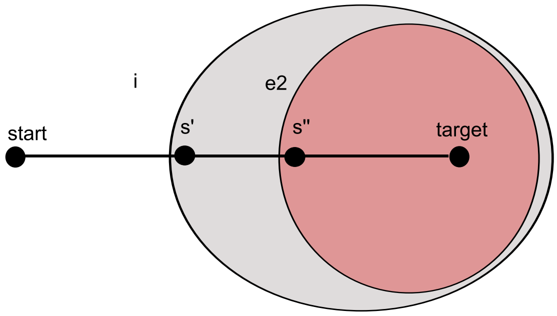

Figure 1: Schematic representation of the sequence.

different levels of granularity. The references appear in the granular route directions ordered by levels of granularity in a decreasing order, from the coarsest reference (initial element i), through references of intermediate granularities (e_2) to the finest reference (the target t). Note that in our test case the granular route directions consist of only two elements, the second reference being identical to the target. This is only due to the location of the target in relation to the hierarchical structure of model environment and the route.

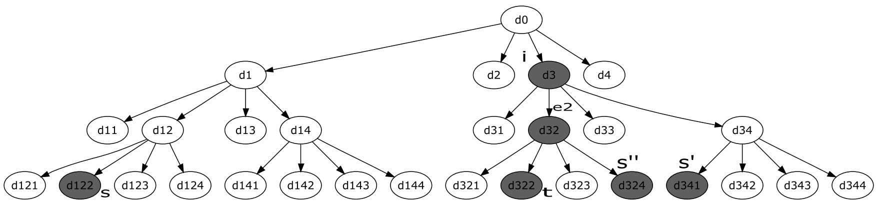

Figure 2: Identification of references in a hierarchical set of partitions: s is the start of a route, t the target, i the initial element, e_2 is the second element of the route directions.

The initial reference in granular route directions

Let us analyze our example of the passenger taking a taxi to Turnbull Alley in Melbourne. We have noted the variable level of detail of the route description, and the fact that the taxi driver, as the wayfinder in this scenario, is expected to find his own route to the element first referred to. One of the characteristics of granular route directions is therefore that the first reference does not belong to the start of the route, or its vicinity.

An algorithm to determine the first reference in granular route directions was proposed by Tomko and Winter (submitted). The algorithm builds exclusively on the analysis of topological relations in hierarchically structured spatial partitions. The elements of these partitions are districts, according to the terminology of Lynch (1960).

The algorithm takes the elements s and t of the set of hierarchically ordered elements in the domain S as inputs. These elements represent a partition of space. Then, before reconstructing the respective hierarchies of superordinate elements of the start and the target, it analyzes their topological relations in order to verify that the spatial configuration of the inputs does not exclude the use of granular route directions. Using the notation $Super_e$ for any ancestor element of element e and Sup_e for a direct superordinate element of e, the conditions can be grouped into four conditions that initially check topological relations, and two other conditions that actually identify an element:

1. Start and target must be member of the shared set of elements ($s, t \in S$).

2. Start and target must not be identical ($s \neq t$).

   If the rules 1 and 2 are not fulfilled, granular route directions cannot be created. These cases represent situation where inputs are not defined or faulty.

3. Start and target should not be neighbors ($s \cap t = \emptyset$).

   If this rule is not fulfilled, turn based instructions should be generated.

4. Start and target should not have neighboring direct superordinate elements ($Sup_s \cap Sup_t = \emptyset$).

   If this rule is not fulfilled the reference to t is returned, and the granular route directions finish.

Following the initial check of topological relations summarized in the rules 1-4, the last two rules for selecting the element i apply (rules 5-6):

5. Element i must not be shared by $Super_s$ and $Super_t$, ($i \notin Super_s$).

   This rule excludes those superordinate elements of s and t that represent the intersection of the two branches of the hierarchy. These elements do not provide any information to the wayfinder in the context of the start s of the route. Note that in the search for the initial reference there is no subordinate element of s in the hierarchy. The definition of the start and target of fine granularities is therefore important for the generation of detailed route directions.

6. Element i should not be neighbor with an element in $Super_s$.

   This rule excludes elements fulfilling rule 5 that are in a neighboring relation with an element of the hierarchy $Super_s$. In such a case an element one step deeper in the hierarchy should be employed ($e \cap Sup_i \neq \emptyset, e \in Super_s$).

Note that the rules need to be ordered as shown, in order to perform a valid set of tests. For an algorithm implementing these rules, an application example along with the testing of the model, see (Tomko and Winter, submitted). After the initial reference is identified, the search for consecutive elements follows.

Recursive construction of granular route directions

Granular route directions represent the reference to elements of the city, in a hierarchical manner. The initial reference in granular route directions narrows the space of analysis to a specific region of the city. The initial element i and the target t belong to the same branch in the hierarchical tree of districts. If they are not identical, they necessarily reside at different levels of the hierarchy. We will show how we can still apply topological distance to identify intermediate elements of this branch for granular route directions.

Not all consecutive elements along this branch are relevant according to Grice's maxims. Thus, the value added by the inclusion of every consecutive reference needs to be verified. The amount of information provided by every consecutive element in granular route directions has the same minimal threshold, defined by the topological rules mentioned earlier.

In human communication, the direction giver mentally constructs a route in his cognitive map, and describes it to the wayfinder. Thus, the direction giver has a clear idea of *where* the wayfinder enters the region described by the reference provided, and can thus base the selection of the consecutive reference on this knowledge. The identification of the consecutive reference is then again based on the application of Grice's maxims, analogically to the identification of the initial entity in granular route directions.

In the case of a city partitioned by districts, the location of the wayfinder is always described by reference to a district. In the case of granular route directions, the wayfinder proceeds along a route described in a granular manner. When accessing a district referred to in the route directions, the wayfinder actually reaches the first district of the finest granularity level within the area covered by the previous reference. The first such district lies within the area of the initial element i. For the wayfinder, this district then takes over the role of the start element s' of the remaining part of the route. The wayfinder can only perceive its immediate neighborhood and this context has to be reflected in the route directions. The topological relation of s' with the target t is then analyzed. This analysis identifies the consecutive reference of the granular route directions. The requirements on the information value provided by every reference in granular route directions are the same.

Note that the route is visualized by the direction giver. The process of selection of references for the granular route directions occurs in the mind of the direction giver. It is not said that the wayfinder actually uses the same route to reach the target, or that he imagines exactly the same route based on the granular route directions provided.

The granularity of the last reference, the target, is the limiting factor of the level of detail of the granular route directions. The process of identification of consecutive references is repeated until the target district is reached in the route description. The process is the same at every stage of the reconstruction of the granular route directions, with a simple test (whether the references reached the target) performed at the beginning of each cycle. We can therefore say that the process is recurrent.

The requirements of the information value of every reference inserted in granular route directions are the reason of the fundamental difference between inserting the complete subtree of the city structure with the initial element i as the coarsest reference, and the recurrent construction of the route directions. This difference is manifested by *omissions*, which means that two consecutive references in the granular route directions don't necessarily have levels of directly consecutive granularity.

The recurrence of the process is an intriguing property, signaling that a set of simple rules can identify references in a complex referring expression. The test of this computational model is described in the following section.

A formal model of recursive granular route directions

The formalized model of recursive reconstruction of granular route directions exploits the topological tests applied for the identification of the initial entity of granular route directions, as introduced in previously. It is based upon the same hierarchical model of the city, consisting of districts organized by granularity in a tree structure. In addition, the model requires the route imagined by the direction giver as input. This route r is formalized as a set of finest granularity level districts, ordered from start to target in a chronological manner, in the same order as the direction giver imagines the wayfinder to visit them. Note that the direction giver does not necessarily know (or visualize) all of the finest granularity level districts. Direction givers conceptualize routes hierarchically, as well as the actions that have to occur when following it (Kuipers, 2001; Timpf et al., 1992; Wiener and Mallot, 2003).

After applying rules 1-4, the hierarchy of the superordinate elements of s and t is identified, effectively reconstructing the branches of the two elements in the hierarchy. The entities in these two branches are then analyzed by additional topological rules. The initial element is found among the superordinate elements of t, applying rule 5 and rule 6.

We review these rules in the context of their recursive call. Thus, the rules will be tested repeatedly on a new set of inputs, a new start element s' and the target t. The initial element i found in the first cycle defines the new search area, and represents the root element of the subtree in which the search is performed. Both s' and t are descendants of the element i, but within its subtree they are not members of the same branch. From a geographical perspective, s' is the district of access to the district i, the first district of finest granularity that is reached by a wayfinder upon arrival to district i. Also, the element s' is the first element of a sub-route r_i, consisting of those elements of the route r, that are also children of the element i.

Imagine the administrative hierarchy of the states and cities in Australia, and a situation in which a wayfinder wants to travel from Darlinghurst in Sydney, New South Wales to Carlton in Melbourne, Victoria. New South Wales and Victoria are neighboring states of Australia. Sydney and Melbourne are respectively located in these states, but are not neighbors. According to our topological tests, the initial element i of the granular route directions would be Melbourne, as Victoria shares boundaries with New South Wales and therefore cannot be used as the initial reference. The first, finest granularity district reached in Melbourne is Mickleham, which acts as a new start s' in the following cycle. The next cycle is at the same time the last one, returning Carlton, the target of the route, as the consecutive element e_2 with $e_2 = t$. Carlton and Mickleham are at the same hierarchical level, but are not neighbors. The granular route directions are: [to] Melbourne, [and then to] Carlton.

Our model for district based granular route directions is noted in Algorithm 1.

IMPLEMENTATION

Algorithm 1 is implemented in the functional programming language Haskell (Peterson and Chitil, 2005), enabling fast prototyping and implementation of algorithms in an executable manner. The efficiency of the code is not our primary objective, although Haskell fits these needs well by enabling lazy programming. The emphasis is on the ability to computationally test our rules, not on the practical execution of the code at runtime.

Algorithm 1: recDirs – recursive granular route directions

Data:
r: route, list of finest granularity districts, consisting of a first element s and a trailing list of elements sx ($r = s : sx$), where target t is the last element of r.
S: domain of all elements, represents the urban hierarchical structure of districts.
Import:
rd: function retrieving the initial element of granular route directions.
Result: e: list of elements (districts)

retrieve initial element i (rd s t S);
case i = t
    return t;
otherwise
    return i;
    recDirs sx S;

The main function of the program is `recDirs` (for "recursive directions"). It takes two arguments, S and r. Both are represented as a concatenation of custom data types `Object`. Objects are, in this case, districts of the city. A definition of `Object` contains the information about its granularity level, its superordinate element, its name (enabling to return directions understandable to humans), and the definition of the bounding polygon of the `Object`, necessary for topological analysis of the relations between the `objects`:

```
data Object = Object Level Super ObjectName Polygon
```

The first argument of the `recDirs` is the *route* r, visualized by the direction giver and communicated to the wayfinder in the granular route directions. The list representing the route consists of the start element s of the route and the remaining elements sx. This list is ordered in natural order as districts appear along the route from start to target. Those elements are districts of the finest granularity level. Note that this route is never communicated to the wayfinder in full detail; instead the granular description of the target is provided. The second argument (`obj`) is the set of all objects S present in our hierarchical model of the city.

```
recDirs :: [Object] -> [Object] -> [Object]
recDirs (s:sx) obj
        |(rd s t obj) == t = [t]
        |otherwise = (rd s t obj):(recDirs (subroute (rd s t obj) (s:sx) obj) obj)
        where t = last sx
```

The function `recDirs` consists of a recursive call of the main part of the program: the analysis of topological relations of the start and target of the route, implemented in the function `rd`. The details on `rd` are covered in (Tomko and Winter, submitted), and the topological analysis it performs are explained in previous Sections.

A test at the beginning of the function `recDirs` ends the recursion if the target district is returned as the initial element. In this case, t is added to the result set. If the test is negative, the initial element is retrieved and the function `recDirs` runs again to find consecutive elements. This time, the parameter `route` is represented by the function `subroute`, that determines the districts constituting the route in the area of the initial element. The districts are in the same sequence as in the complete route.

```
subroute :: Object -> [Object] -> [Object] -> [Object]
subroute i r obj = [x | x <- r, testObject i (findSupersOrd x obj)]
```

The function `subroute` is computed for every cycle of the recursion, returning the list of elements of the route that are children of the current initial element. This is necessary for determining the element acting as the start element of the route for the consecutive cycle. As the `subroute` is an ordered list, the first element of the list is the start element of the next cycle of the recursion. The target of the route is constant for every cycle, and is computed as the last element of the route r. The route r is always the result of the previous cycle of the recursion, and represents the trailing part sx of the previous route. Note that the last element t of the subroute and of the route are identical, as the initial element selected by the topological rules is always the ancestor of t as well.

Note that the result of the granular route directions is a list that need not end with the target element t. The recursion ends with the test at the beginning of the recursion, or by the fulfillment of one of the test cases of the function `rd`. If the start and the target of a subroute evaluated in the recursion are at a topological distance lower than the threshold, the function `rd` recommends the use of turn based route directions, and ends. At this stage the function generating turn based directions could be called. In this case, the last reference of the granular route directions will be a superodinate district of t. One has to realize that at this stage, the wayfinder is effectively perceiving the situation from the context of the current start element, not from the context of the last reference in the granular route directions. In such cases turn based directions should be included from the last start element on. This situation is demonstrated in the test example in the following section.

MODEL TESTING

To test the implemented model, a simple hierarchical structure consisting of a triangular division of space was implemented. It represents a triangle recursively divided into four smaller triangles. The hierarchical structure is four levels deep, and can be represented as a triangular quad tree. The root element has the granularity level 0, and the finest level elements have the granularity level 3. With the exception of the coarsest (root) triangle, noted $d0$, the triangles are numbered as shown on Figure 3.

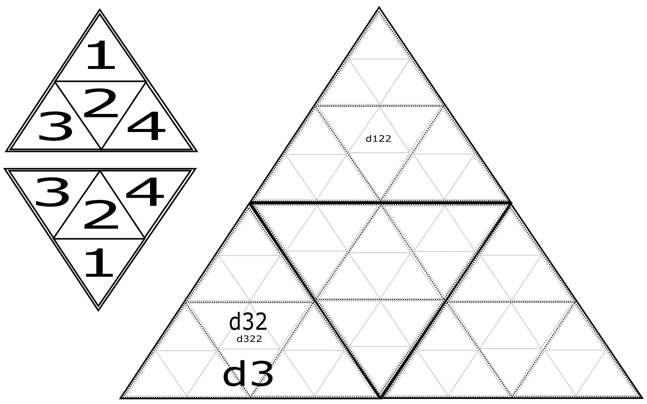

Figure 3: Test hierarchical structure of the city districts.

The triangles are numbered within a granularity level. The granularity level consists of districts (triangles) $d1$, $d2$, $d3$ and $d4$. Districts within district $d1$ are $d11$, $d12$, $d13$ and $d14$, and similar naming convention applies also the the granularity level 3. Two districts are considered neighboring if they share an edge and are not in the relation of parent/child elements.

The rules implemented in the functions `rd` and called through the recursion in the function `recDirs` were tested through a set of test cases. We have modeled these cases as *routes*, and analyzed the granular route directions provided for each route. The behavior of the topological analysis was already known from our previous experiment, so the emphasis was on testing whether the sequence of the references retrieved would provide route directions with the right amount of information value, i.e. similar to human generated route directions. In practice, this meant the evaluation of whether the references provided are adequate in the context of the wayfinder.

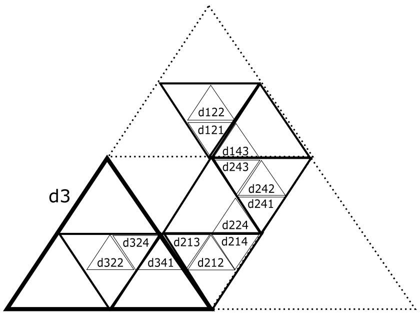

Figure 4: Depiction of the route in the test city structure.

We analyze one test case in detail. Imagine a route defined as the following list of districts (Figure 4):

```
route = [d122,d121,d143,d243,d242,d241,d224,d214,d212,d213,d341,d324,d322]
```

The result of our function returns the following sequence:

```
[d3,d322]
```

As we can see, the granular route directions consist of two references, in this case not of consecutive granularity levels. The start s of the route ($d122$) and the target t ($d322$) are shared only by the coarsest district of the city model, the root district $d0$. The consecutive ancestor elements of the start and the target (granularity level 1) are not neighbors, and therefore the element $d3$, super-element of the element t can be included in the granular route directions.

The next cycle of the recursion reconstructs the sub-route — it finds all the elements of the `route` that are also children of $d3$ — and the first element of this sub-route ($d341$) becomes the start element s' of the second cycle of the recursion. The function `rd` of this cycle returns the element $d322$, which is the target of the whole `route`, and therefore the final element of granular route directions. A detailed look at the topological setting of the districts reveals the reasons for such behavior. The start element s' of the sub-route is an ancestor of the elements $d34$, and the target is a child of the element $d32$ ($e1$ on the schematic representation on Figure 1). If these two elements were not neighbors, $d32$ would be part of the granular route directions and a consecutive sub-route with a start element s'' would be searched for. The topological rules 4 and 6, however, do not allow the element $d32$ to appear in the granular route

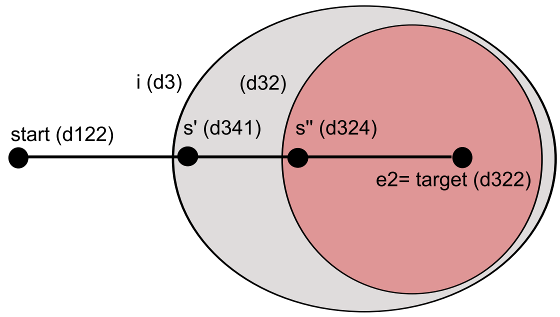

Figure 5: Schematic representation of the sequence.

directions. Thus, the whole route direction statement consists of only two references, $d3$ and $d322$.

Every reference included in the route directions has to be interpreted from the context of the sub-route considered. This allows the brevity of the granular route directions. The presence of the element $d32$ in the route directions, for instance, would be excessive, as the wayfinder is, at this stage, residing in the district $d341$, directly neighboring $d32$. The recursive application of the topological rules assures that the changing context of the wayfinder navigating in the urban environment is taken into account.

DISCUSSION

Route selection

The route that direction givers have in mind and communicate to wayfinders can, in general, be different from that used by the wayfinder to reach the target. This can happen for changed traffic conditions during wayfinding, or in the case of a different preferences (costs) assigned to the network segments (speed, distance, route simplicity,...). In such cases, turn based route directions become invalid and need to be reconstructed. One of the biggest advantages of granular route directions for familiar wayfinders is the wayfinders' flexibility to choose and modify their own route, and at the same time preserve the validity of the route directions. The exact routing of the wayfinder is not known, and is not required either. Direction givers, however, have a specific route in mind when providing granular route directions. The computational determination of this route is beyond the scope of this paper, and therefore a route will be assigned to each combination of start and target in a test case. This is necessary, in order to be able to determine the full set of fine granularity districts as they occur along the route and serve as inputs to our recursive algorithm.

It is probable that direction givers assume a certain prototypical access route to the target, which is a *simple* route. An interested reader is encouraged to refer to the simplest path idea introduced by Mark (1986) and computationally implemented by Duckham and Kulik (2003). The wayfinder is not forced to take the same route as the direction giver has in mind, but is at least guided to arrive from the same *direction*. Alternatively, research in path choices from a more cognitive background is presented in (Caduff and Timpf, 2005), where the salience of landmarks along the route is taken into account.

The conceptual connection of granular route directions to path elements is strongly present, and path segments of the route imagined by the direction giver are often introduced in route direction statements. It enables us to further extend the model with paths, as the transition between adjacent districts of the same or similar granularity levels has to be enabled. Integrated hierarchies of multiple elements of the city (including landmarks and edges) are needed, and we will study this in future work.

Transition to turn-based directions

In granular route directions, the initial reference is followed by consecutive references of lower and lower granularity. In the vicinity of the target, the route description changes, as granularity differences between elements are minimal, and the selection of the most important element is difficult. There, the granular route directions change into turn-based directions of variable level of detail. Such a transition reflects the decreasing familiarity of the wayfinder with the specifics of the large scale environment in which he or she arrives. Thus, the route directions provided have to provide increasing amounts of details, and approaches suitable for naive wayfinders are necessary. This

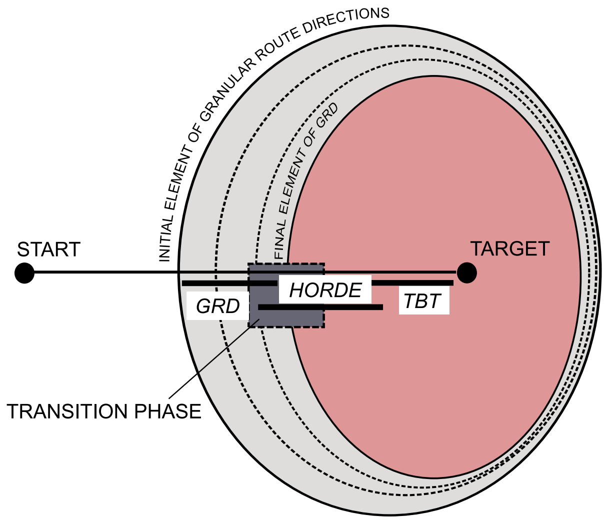

Figure 6: Granular route directions in the context of a route.

represents a transition phase between granular route directions and pure turn-by-turn route directions, as shown on Figure 6. In the transition phase, route segments are often chunked in higher order route elements (Klippel et al., 2003). The principles of this transition are subject to future research.

Urban hierarchies and redundancy in route directions

Our approach exploits a hierarchical structure of the urban environment (such as an administrative structure), with crisp boundaries between districts are assumed. This is a simplification of the reality, where inhabitants of urban environment often conceptualize districts with vague boundaries between adjacent regions, and are not totally bound by the administrative partition. This is similar to the *areas of influence* of landmarks

(Kettani and Moulin, 1999). Such a model could be represented by a lattice structure. The adaptation of our topological rules to a lattice environment is the subject of our further study.

Grice's maxims explicitly require that every information provided is relevant, and the quantity of information transmitted is reduced by evaluating its relevance. Lattice models may require additional disambiguation, leading to some redundancy in the referring expressions created. We argue that this is not a violation of Grice's maxims, nor of the relevance theory of Wilson and Sperber (2002). The goal of referring expressions is to uniquely describe the intended referent, and if additional specification is needed due to the complexity of the urban model, additional references must be provided in order to maintain the relevance of the utterance.

Such conceptualizations are very individual and can differ between agents (e.g., direction giver and wayfinder). From experience, however, we know that two strangers, inhabitants of the same city are able to communicate route directions. Grice as well as Wilson and Sperber state a natural expectation of relevance of an utterance in communication. The relevance of an utterance is then supported by background knowledge of the recipient, allowing to draw meaningful conclusion. Even if the district boundaries in the wayfinder's mental model of the city (be it hierarchical or lattice-like) do not match perfectly those of the direction giver, the two agents are able to communicate and infer correct meaning. They make a mental effort to understand the input of the partner in communication.

In the case of automatically generated route directions, several options of dealing with mismatches in mental models are possible. A simple approach is to rely on the official administrative partition, which we can assume is, at least coarsely, shared by the majority of wayfinders. Another option is to analyze the connectivity of the path network to create a hierarchy of districts clustering highly connected regions. The result is a single spatial database with possibly a more "natural" hierarchy of districts. Finally, we can provide personalized software agents residing in, for instance, mobile phones and continuously tracking the wayfinder. A personalized spatial database of familiar environment is then built. Areas of higher connectivity can then be merged into districts, and used to update the system's database.

CONCLUSIONS

We are exploring the possibilities to automatically construct route directions simulating the granular approach identified in human route directions of wayfinders familiar with the environment. We have explored the information required from every reference included in granular route directions. The information provided by these references was assessed from the point of view of referring expressions and the Grice's maxims of conversation. We have identified the topological distance between the elements in a city structure as an indicator of the information value provided when included in route directions. This value is represented by the initial element of granular route directions in the context of the start and target elements of a route. The information value is equivalent to that required from every consecutive reference. This equivalence and its grounding in the same topological rules lead us to the conclusion that the process is recursive. We have presented a recursive implementation of the topological rules originally applied to the identification of the initial entity of the granular route directions. We have shown in a test case that the route directions generated are plausible and similar to the human generated granular route directions. The test case was applied on a triangular division of space representing a hierarchical structure of districts. In order to generate granular route directions by recursion, the route had to be provided. This knowledge of the route is restricted to the direction giver (human or software agent) and does not require the wayfinder to follow the same route to reach the target. Granular route directions provide wayfinders with flexibility to chose their own routes. Future work will concentrate on the inclusion of other types of elements of the city in the model of granular route directions , as it is the case in human generated route directions. In order to achieve this, it is essential to identify a hierarchy of paths, edges and landmarks that can be integrated with the hierarchy of districts in a homogeneous manner.

ACKNOWLEDGMENTS

The authors would like to thank the three anonymous reviewers for their comments that helped to improve the paper. The work has been supported by the Cooperative Research Centre for Spatial Information, whose activities are funded by the Australian Commonwealth's Cooperative Research Centres Programme.

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