Recursive Construction of Granular Route Directions

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Abstract

Familiar wayfinders communicate route directions in a granular manner. In contrast to current navigation services, the detail of the description is adapted to the relation between the start and the target of the route. References to elements of the city are select in a manner leading to a referring expression respecting the conversation maxims formulated by Paul Grice (1975, 1989). We demonstrate how a granular route directions can be reconstructed based on the selection of appropriate elements of the city from a hierarchical city structure, and we argue that the process is based on a recursive application of a small set of topological rules.

1 Introduction

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

Imagine the following conversation of a taxi passenger with a driver. The route described leads from the airport to a location in the city center of Melbourne, Australia.

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 lane way before the theater. The house at the end, thank you.*"

Both partners of the conversation appear to be 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', 'lane way', 'at the end'. She describes the location of the target, but not the route itself. In fact she assumes that the taxi driver can fill in the route to the referred objects by himself. Furthermore, the passenger describes the location of the target (twice) in a hierarchic 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. In the given situation, however, they appear to be inappropriate: the taxi driver may feel patronized, and has to synchronize the route directions with his cognitive map. Furthermore, turn-by-turn directions are longer (in this situation a Web-based route planner came up with 14 instructions), typically exceeding the capacities of a short term memory (Miller, 1956). 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 is cognitively more occupied.

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

We will propose a formal model of selection of consecutive references, enabling to construct full 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 recurrent function selecting the elements of the city of appropriate granularity levels from the city model (Lynch, 1960). 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 elements of the city, districts. The tests will demonstrate that route directions using this sequence of references form consistent route information, and that violations of the model lead to ambiguous information or broken links. Hence, we can show that Grice's maxims are applied successfully. 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: in Section 2, we 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 Section 4, that demonstrates an implementation of the recurrent call of the rules identified. Section 5 demonstrates 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 in Section 6.

2 Previous work

2.1 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 in route directions. As previous research have shown, good route directions are orderly organized, reflecting the order in which the wayfinder will interact with the environment (Allen, 2000) and include references to salient features along the route—routemarks (Lovelace et al., 1999; Michon and Denis, 2001), mostly found at decision points, where turns occur in the route. For the purpose of this paper, we reserve the widely used term *landmark* to point like elements of the city (Lynch, 1960), and use the term *routemark* for salient features of the environment included in route descriptions (Klippel, 2003; Klippel and Winter, 2005).

Various approaches to adapt route descriptions to human conceptualization of space have been tested for different use case scenarios. Timpf (2002); Timpf and Kuhn (2003); Timpf et al. (1992) developed a hierarchical model of route directions for wayfinders in a hierarchically structured road network (the US interstate highway network). It uses a single type of element of the city, and builds on the traditional turn-by-turn approach to route directions. Further, this approach builds on the hierarchical administrative categorization of roads, which is not necessarily the one of familiar wayfinders. However, this approach is well fitted to the considered context of the wayfinder—a non-familiar car driver.

Cognitive scientists have proved the importance of two dimensional regions for the human conceptualization of space, and have shown how it impacts wayfinder's route planning (Wiener and Mallot, 2003). In urban environment, 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 position of landmarks, to the ability to learn the layout of the environment. Together, this shows that route directions of familiar wayfinders should incorporate references to multiple and different elements constituting the environment's structure in a manner enabling a description of the route that would characterize it best.

2.2 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 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 length is in our case measured in number of references made in the granular route directions, not in the number of words.

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 endeavour. It occurs in context, and is undertaken in a cooperative manner. Partners engaged in communication tend to be cooperative, by making the conversational contribution at the right time, 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. Namely, this context is bounded by the start and target of the route, as well as the functional structure of the city defined by the mode of transport and determining the classification of the city entities into the lynchean categories.

The remainder of this paper builds mainly on the maxims of quantity and manner, and shows how this 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 .

2.3 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 . The conditions are summarized in the following six rules:

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 ($s \neq t$);
3. the start and the target should not be neighbors ($s \cap t = \emptyset$);
4. the start and the target should not have neighboring direct superordinate elements ($Sup_s \cap Sup_t = \emptyset$);

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). Using the notation Sup_e for a direct superordinate element of an element e, we state:

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 6 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 ($e \cap Sup_i \neq \emptyset, e \in Super_s$).

For an application example of these rules, along with the testing of the model, see (Tomko and Winter, submitted).

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. This represents a transition phase between granular route directions and pure turn-by-turn route directions, as shown on Figure 1. In the transition phase, route segments are often chunked in higher order route elements (HORDE) (Klippel et al., 2003). The principles of this transition are subject to future research.

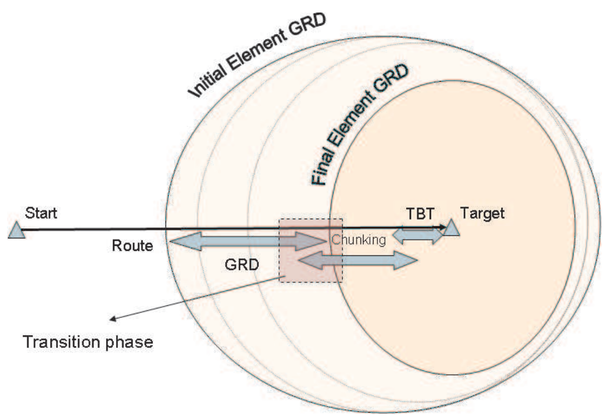

Figure 1: Granular route directions in the context of the route.

3 Identification of consecutive references

3.1 Structure of granular route directions

In human granular route directions references to elements of the city, such as districts, are inserted in a manner respecting Grice's conversational maxims of quantity, 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 the route directions is orderly, thus respecting the Gricean maxim of manner, which is also in accordance with the principles of communicating route knowledge, as explored by Allen (2000). His experiments show that remembering and following routes directions was facilitated, among others, by a correct (read natural) temporal-spatial order.

Consider a city structured only by districts. After retrieving the district representing the initial reference of the granular route directions, the target district of the route is necessarily a child of this initial element. The initial district completely covers the area where the target element will be found. To narrow down the location of the target, additional superordinate districts of the target (and thus children of the initial element) can be specified. It is, however, necessary to verify that the amount of features referred to is kept to a necessary minimum. Every new entity included in the route directions needs to provide some added information value to the full referring expression–the route direction statement. As with the algorithm for identification of the initial reference, we consider the topological situation of the city structure to determine the necessity to include additional features in the granular route directions.

We tackle the problem of retrieving additional entities of granular route directions by testing the validity of the basic principles for retrieving the initial district of the granular route directions (Section 2.3). These principles exploit 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. We define the topological distance of two elements in the city structure as the number of elements of the same type and granularity level lying between the two input elements. Thus, this measure enables to assess the added information provided by the insertion of a specific element in route directions. The topological distance is a concept adhering to Grice's maxims of information quantity and manner, as is the basic principle for the identification of the initial element of granular route directions. There, we have *de facto* defined that the topological distance of two consecutive entities inserted in the route directions has to be greater than one, in minimum. Further rules increase this distance in relation to the topological distances of the superordinate elements.

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 recipient. 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.

Assuming a hierarchical structure of the environment, for instance a partition of space based on districts (Fig. 2), a schematic sequence of granular route directions from start s to target t should look as follows:

$$\text{route}(s,t) \;::\; i \rightarrow e_1 \rightarrow e_2 \rightarrow t$$

where i is the initial reference, and e_1 and e_2 are consecutive references of granular route directions, in our case of the same type of element, districts. 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 to the finest reference (the target t).

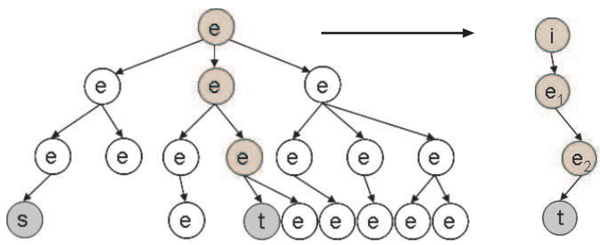

Figure 2: Identification of granular route directions references in a hierarchical set of partitions.

3.2 Recursive construction of granular route directions

Granular route directions represent the reference to multiple elements of the city (in our simplified case of a single type), in a hierarchical manner. The initial reference in granular route directions narrows the space of analysis to a specific region of the city. A simple selection of the branch containing the target t and starting with the initial element would, however, not necessarily provide sufficient topological distance between two consecutive elements of the branch. Thus, the value added by the inclusion of every consecutive reference need 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, based upon the Gricean maxims.

In human communication, the direction giver travels through his cognitive map and visualize the route taken to reach the target described to the wayfinder. Thus, the narrator has a clear idea of *where* the wayfinder enter 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 Gricean maxims, analogically to the identification of the initial entity in granular route directions. In our case of a city structured by districts, the first district of the finest granularity level reached within the area covered by the precedent reference can be used describe the location of the wayfinder. Then, the topological relation between this location and the target can be analyzed. This analysis then enables to identify 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 it is not necessary that the wayfinder actually uses the same route to reach the target, or that based on the granular route directions provided he he even imagine exactly the same route. The route is visualized by the narrator.

The granularity of the last reference–the target–is the limiting factor of the level of detail of the granular route directions . Consider the two Australian states *Victoria* and *New South Wales* as inputs. If our structure assigns the same hierarchical level to both, it is impossible to construct granular route directions between the two neighboring districts, due to small topological distance. However, a wayfinder's start element is probably better described by *Melbourne*, or even *Carlton*, a suburb of *Melbourne*, than by *Victoria*. The wayfinder's target might be *Darlinghurst*, a suburb of *Sydney*. Based on the different set of inputs, granular route directions for this situation are possible. If the input reference to the target is too coarse, the wayfinder may request additional turn based 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 (reaching the target) performed at the beginning of each cycle. We can therefore say that the process is recurrent.

The requirements on 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 are not necessarily of directly consecutive granularity level. Imagine the omission of the element e_2 (Figure 2) from the route directions:

$$\text{route}(s,t) \;::\; i \rightarrow e_1 \rightarrow t$$

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 hypothesis in a computational model is described in the following section.

3.3 The model of recursive granular route directions

The 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 Section 2.3. It is based upon the same hierarchical model of the city, consisting of districts organized by granularity levels in a tree structure. In addition, the model requires the route imagined by the narrator as an 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 way as the narrator imagines the wayfinder to visit them.

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 (Section 2.3).

It is necessary to review these rules in the context of their recursive call. In such a case, these rules will be tested again 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 from the tree-hierarchical point of view equals to the root element of the subtree in which the search is performed. The element s' is a member of this subtree, but does not belong to the same branch as t. 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 (see Section 3.2). 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. Again, imagine a situation in which the wayfinder travels from Darlinghurst (Sydney, New South Wales) to Carlton in Melbourne, Victoria. The granular route directions than are: Melbourne, Carlton. The initial element of the granular route directions i is Melbourne. 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 ($e_2 = t$).

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

Algorithm 1: Recursive granular route directions (recDirs)

Data: The urban hierarchical structure of districts: domain S, route r (list of finest granularity districts, consisting of first element s and trailing list of elements sx ($s : sx$), where target t is the last element of$r$

Result: List of elements e

Retrieve initial element i (rd s t S);

case i = t

  Return t

otherwise

  Return i;

  recDirs sx t S

---

4 Implementation

The 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, and Haskell fits well these needs 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.

The main function of the program is `recDirs` (recursive directions). It takes two arguments–both represented as a concatenation, a *list*, of custom data types `Object`, representing, in this case, districts of the city. It consists of the information about the granularity level of the specific `Object`, its superordinate element, its name (enabling to return direction 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 narrator 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. 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 present in our hierarchical model of the city.

```
recDirs :: [Object] -> [Object] -> [Object]
recDirs (s:sx) obj
        |(rd s t objlist) == 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 the implementation are covered in (Tomko and Winter, submitted), and the topological analysis it performs are mentioned in Section 2.3.

A test at the beginning of the function `recDirs` resolves the situation at the end of the traveler's route, ending the recursion when the target district is reached. This element is added to the set of result. The recursion can also end if the function `rd` evaluates the topological distance of the target from the current start element to be too small for granular route directions , and recommends to use turn based instructions. This means, that the target is not always the last element of the list representing the elements selected to be part of the granular route directions. In such cases turn based directions should be included from the last element on. 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 .

The function `subroute` is computed for every cycle of the recursion, in order to determine the element acting as the start element of the route for each cycle. It returns the list of the elements of the route, that are children of the current start element. 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.

5 Model testing

To test the implemented model, a simple hierarchical structure consisting of 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.

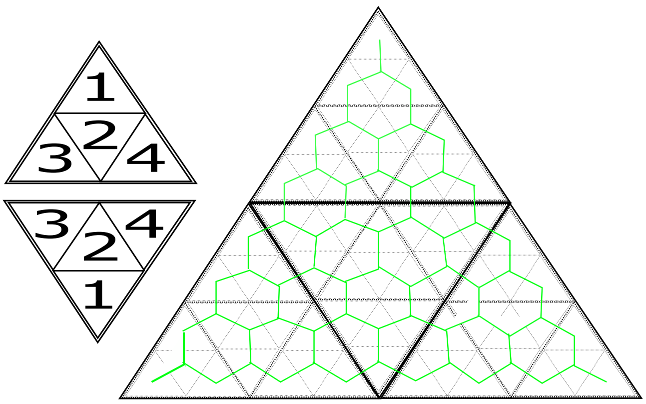

Figure 3: Test hierarchical structure of the city districts.

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 parent/child (superordinate/subordinate) 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 those 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 the testing whether the sequence of the references retrieved would provide for route directions with the right amount of information value, i.e. similar to human generated route directions. In practice, this meant the evaluation whether the references provided do not omit or include references which are necessary for the wayfinder.

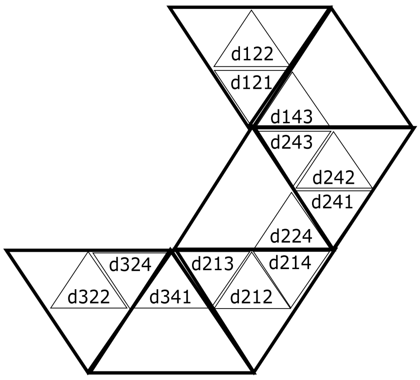

Figure 4: Test hierarchical structure of the city districts.

We will 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, as result, the following sequence:

```
[Object 1 "d0" "d3" [46,43,34,31,82,80,75,72,70,67,59,57],
Object 2 "d3" "d32" [74,68,61,63,76,78]],
Program error: This are neighboring objects, TBT directions
```

As we can see, the granular route directions consists of two references, in this case 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 next consecutive elements (granularity level 1) of the start and target 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 — all the elements of the route that are children of $d3$ — and the first element of this sub-route (d) becomes the start element of the second cycle of the recursion.

The function `rd` of this cycle returns the element $d32$, and the element $d324$ becomes the next start element for the next cycle of the recursion. This element, however, is a direct neighbor of the route's target. The functions `rd` signalizes the end of the granular route directions, and turn based directions should follow from this point on.

6 Discussion and conclusions

6.1 Path selection and recursive construction of granular route directions

A note is necessary on the subject of path selection (or, in our terminology to avoid confusion with Lynch's elements of the city, route selection). Until now, we did not reason about the route selection process of the narrator and the wayfinder.

The route selection process was not mentioned, as one of the biggest advantages of granular route directions for familiar wayfinders is the wayfinder's flexibility to chose and modify its 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 a specific combination of start and target. 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 *simple*. 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 narrator 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 should be enabled. Integrated hierarchies of multiple elements of the city are clearly needed, and we will study this in future work.

6.2 Conclusions

We have explored the information required from every reference included in granular route directions from the point of view of referring expressions and the Gricean maxims of communication. We have identified that the information value represented by the topological distance between the start and target elements of a route, imagined by the narrator is equivalent to the value required from every consecutive reference, which leads us to the conclusion that the process is recursive. A recursive implementation of the topological rules applied to the identification of the initial entity of the granular route directions showed, in the test cases explored in a triangular division of space representing a hierarchical structure of districts, that the route directions generated are plausible and similar to the human generated granular route directions.

Acknowledgments

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